Agrimonde®

Scenarios and Challenges for Feeding the World in 2050

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Summary Report

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Agrimonde
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Contacts:

Bruno Dorin (especially for Agribiom)
CIRAD - UMR CIRED
TA C-56/15, 73 rue Jean-François Breton
F-34398 Montpellier Cédex 5
email: bruno.dorin@cirad.fr
Tel.: +33 4 67 61 75 82
Fax: +33 4 67 61 44 15

Sandrine Paillard
INRA – Foresight Unit
147 rue de l'Université
F-75338 Paris Cédex 07
email: sandrine.paillard@paris.inra.fr
Tel.: +33 1 42 75 95 37
Fax: +33 1 42 75 95 32

Agrimonde
Scenarios and Challenges for Feeding the World in 2050

Research on the world's agricultural production and food, as regards its approach to the objective of sustainable development, has become the subject of countless studies and debates. It is one of the fields in which positions and even ideologies enter into conflict and emerge in the geopolitical arena. Issues of international regulations for the management of public goods and international trade are concerned, as are conceptions of the science-society nexus, of progress, and ultimately of the future of our planet.

The field has thus been enriched considerably over the past few years, through the convergence of seminal studies and various traditions: econometric models for analysing agricultural policy; international forecasting of geopolitical inspiration or concerned by global sustainable development; models of climate change impacts. Recently there have additionally been studies on energy and reports produced by international scientific experts on ecosystems and biodiversity. There is consequently a profusion of information, data and results and, correlatively, a vast overall illegibility. Although the awareness of global risks has triggered a proliferation of analyses and international forums, the challenges and options have not necessarily become any clearer.

To promote reflexivity and in-depth discussion based on existing studies, it is necessary to decipher and interpret or reinterpret them, and to assess them critically in view of their objectives, hypotheses and implications. They also still need to be enriched and broadened, and their quality continuously improved. The stakes are high, since these studies and the debates that they generate are the crucible of international standards and of a large number of concepts, rationales and results. The goal is the construction of a 'scientific', 'reasonable' discourse, 'commonly accepted by the experts', which shapes the actions of international organizations and of most governments. This discourse then influences the agenda of international negotiations on agriculture, international trade or development aid and debates concerning them. It likewise affects the actions of multilateral organizations and the orientation of agricultural research, broadly speaking.

Along with the necessary pursuit of research, there is a need to build a mechanism that actually allows for reflexivity and in-depth discussion. That is the objective of the Agrimonde foresight project, which should thus occupy a specific place in international evaluation and forecasting exercises, especially in the follow-up to the IAASTD[1] and the discussions presently underway on the reform of the international agricultural research system. In view of the implications of these issues in research orientations and public policies, the presidents of INRA and CIRAD have asked us to *"produce scenarios of global and regional evolution in agricultural production, consumption and trade, as well as in scientific and technical knowledge on agriculture, with a view to drawing conclusions on the possible roles for research, public policies and international regulations."*

The Agrimonde foresight project, thus defined, has been entrusted to an INRA-CIRAD project team coordinated by Sébastien Treyer, under the responsibility of the FI4IAR[2], with the following general objectives: 1) to design the modalities of strategic reflection based on a foresight approach, with the aim of illuminating research orientations in the fields of agriculture and food, in the broad sense of the term; 2) to initiate the process of debates and interactions on these topics, and their appropriation, on a national scale; 3) to promote the participation of French experts in international debates on the subject.

To that end, the team has endeavoured to set up a permanent foresight tool through the creation of a platform for constructing, analysing and debating on scenarios. The first condition for the exercise to be realistic was of course that this tool had to function with existing data and results. The second condition was that the platform had to be constructed basically as a system of interaction with the experts, that is, researchers, deciders and, more generally, stakeholders and actors.

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[1] *International Assessment of Agricultural Knowledge, Science & Technology for Development.*
[2] French Initiative for International Agricultural Research (public interest grouping set up in 2007 by INRA and CIRAD).

The Agrimonde project therefore consists of three products which structure the summary report proposed in the present document:

Part I. The Agrimonde platform: designing a platform for facilitating collective scenario development and debate on the world's food and agriculture, which can serve to examine the question of possible roles for research, public policy and international regulations.

Part II. The construction and strategic analysis of two scenarios: implementation of the platform to build and examine two scenarios: first, the reconstruction of the existing "Global Orchestration" scenario of the Millennium Ecosystem Assessment (MA), to show possible dead-ends; and second, the creation of a new scenario, Agrimonde 1, with which it could be compared.

Part III. Debate: debate on the analyses and reflection concerning these scenarios, which may lead to recommendations and prospects for extending the platform. At this stage this part has only been outlined.

The report synthesized in this document presents the results of the first phase of the Agrimonde project (2006-2008). This phase was entrusted to a panel composed of researchers and experts from INRA, CIRAD and other French research organizations and think tanks, led by the standing project team. An expert committee, consisting of twenty representatives of the main French institutions that are stakeholders in the debates and decisions concerning food systems, had an advisory role.

I. A platform for facilitating collective scenario-building

This first section is devoted to the methodology developed in the 2006-2008 phase of the Agrimonde project. It first sets out the method used to facilitate collective scenario-building, and its position in relation to other approaches on long-term food balances. The Agribiom quantitative tool, a central feature of the Agrimonde platform, is then presented.

I.1 A platform based on interactive quantitative and qualitative analyses

The Agrimonde platform has been designed to facilitate collective analysis of the challenges facing the world's food and agricultural system. These can be summed up as the key challenge of properly feeding a population of nine billion individuals in 2050, while preserving the ecosystems from which other services are also expected: bioenergies, biodiversity, carbon storage, climate regulation, etc. The variables to consider when analysing these questions are multifarious: geopolitical, social, cultural, sanitary, economic, agronomic, ecological, technological, etc. Moreover, the global scale on which this question is raised does not preclude reflection at the regional level. The diversity of the world's food and agriculture, and their interactions, through trade and global environmental change, are indeed key variables for the future.

Considering the number and diversity of variables, as well as the importance of the articulation between regional and global scales, the classical method of scenario-building would be inappropriate[3]. It is hardly feasible to combine assumptions on all the key variables for the future of the system studied, on both regional and global scales; this would make the exercise both unwieldy and largely illegible. The scenario method has therefore been adapted by building a platform based essentially on the complementarity of quantitative and qualitative analyses. The quantification is based on the quantitative tool Agribiom, presented below. By formulating quantitative assumptions at regional level, on a limited number of variables, it is possible to reduce the complexity while affording an entry point for in-depth qualitative reflection on all the dimensions of the system.

The scenario-building consists of three main steps:

- Choosing the scenarios and the principles underlying their construction;
- Building quantitative scenarios;
- Building complete scenarios, by completing the quantitative scenarios with qualitative assumptions.

[3] The classical scenario method is based on a first step of exhaustive recording of all kinds of variables likely to impact on the future of the system studied, within the timeline chosen for the foresight study. For further details see, for example, De Jouvenel, 2000, "A Brief Methodological Guide to Scenario Building", *Technological Forecasting and Social Change*, 65 (1) pp 37-48.

The panel first chooses scenarios to build and their underlying principles, that is, their salient features (e.g. "Do we wish to build a scenario based on past trends on food consumption versus a rupture scenario?"; "Do we wish to build a scenario characterized by an energy crisis?"). The timeline and the geographical division into regions are defined according to the foresight objectives.

On the basis of the scenario principles, the panel then builds quantitative assumptions by giving a value to each of the variables of the Agribiom quantitative tool within the timeline chosen and for each of the regional zones. These variables serve to calculate the agricultural resources and their uses for each zone and for the world. For this purpose, the panel bases its assumptions not only on retrospective analyses and therefore on past trends – since in Agribiom the variables to quantify are informed for several past decades – but also on the exploration of possibilities of changing trends. It draws on its members' expertise, and analyses and discusses academic and futures studies that can help it to envisage contrasting scenarios.

Assumptions on the use of biomasses at regional level concern above all human populations, their diets in terms of calories, and the composition of those diets depending on the origin of the calories (plant, land animals, aquatic plants and animals). Assumptions are built on resources at regional level, essentially concerning land use (areas under crops, pastures, forests, etc.), productivity of croplands in terms of plant calories, and conversion of plant calories into animal calories.

Once the quantitative assumptions are formulated, the Agribiom tool is used to test whether the resource-use balances are positive or negative in each region and at global level, including quantities of biomass necessary to produce food of animal origin. The sets formed by the quantitative assumptions and the corresponding resource-use balances form quantitative scenarios. These are discussed by the panel so that it can complete them with qualitative assumptions in order to build complete scenarios. To this end, the quantitative scenarios are analysed for each region and at global level, in relation to three questions:

1. Is the quantitative scenario for a particular region consistent with the principles posed at the outset for building this scenario? If not, what qualitative assumptions should be made to remedy that?
2. What does the comparison between the scenarios teach us? Are they very different? If not, what qualitative assumptions should be made so that they recount contrasting stories?
3. What are the main implications of this scenario? What levers should be activated for it to come true? What qualitative assumptions should be made to integrate these levers into the scenario?

I.2 Agrimonde, complementary to other approaches on long-term food balances

When it set itself the objective of exploring the future of the world's food and agricultural systems, the Agrimonde platform made methodological choices that complemented existing ones, and that can be sorted into two main sets:

- Forecasting centred on possibilities of growth of the world's agricultural production;
- Exercises with global scenarios on natural resources and globalization, based on integrated models.

The first set of studies, which compares the potential biomass production with future food needs, includes approaches often described as neo-Malthusian[4], forecasted trends over 15-20 years[5] mainly carried out by the FAO[6], and exercises aimed at highlighting a maximal potential for biomass production in agriculture that would have to be reached by removing technical or socio-economic obstacles. Of the latter type of exercise, two influenced the design of Agrimonde's first scenarios: the scenarios put forward by Philippe Collomb and Michel Griffon, respectively[7]. In both cases the emphasis is not only on meeting global needs with resources, but also on regional capacities to cover regional needs.

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[4] From the Meadows Report submitted to the Club of Rome in 1972 (Meadows D. H., Meadows D. L., Randers J. and Behrens III W. W., 1972, *The Limits to Growth*, Universe Books, New York), to the more recent book by Lester Brown, (Brown L., 1995, *Who Will Feed China?: Wake-Up Call for a Small Planet*, W. W. Norton & Company).
[5] FAO, 2002, *World Agriculture: Towards 2015/2030* – Summary Report.
[6] *Food and Agriculture Organization of the United Nations.*
[7] Griffon M., 2006, *Nourrir la planète – Pour une révolution doublement verte*, Odile Jacob; Collomb P., 1999, *Une voie étroite pour la sécurité alimentaire d'ici à 2050*, Economica, Paris.

Agrimonde partially corresponds to this first set of approaches, especially from the point of view of methods for representing food and agricultural systems. It is based on data aggregated at the level of the world's main regions. The purpose of this platform is to draw conclusions from an evaluation of regional and global balances between resources and their uses. In this respect, the Agribiom quantitative tool has various advantages, notably:

- It takes into account the totality of food biomasses;
- It uses units (calories, proteins, etc.) that allow for unusual aggregates, models and simulations of production, trade and uses of food biomasses;
- It allows for an innovative and robust processing of the conversion of plant biomass into animal biomass for food.

However, like other similar approaches, the quantitative evaluations of Agribiom do not afford access to the territorial complexity of agricultural systems, even though this tool and the Agrimonde scenarios could allow for more targeted analyses in a particular country. The quantitative scenarios constructed in Agrimonde are not intended to encompass all the challenges regarding agriculture and food, which cannot be grasped through the global biophysical potential of biomass production only. The evaluation of the potential to increase production also aims here to assess the capacity of agricultural systems to participate in the effort to reduce poverty. The construction of complete scenarios that combine quantitative and qualitative assumptions is therefore indispensable for the construction of coherent and relevant visions of the future of agriculture and food.

Through the second set of studies, a family of global reference scenarios is busy emerging (scenarios of the IPCC[8] and the MA, in particular, and more generally the variety of approaches included under the heading "integrated assessment"), built in relation to one another and with the same integrated modelling tools. The main quality of these scenarios is that they allow for the integration and articulation of projected socio-economic scenarios of greenhouse gas emissions, along with their translation in terms of impacts on climate change and consequently on the resources and activities under study, i.e. agriculture among others.

These reference scenarios are used to explore four contrasting images of the state of the world in 2050, differentiated in terms of: 1) global development (globalization versus regionalization); and 2) ecosystems management (proactive versus reactive). These four sketches of the world are then translated by the integrated models as part of an approach presented under the heading "Story and simulation", consisting in combining the qualitative scenarios with the integrated models[9].

Because of the highly complex architecture of integrated modelling and the large number of models, the study is limited to the four reference families which are supposed to represent the multiplicity of possible futures for the planet. But within the framework of the IAASTD, it appeared that these reference families did not provide a satisfactory framework of reflection on the future of food and agricultural systems.

The Agrimonde platform therefore constitutes a complementary approach to integrated assessment exercises. It aims for a faster exploration of the quantitative coherence of assumptions formulated in the scenarios, and centres a large proportion of the work on discussions on all the qualitative assumptions and their coherence. In this sense, Agrimonde aims to provide a larger capacity for generating coherent scenarios, other than the reference scenarios, and which could then be modelled, particularly in economic terms.

I.3 The Agribiom quantitative tool

Agribiom is a quantitative tool devoted to the analysis of the world's production, trade and uses of biomasses. The (past or future) balance, in physical terms, between production of food biomasses and their uses is the core and the driver of Agribiom. Such balances can be reconstituted (from the 1960s to date) or simulated by Agribiom on various geographical scales (from a country to the whole world) according to some units and categories thought to be useful for developing new analyses and models in fields and on scales where statistical information and modelling are limited (e.g. the conversion of plant biomass into animal biomass on national scales) and need to be improved.

[8] The Intergovernmental Panel on Climate Change.

[9] European Environment Agency, 2001, "Scenarios as Tools for International Environmental Assessments", *Environmental Issue Report*, 24.

To that end, Agribiom hinges on four work packages, with the first phase of the Agrimonde project (2006-2008) concentrated on the first three:

(1) Collecting and collating, over a fairly long period (from the 1960s to date), millions of data related to national production, exports, imports and consumption of food and agricultural products;

(2) Using these basic data to generate new statistical series that serve for new readings of the past and new modelling exercises;

(3) Constructing an interface so that these data and models can easily be shown to a varied public (researchers, experts, policy-makers, etc.), with a view to discussing them and then simulating and debating various scenarios of future possible supplies and utilizations of food biomasses;

(4) Interacting with other quantitative tools, especially economic models of computable general equilibrium and biophysical models.

Retrospective data

Owing to the compilation and processing of a large number of data from different databases (mostly from the FAO, with at the centre its Supply Utilization Accounts – SUA)[10], Agribiom has enabled the Agrimonde panel to analyse long series (1961-2003) in order to discuss past trends and scenarios of possible evolution towards 2050. These analyses focus primarily on:

- Human populations;
- Uses of food products (food, feed, seed, non-food uses, waste), in calorie equivalents and according to their origin : land plants, land animals (ruminants and monogastric) and aquatic plants and animals (fresh water and marine);
- Land uses according to five categories: annual and permanent crops[11], permanent meadows and pastures, forests, other emerged land and, finally, inland water (lakes, rivers and other immersed land);
- Food production and yield, in calorie equivalents;
- Net trade (exports – imports), in calorie equivalent.

From over 250 geographic units present in FAO databases during the studied period (1961-2003), 149 were selected for Agribiom. A large number of islands and micro-states were excluded because of data being too irregular or incoherent, along with a few larger areas for which the same statistical problem existed (Afghanistan, Antarctica, French Guyana, Iraq, Western Sahara, and Somalia). These 149 entities represent about 98% of the world in many areas[12].

Models of animal production

Agribiom also proposes models of animal food production on which the Agrimonde panel drew. The transformation of plant biomass (food products or by-products used as feed, fodder, pastures, crop residues, food residues, etc.) into animal food biomass (milk, meat, eggs, etc.) is a crucial dimension of the world food economy. But the technologies of this transformation are highly variable from one area of the world to another, while statistics and modelling in this field are particularly limited on the geographic scales considered. Agribiom is trying to improve the representation of regional transformations of plant biomass into animal food biomass through "animal production functions", after having shown that the average productivity of plant feed such as cereals, grains and oilseed cakes varies widely in space and time, in terms of calories and proteins. In other words, long-term simulations of animal production using only such feed as input, along with fixed transformation coefficients, present limitations that the development of cross-country animal production functions have sought to surpass.

Several types of animal food production functions have been developed. Those chosen for Agrimonde (see Box 1) are able to reproduce regional animal production over the past forty years with a fair degree of accuracy. They also limit the number of hypotheses to formulate for simulations, and are relatively robust to a change of values far from those used to develop each model (in foresight exercises such as Agrimonde, very different worlds to those observed in the past can be imagined).

[10] See the report for a detailed description of the series mobilized and a description of the data reprocessing.
[11] Called "cultivated area" in this document and in the report.
[12] In 2000: 98.3% of human populations, 98.6% of cultivated lands, 97.3% of land surfaces, etc.

Box 1: The choice of animal production functions
Main characteristics of the animal production functions used by Agrimonde: - Linear; - Geographic and, in this case, for each of the six MA regions[13] (12 to 40 countries per region, depending on the case); - Without trend or dummies; - Using the caloric value of proteins as a working unit; for the simulations, the conversions into total calories are set on the last protein contents observed (2003) but can be altered, depending on the scenarios imagined (increase/reduction of the protein content of the feed and/or of the outputs); - Organized in a system of two equations (production of ruminant proteins and of monogastric proteins), with three explanatory factors: feed (excluding fodder) in protein equivalents, hectares of pastures, and level of production of the "substitute" (production of monogastric proteins or of ruminant proteins, depending on the case).

Food balances

After the development of the various assumptions constituting the quantitative scenarios Agrimonde 1[14] and Agrimonde GO[15] (see part II), Agribiom simulated regional supplies, uses and balances of food biomasses. These balances present three particularities:

- They are developed for almost all "food biomass"[16] merged into five categories relating to product origins and land use (food products from plants, terrestrial ruminants or big herbivores, other terrestrial animals, fresh water, sea);
- They use the food calorie (kcal) as a common unit of volume[17], for consumption, production or trading of biomass; this has both advantages[18] and limits[19];
- They simulate the annual vegetal food biomass resources and uses according to the basic following equation (see the report for animal productions and any further details).

(Surface area x Yields) – (Exports – Imports) +/– Stock variations = (Population x Calorie consumption per capita) + Feed + Seed + Non-food uses + Waste

The left-hand term of the equation represents regional food biomass resources: productions increased or reduced by the net trade balance and (for past balances only) the net stock variations. The right-hand term of the equation represents regional food biomass uses, where direct human consumption of a food category (plant products, ruminant products, etc.) is estimated by multiplying a number of persons with an average calorie consumption per capita.

Interactive interface and simulations

The quantitative assumptions selected do not always allow for the targeted global resource-use balance to be found immediately[20]. In such cases, the balance is found after adjusting some assumptions upwards or downwards, by trial and error, following certain rules. It may also be interesting not to automatically look for a balance so that surpluses and shortages can be shown and collective debates can be held on the various ways or conditions for benefiting from the surpluses, or for making up for the shortages. With regard to questions such as how the production of a region can meet its needs, it can also be interesting to simulate and debate extreme solutions, even if they are not the most realistic, for instance an increase of yields without an increase of the cultivated area, or vice-versa. In that way, the added value of the Agribiom interface lies in the learning of the role of each

[13] Asia; the former Soviet Union; Latin America; Middle East-North Africa; OECD-1990; and sub-Saharan Africa.

[14] Agrimonde 1 is named AG1 in figures and tables.

[15] Agrimonde GO is named AGO in figures and tables.

[16] By "food biomass" we mean any organic matter that, in its primary form, can serve as food for human beings. This definition therefore encompasses a very wide variety of farm products, but not all of them since it excludes products such as rubber, plant fibres, silk, wool, leather, essential oils, fodder, etc. The food balances also exclude live animals, partly because only their products (milk, meat, etc.) are taken into account in the SUA.

[17] By "volume", we mean a physical quantity, as opposed to a "value".

[18] In particular, this unit serves to add up (and sort into categories) quantities of products that cannot be added up when they are expressed in tons, litres or numbers.

[19] There are limits, especially economic (e.g. a calorie from a grain of maize does not have the same market value as a calorie from a grain of coffee) and nutritional (cf. Deaton A., Dreze J., 2009, "Food and Nutrition In India: Facts and Interpretations", *Economic & Political Weekly*, XLIV(7), pp. 42-65; Dorin B., 1999, "Food Policy and Nutritional Security. The Unequal Access to Lipids in India", *Economic and Political Weekly,* XXXIV(26), pp. 1709-17.

[20] At its present stage of development, Agribiom is not intended to model economic equilibrium with automatic adjustments through price and income elasticities.

variable, model and decision-making rule used to reach a physical balance, and not only in the final image of the resource-use balance simulated. It is in this respect that Agribiom is fundamentally an interactive tool.

II. Agrimonde 1 and Agrimonde GO: scenario development

This part examines the ground covered by the panel in its scenario development. Starting with the analysis of the MA scenarios, the panel first chose the scenarios to build and the principles underlying that construction. It then proceeded with the quantification, region by region, of the food biomass resources and uses in the Agrimonde scenarios, to be able to inform the regional states of resource-use balances by 2050 in the scenarios. Finally, the analysis of the coherence of the scenarios, their comparison and the identification of the levers of action characterizing them served to specify the qualitative dimensions of the scenarios, left open by the quantification, so that complete scenario descriptions for 2050 could be produced.

II.1 Choice and building-principles of the two scenarios

The panel chose to analyse the MA scenarios, and particularly Global Orchestration, from the angle of food and agricultural systems, and to construct only one new scenario that departed from the MA scenarios (see Figure 1).

The MA scenarios, built to study the future of ecosystems, are references in international debates. The principles on which they are built are not necessarily the most relevant for discussing the future of food and agricultural systems. It is nevertheless interesting to compare the two approaches, one regarding ecosystems and the other regarding the human activities that have the strongest impact on ecosystems. The panel therefore wanted to analyse the MA scenarios in depth, and to use the Agrimonde platform to translate them into food and agricultural scenarios.

As the MA scenarios are exploratory – they explore the consequences of various possible trends, starting with the present situation – certain experts, including some involved in the MA, regretted the absence of a desirable scenario on the future of ecosystems. In *Nourrir la planète* (“Feeding the Planet”), Michel Griffon had proposed a scenario describing agricultural systems in which all the characteristics of sustainability were sought, and the potential and conditions of a "doubly green revolution" were explored[21]. This type of agriculture would be characterized by agricultural production technologies likely to both preserve ecosystems and allow for development through agriculture in countries in which the lack of capital limits the implementation of production systems making intensive use of equipment, pesticides and fertilizers. The panel therefore constructed what it saw as a desirable scenario, labelled Agrimonde 1, freely inspired by Michel Griffon's scenario.

In concrete terms, the scenarios of the MA and of Michel Griffon constituted the reference for the development of the Agrimonde 1 assumptions. Additionally, the panel chose to 'reconstruct' a MA scenario, Global Orchestration, so that it could compare Agrimonde 1 to a trend-based scenario on food consumption, but with different underlying societal priorities. Global Orchestration is actually the MA scenario with the largest reduction of poverty and malnutrition. It is based on both the liberalization of trade and on major technological advances in terms of agricultural yields. The priority given to economic development in this scenario nevertheless results in a mainly reactive management of ecosystems and environmental problems. Here this scenario is called "Agrimonde GO", not only because it was reconstructed on the basis of the quantification method adopted in Agrimonde, but also because the population assumptions chosen for this scenario are not the ones used in the MA. To really be able to compare the Agrimonde 1 scenario to another scenario, it seemed important for the panel to make the same 'population pressure' assumptions in both scenarios.

The choice of constructing a scenario with reference to those of the MA and Michel Griffon led to select the same timeline, 2050, and the same geographic zoning into six main regions: Asia (ASIA); the former Soviet Union (FSU); Latin America (LAM); Middle East-North Africa (MENA); OECD-1990 (OECD); and sub-Saharan Africa (SSA).

Agrimonde 1 aims to explore the meaning and conditions of existence of a scenario of a sustainable food and agricultural system. In this respect, it is clearly what is called a normative scenario.

[21] Griffon M., 2006, *Nourrir la planète – Pour une révolution doublement verte*, Odile Jacob.

Nevertheless the assumptions forming the scenario do not have the status of norms and even less so of prescriptions. It assumed that by 2050 the world would have been able to implement a sustainable food and agricultural system. This has afforded a better understanding of the meaning of such development, with the dilemmas and the main challenges that this type of scenario entails, and through the changes and discontinuities that it implies. The assumptions proposed by the panel are intended to initiate reflection and debate on a diversity of possible futures. The idea is thus to contribute to enlightening the choices which have to be made today if we are to have real part to play in shaping our future.

The world in 2050 as described in Agrimonde 1 is based above all on sustainable food conditions, allowing for the reduction of inequalities in food and health, through a drastic reduction of both undernourishment and excessive food intake. Moreover, the world in 2050 will have implemented a set of actions to intensify productive systems and to increase production in most regions. These actions will have met three objectives: satisfying the growing demand; allowing for the development of income from agriculture in rural areas of the South, and developing environment-friendly agricultural practices. The panel therefore set out to explore the different possible trajectories of ecological intensification, and to examine their nature, assets and limits in their regional contexts and in relation to the above-mentioned objectives.

These two scenarios are therefore constructed differently: while Agrimonde GO is essentially a trend-based scenario starting from the current situation, Agrimonde 1 is built on the basis of sustainability objectives that are supposed to be met by 2050, and explores the trajectories that would enable them to be attained.

The two underlying principles in the construction of the Agrimonde 1 and Agrimonde GO scenarios are the following:

- The capacity of each large region of the world to satisfy its food needs in 2050 was to be assessed, which implied that interregional trade would be considered only after the extent to which agricultural production in each of the regions covered local needs had been evaluated;
- The effects of future demographic trends were to be analysed without them being masked by large international migratory flows, so that the implications of expected population explosions could be examined fully with regard to each region's capacity to feed its own population.

In its present form – to be enhanced in future studies - the tool nevertheless limits to some extent the capacity to construct scenarios for the world's food and agriculture in 2050. First, there are no precise and complete quantitative estimations for the interactions between climate change and agriculture. Consequently, climatic phenomena (greater variability, alterations in rainfall, rising temperatures, melting of certain areas, etc.) were taken into account only roughly, based on panel experts' statements on the subject. On the basis of the IPCC's scenarios, the experts modulated their assumptions on cultivable lands and yields in 2050 in the different regions. Second, even if the notion of pressure on natural resources is dominant in the analysis in various respects (deforestation resulting from the extension of farmlands, water stress induced by climatic and demographic changes, deterioration of the quality of the soil and water caused by farming practices, etc.), the quantitative tool Agribiom does not yet integrate indicators of the consumption of natural resources, such as quantities of water or energy consumed. Finally, Agrimonde 1 is based on the hypothesis that agricultural development is a driving force of global economic development and poverty alleviation[22]. However, this tool does not enable us to verify whether the supposed increases in agricultural production in each region do effectively make it possible to contribute to sufficient economic development, especially to avoid phenomena of mass migration.

[22] World Bank, 2008, *World Development Report 2008: Agriculture for Development*.

Figure 1: The *Millennium Ecosystem Assessment* scenarios[23]

Globalization

GLOBAL ORCHESTRATION: *a worldwide connected society in which global markets are well developed. Supra-national institutions are well placed to deal with global environmental problems, such as climate change and fisheries. However, their reactive approach to ecosystem management makes them vulnerable to surprises arising from delayed action or unexpected regional changes.*

The scenario is about global cooperation not only to improve the social and economic well-being of all people but also to protect and enhance global public goods and services (such as public education, health, and infrastructure). There is a focus on the individual rather than the state, inclusion of all impacts of development in markets (internalization of externalities), and use of regulation only where appropriate. Environmental problems that threaten human well-being (such as pollution, erosion, and climate change) are dealt with only after they become apparent. Problems that have little apparent or direct impact on human well-being are given a low priority in favor of policies that directly improve well-being. People are generally confident that the necessary knowledge and technology to address environmental challenges will emerge or can be developed as needed, just as it has in the past. The scenario highlights the risks from ecological surprises under such an approach. Examples are emerging infectious diseases and other slowly emerging problems that are hard to control once they are established. Other benefits and risks also emerge from the inevitable and increasing connections among people and nations at social, economic, and environmental scales.

TECHNOGARDEN: *a globally connected world relying strongly on technology and on highly managed and often-engineered ecosystems to deliver needed goods and services. Overall, eco-efficiency improves, but it is shadowed by the risks inherent in large-scale human-made solutions.*

Technology and market-oriented institutional reform are used to achieve solutions to environmental problems. In many cases, reforms and new policy initiatives benefit from the strong feel for international cooperation that is part of this scenario. As a result, conditions are good for finding solutions for global environmental problems such as climate change. These solutions are designed to benefit both the economy and the environment. Technological improvements that reduce the environmental impact of goods and services are combined with improvements in ecological engineering that optimize the production of ecosystem services. These changes co-develop with the expansion and development of property rights to ecosystem services, such as requiring people to pay for pollution they create or paying people for providing key ecosystem services through actions such as preservation of key watersheds. These rights are generally created and allocated following the identification of ecological problems. Because understanding of ecosystem function is high, property rights regimes are usually assigned long before the problem becomes serious. These property rights are assigned to a diversity of individuals, corporations, communal groups, and states that act to optimize the value of their property. We assume that ecological management and engineering can be successful, although it does produce some ecological surprises that affect many people due to an over-reliance on highly engineered systems.

Reactivity | **Proactivity**

ORDER FROM STRENGTH: *a regionalized and fragmented world concerned with security and protection, emphasizing primarily regional markets, and paying little attention to the common goods, and with an individualistic attitude toward ecosystem management.*

Nations see looking after their own interests as the best defense against economic insecurity. They reluctantly accept the argument that a militarily and economically strong liberal democratic nation could maintain global order and protect the lifestyles of the richer world and provide some benefits for any poorer countries that elect to become allies. Just as the focus of nations turns to protecting their borders and their people, so too their environmental policies focus on securing natural resources seen as critical for human well-being. But, as in Global Orchestration, people in this scenario see the environment as secondary to their other challenges. They believe in the ability of humans to bring technological innovations to bear as solutions to environmental challenges after these challenges emerge.

ADAPTING MOSAIC: *a fragmented world resulting from discredited global institutions. It sees the rise of local ecosystem management strategies and the strengthening of local institutions. Investments in human and social capital are geared toward improving knowledge about ecosystem functioning and management, resulting in a better understanding of the importance of resilience, fragility, and local flexibility of ecosystems.*

There is optimism that we can learn, but humility about preparing for surprises and about our ability to know all there is to know about managing socioecological systems. Initially, trade barriers for goods and products are increased, but barriers for information (for those who are motivated to use it) nearly disappear due to improving communication technologies and rapidly decreasing costs of access to information. There is great regional variation in management techniques. Some local areas explore adaptive management, using experimentation, while others manage with command and control or focus on economic measures. Eventually, the focus on local governance leads to failures in managing the global commons. Problems like climate change, marine fisheries, and pollution grow worse, and global environmental surprises become common. Communities slowly realize that they cannot manage their local areas because global problems are infringing, and they begin to develop networks among communities, regions, and even nations to better manage the global commons. The rebuilding is more focused on ecological units, as opposed to the earlier type of management based on political borders that did not necessarily align with ecosystem boundaries.

Regionalization

[23] Carpenter S. R., Pingali P. L., Bennett E. M., Zurek M. B. (eds), 2005, *Ecosystems and Human Well-being: Scenarios,* Volume 2, The Millennium Ecosystem Assessment, Washington DC. MA scenarios are differentiated in terms of: 1) global development (globalization versus regionalization); and 2) ecosystems management (proactive versus reactive).

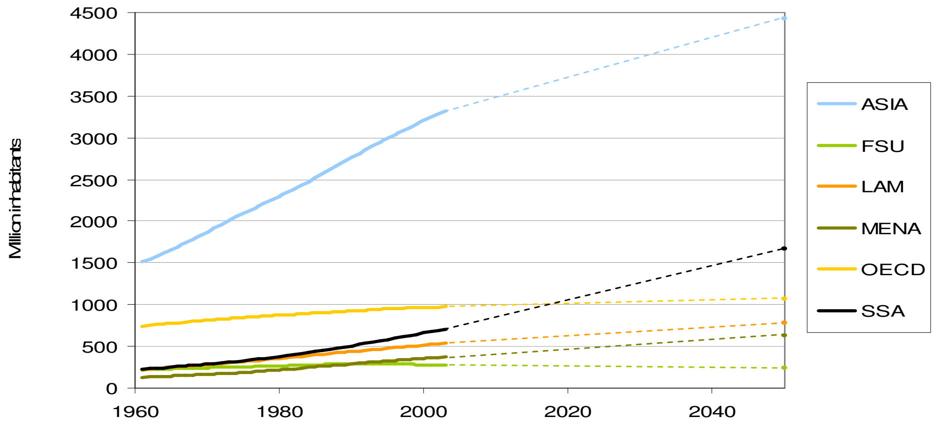
II.2 Quantitative scenarios

In the Agrimonde scenarios, food resources and their uses for 2050 have been quantified on the scale of each region. Uses are simulated on the basis of assumptions on populations and the level of calories consumed for each type of biomass considered (plant, animal, and aquatic). The quantification of resources is based primarily: (i) for plant calories, on assumptions of food crop areas and calorie yields per hectare; (ii) for animal calories, on regional animal production functions (see Box 1); and (iii) for aquatic calories, on the assumption that regional production will cover regional needs in 2050.

Population in 2050

The assumptions of Agrimonde 1 and Agrimonde GO[24] concerning world and regional populations in 2050 are based on the United Nations' median projection[25] (see Figure 2). This projection estimates the number of inhabitants on the earth at 9 billion in 2050. Note that this projection includes a flow of international migration considered to be normal, corresponding to roughly 100 million migrants over 50 years. As noted above, this assumption of low migratory levels enables the scenarios to fully take into account the consequences on regional food needs of high levels of population growth anticipated in Africa, Asia and Latin America.

Figure 2: Regional populations from 1961 to 2003 and in 2050 in the Agrimonde scenarios



Source: FAOSTAT (1961-2003) & UNSTAT (2050)

Food consumption in 2050

The evolution of food consumption is very different in the two scenarios (see Figure 3). The Agrimonde GO scenario uses the assumptions of the MA Global Orchestration scenario in which economic growth largely explains consumption levels[26]. We can qualify it as a trend-based scenario in terms of the evolution of the consumption of food calories, where economic growth boosts consumption in all the regions, to reach a mean global availability (see Box 2) of 3,590 kcal/cap./day (of which 2,700 of plant origin) and undernourishment is reduced substantially. The Agrimonde 1 scenario is clearly distinguished from this trend-based scenario. In Agrimonde 1, the income-food consumption nexus is not the most determining one, due to concerns for health, equity and the environment. The assumption of food availability (see Box 2) for 2050 is 3,000 kcal/cap./day in all regions, notwithstanding certain regional particularities visible in the break-down in terms of animal calorie sources (monogastric, ruminants, and aquatic). This set of assumptions is a sharp contrast with the trends observed between 1961 and the beginning of the 21st century. It corresponds to a slow growth of food availability per capita in most regions up to 2050, except in sub-Saharan Africa where the per capita food availability has increased by 25% in 50 years, and the OECD-1990 region where it has

[24] Note that Agrimonde GO uses the same population assumptions as Agrimonde 1. This is so that the two scenarios' ability to meet food needs in 2050 can be compared.
[25] UNSTAT, 2006, *World Population prospects: the 2006 revision.*
[26] Total availability at regional and world levels is given in the MA report, but it has not been broken down by product. Thus, to quantify the food consumption assumptions of the Agrimonde GO scenario, we have made some extrapolations that are specified in the report.

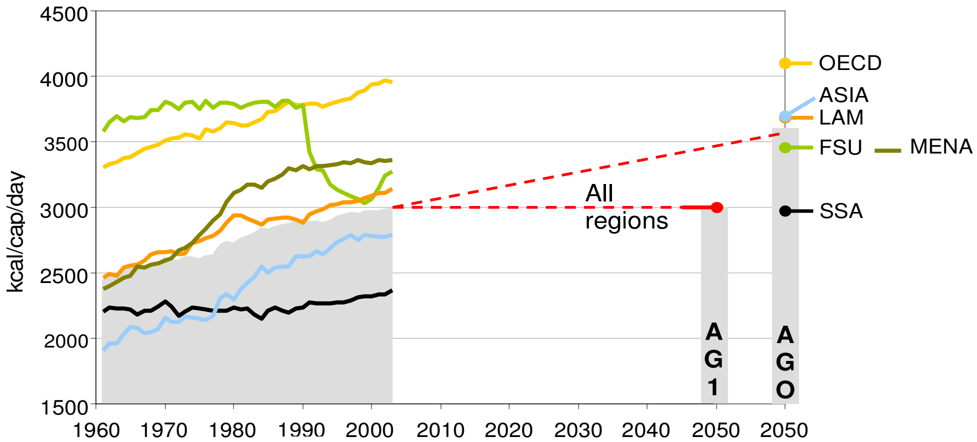
decreased by a quarter (see Figure 3). These 3,000 kcal are broken down into 2,500 kcal of plant products and 500 kcal of animal and aquatic products. The distribution between monogastric and ruminants varies from region to region. Globally, the proportion of monogastrics is increasing in all regions, whereas the proportion of ruminants is declining despite high levels in OECD-1990 countries, the former Soviet Union and Latin America, and an increase in sub-Saharan Africa. The share of calories of aquatic origin has increased in varying proportions, linked to regional productive possibilities. A distinction was introduced between freshwater calories and marine calories. Although the oceans are a considerable source of food production, fishing will face structural limits related to several factors (over-fishing, artificialization of the littoral, pollution, accelerated erosion of the biodiversity), while tension over uses of fresh water will worsen. It is therefore assumed that marine aquaculture can increase at a faster pace than it has over the past 40 years, but at a different pace depending on the region[27]. Given the tensions over water, a relative stability in per capita availability of calories from fresh-water sources is assumed. In each region, the evolution of per capita availability is then supposed to be the same as that of regional population.

Box 2: Availability as an approximation of food consumption

In the Agrimonde scenarios, as in the MA scenarios, "food availability" serves as an approximation of food consumption. We calculated it as the ratio between the calorie equivalent of quantities of available foodstuffs (production + imports – exports +/- stock variations) to feed the human population of a region (i.e. excluding feed, non-food uses, seeds and losses after harvesting), and the number of inhabitants of that region. This availability reflects the quantity of calories available to consumers, at home and outside the home. It includes calories that are lost between the purchase of the products and their ingestion. It should not be confused with the quantity of calories actually ingested, which is difficult to estimate. In terms of ingestion, the net energy needs of a human being are around 2,000 to 3,000 kcal/day, depending on gender, height, weight, intensity of physical activity, climate, etc.

The set of assumptions on food consumption supposes that people's diets will depart from current tendencies as they take into account the objectives of sustainable development, due to mounting pressure on resources and diet-related public health problems. It is therefore a very strong set of assumptions since it implies that consumers, producers and public policy-makers will take into account the global and local impacts of modes of food production and consumption on health and the environment.

Figure 3: Mean regional food availability from 1961 to 2003 and in 2050 in the Agrimonde scenarios[28]



The panel made this set of assumptions in order to highlight four challenges:

- The wide gap observed nowadays between availabilities and FAO recommendations. Whereas the FAO deems satisfactory a mean availability of 3,000 kcal/cap./day in a given population, to

[27] In Agrimonde 1, the pace of the development of marine aquaculture is high in Asia, in OECD-1990 and in Latin America, and moderate in the other regions.
[28] The data used for this and for the following figures, for the years 1961-2003, were produced by reprocessing FAO data. AG1 refers to Agrimonde 1 and AGO refers to Agrimonde GO.

guarantee that each individual can have sufficient and healthy food[29], the per capita mean availability in 2000 ranged from below 2,500 kcal/cap./day in sub-Saharan Africa, and to 4,000 kcal/cap./day in the OECD-1990 zone (just under 4,500 kcal/cap./day in the US).

- The importance of equity in a sustainable development scenario. On this point, the panel could have opted for the assumption, like P. Collomb in *Une voie étroite pour la securité alimentaire en 2050*[30] ("A Narrow Road to Food Security in 2050"), that each region attains at least 3,000 kcal/cap./day, and that some exceed that level. The panel chose to test a stronger assumption: the convergence of average availabilities of food towards 3,000 kcal/cap./day in all regions.
- The food/health nexus. An availability of 3,000 kcal/cap./day can have positive consequences in terms of public health by: (i) maintaining the proportion of under-nourished people at a relatively low level, thus reducing the risks of undernourishment in developing countries, and (ii) limiting over-consumption, a determinant of nutrition-related non-communicable diseases such as obesity.
- The relationship between diet and pressure on natural resources. The aim of adequately feeding 9 billion people in 2050 implies that, irrespective of the production methods, there will be considerable pressure on natural resources that will increase along with the growing proportion of animal products in people's diets. The production of animal calories requires a substantial volume of plant calories, water[31] and energy[32], and generates greenhouse gasses (methane, carbon dioxide and nitrous oxide) directly (respiration, rumination) or indirectly (feed, processing, transport)[33]. Caution is nevertheless required as regards the environmental impact of animal production. For example, one can consider that there is an advantage in producing animals which optimize the use of plant resources (they graze on pastures, thus eating fibres that humans cannot digest). Producing ruminants still has the advantage of using land that is often unfit for crops (high-altitudes, slopes, semi-arid areas, etc.), and which stores carbon and biodiversity.

Land use in 2050

In Agrimonde GO we selected the MA's land use assumptions used in its Global Orchestration scenario (see Table 2)[34]. In the MA, different types of land use are quantified by means of the IMPACT model, which treats them as one of the components of the equation designed to balance food production with demand.

In Agrimonde 1 the comparison of physical factors of availability and quality of the soil with sustainability criteria guided the construction of land use assumptions. In concrete terms, the panel proceeded in three steps:

1. Identification of reserves of land with cultivation potential in each region, using evaluations of the IIASA-FAO[35] and the FAO[36];
2. Quantifying newly cultivated land areas and new areas under irrigation in 2050, and consequently remaining areas under forest cover or pastures. This is based on the analysis, in each region, of former dynamics, hypotheses used in other foresight and forecasting exercises (scenarios of, *inter alia*, the MA, Michel Griffon, the IFPRI, and the IWMI[37]), and the identification of driving forces behind the expansion or reduction of agricultural areas (see Table 1). The panel chose to limit deforestation, even when that implied sharp discontinuities compared to past trends, considering that sustainable agriculture is based decisively on ecosystem services rendered by forests.

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[29] FAO, 2002, *World Agriculture: Towards 2015/2030 ;* Naiken, L. 2003. FAO Methodology for Estimating the Prevalence of Undernourishment. *In Measurement and Assessment of Food Deprivation and Undernutrition,* pp. 7-42. Rome: FAO.

[30] Collomb P., 1999, *Une voie étroite pour la sécurité alimentaire d'ici à 2050*, Economica, Paris.

[31] According to Zimmer and Renault, in California, 100 litres of water are required to produce 1kg of potatoes, 4,600 litres for 1kg of pork, 4,100 litres for 1kg of poultry, and 13,000 litres for 1kg of beef. These figures are indicators that vary, depending on soil, climate, productive systems, especially when pigs are fed waste. They nevertheless give an indication of the gap between water consumption of various foodstuffs. (Zimmer D. and Renault D., 2003, "Virtual Water in Food Production and Global Trade: Review of Methodological Issues and Preliminary Results"*, Value of Water Research Report Series No. 12).*

[32] According to Pimentel, in the US, 2,700 kcal of fossil fuel are required to produce 100 kcal of pork and 1,600 kcal for 100 kcal of beef (Pimentel D. and Pimentel M., 1996, *Food, Energy and Society,* CRC Press).

[33] Animals also have various uses: for their owner they represent a form of capital, they provide organic fertilizer and are often used as draught animals; they provide food and regular income for populations that are often among the poorest in the world in economic terms, as well as leather or wool; etc.

[34] As the reference surface areas for the year 2000 differ in the MA and Agribiom data, a corrective factor has been applied to the MA gross surfaces of 2050, to be comparable with those of Agrimonde 1.

[35] Fischer G., Velthuizen H. van, Nachtergaele F. O., 2002, *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results*, Research Report RR-02-02, IIASA, Laxenburg, March.

[36] *FAO, 2002, World Agriculture: Towards 2015/2030 – Summary report.*

[37] *International Food Policy Research Institute* and *International Water Management Institute.*

3. The specific quantification of non-food crop surface areas among the total cultivated area[38]. The panel assumed that a new generation of agro-fuels, produced from ligno-cellulose, from food by-products or from micro-algae with a high lipid yield, will have emerged by 2050.

Table 1: Driving forces behind evolving land use in the Agrimonde 1 scenario

Region	Driving forces of growth of cultivated areas	Forces limiting the growth of cultivated areas
ASIA	- Strong growth of agricultural population	- Saturation of the potential of cultivable land - Accentuation of water stress due to climate change in Northern China - Artificialization due to urbanization
FSU	- Reserve of cultivable land - Melting of the permafrost	- Population decline
LAM	- Reserve of cultivable land - Agricultural policy (research, training, development) - Increasing production of agro-fuels	- Aridification in Central America and the *cerrado* due to climate change - Growth of pressure groups to preserve the Amazon jungle
MENA		- Saturation of the potential of cultivable land - Accentuation of water stress due to climate change - Necessity to preserve forest areas for hydrological functioning - Artificialization due to urbanization
OECD	- Reserve of cultivable land - Melting of the permafrost in Canada - Increasing production of agro-fuels	- Reforestation - Mechanisms to preserve protected species
SSA	- Reserves of cultivable land - Limited capacity, in terms of governance, to curb the progression of the pioneering front on the savannah and Congo forest basin - Rural and agricultural development policies: opening up of isolated areas and organization of rural areas	- Aridification due to climate change

Table 2: Regional land use rates of variation: 1961-2000 and 2000-2050 in the Agrimonde scenarios

Type of land use	Region	Rate of variation 1961-2000	Rate of variation 2000-2050		Region	Rate of variation 1961-2000	Rate of variation 2000-2050	
			AG1	AGO**			AG1	AGO**
Cultivated land*	ASIA	+ 23%	+ 23%	+ 11%	FSU	- 15%	+ 53%	+ 10%
Pasture land	ASIA	+ 36%	- 9%	+ 30%	FSU	+19%	- 16%	- 41%
Forests	ASIA	- 5%	- 10%	- 11%	FSU	- 8%	0%	+ 12%
Cultivated land*	LAM	+ 58%	+ 91%	+ 64%	MENA	+ 14%	+ 9%	+ 12%
Pasture land	LAM	+ 20%	- 20%	- 1%	MENA	+ 39%	- 2%	- 2%
Forests	LAM	- 9%	-4%	- 1%	MENA	- 33%	0%	- 35%
Cultivated land*	OECD	- 2%	+ 18%	+ 12%	SSA	+ 33%	+ 76%	+ 58%
Pasture land	OECD	- 8%	- 23%	- 19%	SSA	+ 2%	- 12%	+ 49%
Forests	OECD	- 9%	+ 10%	+ 13%	SSA	-10%	- 9%	- 31%
Cultivated land*	World	+ 12%	+ 39%	+ 23%				
Pasture land	World	+ 11%	- 15%	+ 7%				
Forests	World	- 9%	- 1%	- 1%				

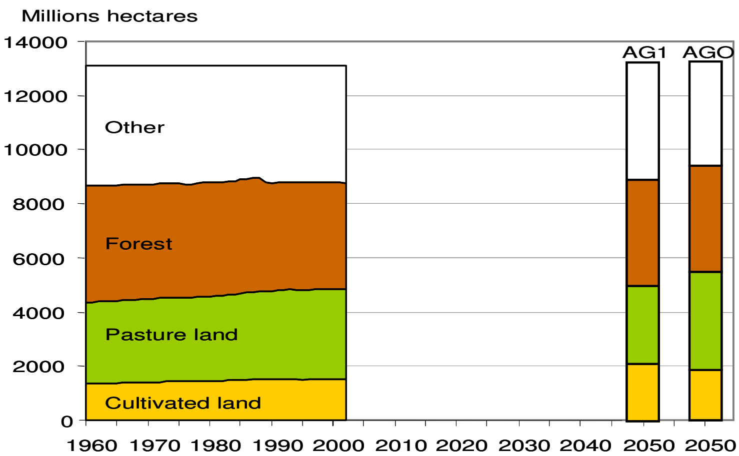
* Cultivated land = food crop area + non-food crop area

** As the reference surface areas for the year 2000 differ in the MA and Agribiom data, a corrective factor has been applied to the MA gross surfaces of 2050 (for the Global Orchestration scenario), to be comparable with those of Agrimonde 1.

[38] The surface areas under agro-fuel crops constitute a part of the "NFFL", non-food farmed land. Crops include fibres, tobacco, rubber, biomaterials, etc.

To sum up, in Agrimonde GO, between 2000 and 2050, the cultivated land area has increased by 23%, at an average pace of 6.8 million newly cultivated hectares per year, i.e. a pace more than twice as fast as that observed between 1961 and 2000 (see Table 2 and Figure 4). The new cultivated land areas are mainly in sub-Saharan Africa and Latin America, and to a lesser extent in Asia and in OECD-1990, whereas in the other two regions the cultivated land areas have remained stable. The deforestation and increase of pasture lands observed from 1961 to 2000 have continued in the Agrimonde GO scenario, although at a slower pace. Pastures have gained 244 million hectares, largely to the detriment of "other" and of forests which have lost 38 million hectares (i.e. 1% of their current area[39]). This phenomenon is clearly evident in sub-Saharan Africa and in Asia where the savannah has grown respectively by 288 and 170 million hectares, primarily in areas that were previously under forest cover. Trends are the opposite in former Soviet Union and the OECD-1990 countries, which have replaced respectively some 147 and 144 million hectares of pastures essentially by forests. In Latin America, deforestation has almost stopped. Finally, in Agrimonde GO irrigated areas in the world have increased very little.

Figure 4: Land use from 1961 to 2003 and in 2050 in the Agrimonde scenarios



Cultivated land = food crop area + non-food crop area
AG1 refers to Agrimonde 1 and AGO refers to Agrimonde GO

In Agrimonde 1 the cultivated land area extension has been greater than in Agrimonde GO since the world's total cultivated lands have grown by 39% from 2000 to 2050 (see Table 2 and Figure 4). With an average of 12 million hectares of newly cultivated land per year, the rate of cultivated land extension has tripled in Agrimonde 1 compared to the period 1961-2000. The conquest of new croplands essentially concerns Latin America and sub-Saharan Africa, as in Agrimonde GO, followed by the former Soviet Union and Asia, and lastly the OECD-1990 region. Cultivated land areas in Middle East-North Africa have stagnated. Since preservation of forests is a strong objective in Agrimonde 1, pastures have become the adjustment variable, in contrast with Agrimonde GO. They have lost 495 million hectares (i.e. 15% of their area) whereas the forests have shrunk by only 46 million hectares (i.e. 1% of their area[40]).

In Agrimonde 1, deforestation has been concentrated essentially in sub-Saharan Africa, Asia and Latin America (although to a lesser extent, as the panel considers that the action of the various pressure groups to preserve the Amazon jungle has been effective). In parallel, the regions of Middle East-North Africa and the former Soviet Union have managed to preserve all their forest areas – in the former, owing to a will to preserve their water resources and, in the latter, because countries in the region have oriented the extension of their productive lands towards former permafrost areas. In the OECD-1990 region the phenomenon of reforestation observed from 1990 to 2003 has intensified up till 2050. As for the irrigated areas, they have been maintained in all regions except for sub-Saharan Africa where they have doubled, and in Asia where they have increased slightly. To sum up, in 2050 in the Agrimonde 1 scenario, Latin America and sub-Saharan Africa are far from having exploited the full

[39] Compared to the surface area in 2000, calculated by the MA.
[40] Compared to the surface area in 2000 in Agribiom.

potential of their cutivable land, and are able to exploit only lands with a high-yield potential. The OECD-1990 region and former Soviet Union have to farm some of their lands with a lower potential, while Asia and Middle East-North Africa have to farm marginal lands.

Food crop yields in 2050

In Agrimonde GO, the regional productions of food calories per unit of food crop area in 2050 (the "food crop yields" in kcal/ha/day) are those of 2000 augmented by the 2000-2050 cereal yield increases assumed in the MA Global Orchestration scenario (see Table 4). In the MA scenarios, yields are calculated by means of the IMPACT model. In this model they depend on global prices of commodities, labour and capital, as well as technological progress, determined primarily in terms of investments in agriculture and effective use of water and energy.

In Agrimonde 1, assumptions on yields (that is, regional productions of food calories per unit of food crop area) are based on the conclusions of experts, who consider past trends in regional yields, the expected impact of climate change on regional potential yields, and expected potential yields from ecological intensification practices (see Table 3). Moreover, as part of a foresight study intended to inform reflection on long-term research orientations, the panel chose to propose a range of yields rather than making a single assumption with a set yield for each region. This made it possible to test the leeway associated with the yields of each system. Hence, if the low variant does not allow for a level of resources higher than or equal to the level of world use, it is possible to test the capacity to cover needs allowed for by the high variant and to draw conclusions on the size of the challenge facing research and innovation.

To construct assumptions on yields, the work proceeded in three steps:

1. The observation of past trends and the identification of possible shifts: the analysis of regional productivity curves per hectare, shown by Agribiom, made it possible to some extent to assess each region's capacity to maintain, pursue or accelerate its pace of yield gain (see Figure 5). Two criteria in particular guided this analysis and allowed for the identification of possible changes in trends. The first was the form of the curve, which reflected the fact that the region under consideration was possibly experiencing a phase of technical progress if the curve was climbing, or stagnation if it was levelling out. The second was the yield level reached in 2000, which could suggest that the possibilities of yield gains had not yet been fully activated when the yield level in 2000 was particularly low.
2. The coherence of the range of yields selected with the assumptions of cultivated areas in Agrimonde 1, especially with the yield potential of cultivated land of the different regions, and with the expected impacts of global warming on crops in each large ecosystem of those regions (see Table 3).
3. The comparison with existing agricultural foresight and forecasting studies: MA, IAASTD, Michel Griffon's scenario for 2050 and the scenarios of the IFPRI and the IMWI for 2020 and 2025[41].

The analysis of past trends in food calorie production per hectare cultivated, from 1961 to 2000, reveals two main groups of regions (see Figure 5): those that maintained the lowest yields throughout the period (sub-Saharan Africa, Middle East-North Africa, former Soviet Union), and those that maintained the highest yields throughout the period (Latin America, Asia and OECD-1990). Moreover, the disparities between yields continued to grow: whereas in 1961 the most productive region's yields were twice those of the least productive region, by 2000 that ratio was 1 to 3.4.

In Agrimonde GO, these two groups of regions are maintained until 2050. Asia, whose food crop yields have grown by 85% between 2000 and 2050, is by far the most productive region in the world with more than 46,000 plant kcal/ha/day in 2050. Even if the OECD-1990 remains the third most productive region, its increase in yields has been the lowest in the world (+48%). In contrast, sub-Saharan Africa is the region with the most spectacular yield gains (+144%). In 2050, with Middle East-North Africa, it attains the yield levels of the OECD-1990 in 2000. Finally, with a 71% yield growth between 2000 and 2050, the former Soviet Union remains the least productive region in the world. The gap between the least productive and the most productive regions grows slightly compared to 2000, from 1 to 3.6 in 2050 (see Table 4 and Figure 6).

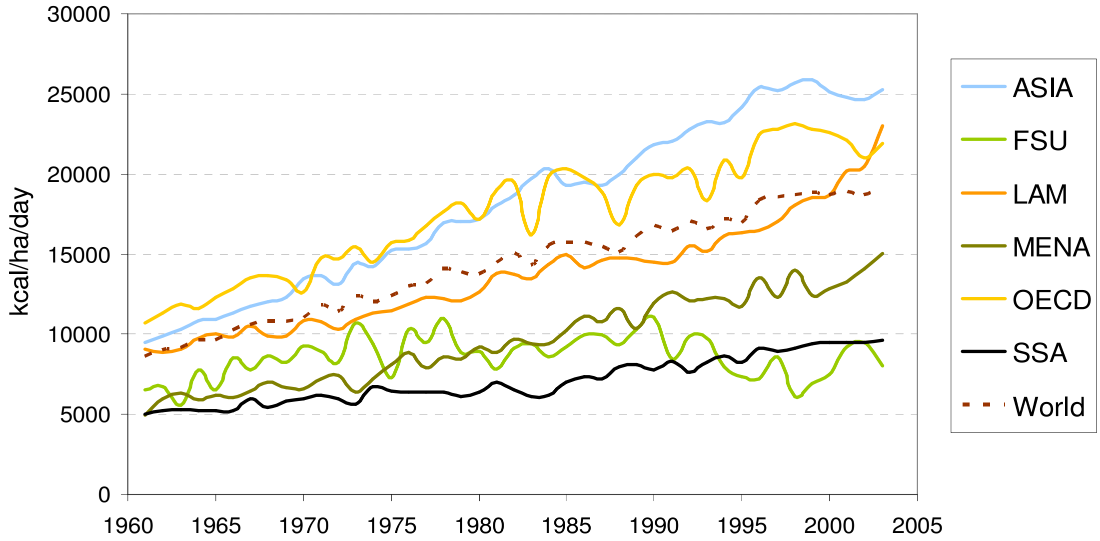
In the Agrimonde 1 scenario, the panel considered that there was little potential for increasing yields in Asia, OECD-1990 and Middle East-North Africa countries. These regions therefore experience, in this

[41] Note that these scenarios present cereal yield trends whereas in the Agrimonde scenarios we worked on yields for all types of food crops, expressed in kcal/ha/day.

scenario, a slow growth of their food crop yields between 2000 and 2050 (0 to 20% for the low variant of yields selected and 40 to 50% for the high variant). Latin America and sub-Saharan Africa have found it easier to increase the level of their food crop yields and have both gained between 30% and 100% of yields in respectively the low and high variants. Finally, the former Soviet Union has caught up spectacularly between 2000 and 2050, doubling the level of its food crop yields in the low variant and tripling it in the high one.

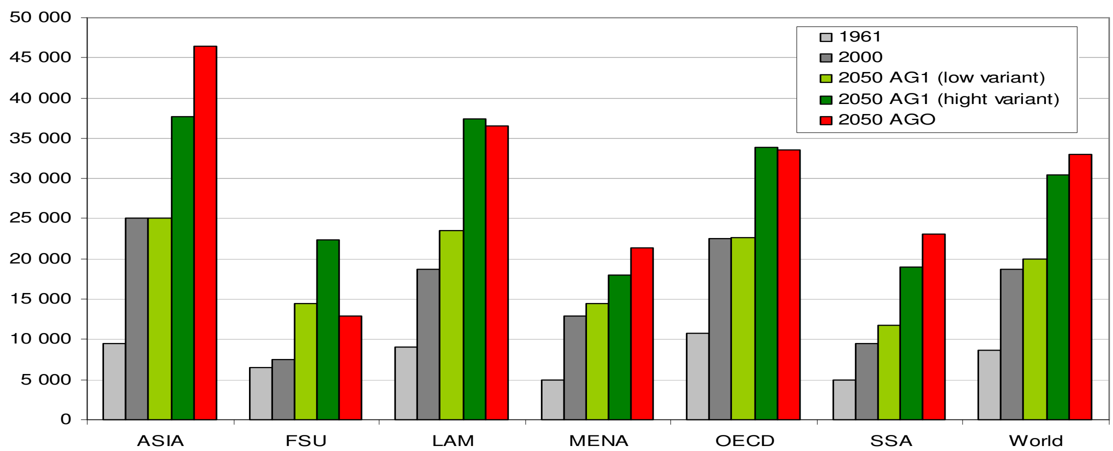
The two groups of regions differentiated by their yield levels in the past have changed little between 2000 and 2050 in Agrimonde 1. However, the gap in yields between the least productive and the most productive regions has narrowed down compared to the situation in 2000. In 2050 the ratio is 1 to 2, which corresponds to the yield disparities found in 1961 (see Table 4 and Figure 6).

Figure 5: Regional food yields (1961-2003):
Production of plant food calories per hectare of cultivated land (kcal/ha/day)



Source: B. Dorin (cf. Agribiom)

Figure 6: Regional food yields in 1961 and 2000 and in 2050 in the Agrimonde scenarios: Production of plant food calories per hectare of cultivated land (kcal/ha/day)[42]



[42] Between 1961 and 2003, cultivated land and food crop land areas were assumed to be the same since non-food crop areas were generally insignificant (see the report for more details). Thus, in this figure, yields are defined as production of plant food calories per ha of cultivated land in 1961 and 2000 while they are defined as production of plant food calories per ha of food crop land in 2050.

Table 3: Driving forces behind the evolution of food crop yields in Agrimonde 1

Region	Driving forces of increasing yields	Forces limiting the increase of yields
ASIA	- Very fast increase of yields in the period 1961-1990	- Farming of marginal lands - Stagnation of yields per hectare since the early 1990s - Slowdown of yield increases in other foresight and forecasting exercises - Impacts of climate change: salinization of irrigated rice farming deltas; increasingly frequent violent climatic events and accentuation of water stress in Northern China.
FSU	- Yield level relatively low in 2000	- Slow increase of yields in other foresight and forecasting exercises
LAM	- Continued increase of yields in other foresight and forecasting exercises - Heavy investments in the past in research, training and agricultural development	- Fragility of the *cerrado* soil and soil on the pioneer front in forests - Aridification in Central America and of the *cerrado* due to climate change - Unequal access to factors of production.
MENA	- Very rapid increase of yields over the period 1961-2003, without perceptible deceleration	- Farming marginal lands - Accentuation of water stress due to climate change - Slowdown of yield gains in other foresight and forecasting exercises compared to past trends
OECD	- Very fact increase in yields in the period 1961-2000	- Stagnation of yields per hectare since the early 2000s - Slower yield increases in other foresight and forecasting exercises - Agricultural sector objectives moving towards more quality in food products
SSA	- Relatively low yield levels in 2000 - Continued increase of yields in other foresight or forecasting exercises - Doubling of irrigated areas - Investments in research, training and agricultural development	- Aridification due to climate change - Deficit from the past in human capital and infrastructure providing access to markets

Table 4: Food crop yields: levels and annual growth rates: 1961-2000 and 2000-2050 in the Agrimonde scenarios

	1961-2000			**2000-2050**					
				AG1, low variant		**AG1, high variant**		**AGO**	
	Food crop yields kcal/ha/day		Annual growth rate	Food crop yields kcal/ha/day	Annual growth rate	Food crop yields kcal/ha/day	Annual growth rate	Food crop yields kcal/ha/day	Annual growth rate
Region	1961	2000	1961-2000	2050	2000-2050	2050	2000-2050	2050	1997-2050
ASIA	9,485	25,134	2.53	25,100	0	37,700	0.81	46,416	1.15
FSU	6,549	7,476	0.34	14,500	1.33	22,428	2.22	12,825	0.75
LAM	9,041	18,688	1.88	23,500	0.46	37,376	1.40	36,494	1.45
MENA	4,921	12,836	2.49	14,500	0.24	17,970	0.67	21,362	1.05
OECD	10,742	22,587	1.92	22,600	0	33,880	0.81	33,507	0.73
SSA	5,027	9,460	1.63	11,750	0.44	18,920	1.40	23,133	1.81
World	8,607	18,703	2.01	20,027	0.14	30,462	0.98	32,940	-

Resource-Use balances

Assumptions on the population, food consumption (plant and animal), land use (crop and pasture surfaces) and yields enable us to calculate, by means of Agribiom, regional and global balances of vegetal and animal biomass resources and their utilization (see Table 6).

A resource-use balance is established for each region and each product type (plant, ruminants, monogastrics). For fresh water and sea water products, it is simply assumed that in 2050 each region will produce the calories that it consumes from aquatic sources, and that the calories of aquatic origin do not interact with calories from land sources[43]. Use consists of regional food consumption by humans (population x per capita food availability), animals (feed), and other uses (seed, waste, non-food uses). Resources are composed of regional food production (for plant products, yields x food crop areas) to which the trade balance (import-export) is added.

First, resources and uses, before trade, are calculated for each region. The resource-use balances of calories from land sources (plant and animal) thus obtained reflect each region's capacity to feed its own population. They enable us to identify, in each scenario, areas that will have a calorie shortage in 2050 and those that will produce surpluses. Second, to verify the planet's capacity to feed its entire population in 2050 in each scenario, inter-regional calorie transfers are envisaged, from regions with surplus calories to those with shortages. These transfers are assumed to take place in the form of plant calories only[44].

The global results of the balances are presented in Table 5. Their analysis constitutes a first test of coherence of the scenarios and should not be interpreted as a simulation of trade between regions of the world. In Agrimonde 1 with low variants of yield, an equilibrium can be reached in the global resource-use balance. Thus, in the following, the Agrimonde 1 scenario always refers to low variants of yield.

We note that the total consumption of food calories at global level increases by 28% in Agrimonde 1 and by 83% in Agrimonde GO compared to 2003. Overall global production nevertheless meets the global demand for food calories in both scenarios, and Agrimonde GO even shows a surplus. Three regions have shortages in these two scenarios and have to import calories to feed their population: Middle East-North Africa, sub-Saharan Africa and Asia. In Agrimonde GO, these regions cover their needs in plant calories for direct human food but have to import calories for animal feed. In Agrimonde 1, Asia is in the same situation, but Middle East-North Africa and sub-Saharan Africa do not have enough plant resources to satisfy their populations' direct human food needs. At the same time, three regions have surpluses in both scenarios: OECD-1990, Latin America and the former Soviet Union. Regional shortages and surpluses are however greater in Agrimonde 1 than in Agrimonde GO.

Table 5: Resource-Use balances

		World resources in Gkcal/day	World use in Gkcal/day	World balance in Gkcal/day
World in 2003	Plant	29,341	29,341	0
	Animal	3,544	3,543	0
World in 2050 AG1	Plant	37,646	37,646	0
	Animal	4,274	4,274	0
World in 2050 AGO	Plant	53,990	53,551	440
	Animal	8,407	8,408	0

[43] Actually, interactions exist, such as fish meal used to feed cattle or certain terrestrial plant products used in feed on fish farms.
[44] It is also possible to carry out transfers between regions on the basis of animal calories instead of plant calories for animal feed. This mode of transfer is calculated separately, which produces a second variant of the resource-use balances. For further details, the reader is referred to the report.

Table 6: Recap of quantitative scenarios

	Region	Population 10^6 inhab.	Human food kcal/cap/day	Other Uses[1] Gkcal/day	Total use Gkcal/day	Food crop area Mha	Food yields[2] kcal/ha/day	Total resource Gkcal/day	Resource-Use balance Gkcal/day
Agrimonde 1	**ASIA**	4,427	3,000 Incl. 2,500 from plant	p:5,664 a: 93	p:16,732 a: 1,918	540	25,100	p:13,554 a: 1,918	p: -3,178 a: 0
	FSU	239	3,000 Incl. 2,500 from plant	p: 419 a: 0	p: 1,017 a: 106	300	14,500	p: 4,350 a: 106	p: +3,333 a: 0
	LAM	774	3,000 Incl. 2,500 from plant	p: 2,043 a: 77	p: 3,977 a: 431	250	23,500	p: 5,875 a: 431	p: +1,898 a: 0
	MENA	632	3,000 Incl. 2,500 from plant	p: 1,969 a: 45	p: 3,549 a: 335	90	14,500	p: 1,302 a: 335	p: -2,247 a: 0
	OECD	1,066	3,000 Incl. 2,500 from plant	p: 2,190 a: 151	p: 4,856 a: 632	400	22,600	p: 9,040 a: 632	p: +4,184 a: 0
	SSA	1,662	3,000 Incl. 2,500 from plant	p: 3,360 a: 56	p: 7,515 a: 852	300	11,750	p: 3,525 a: 852	p: -3,990 a: 0
	World	**8, 800**	**3,000 Incl. 2,500 from plant**	**p: 15,646 a: 418**	**p:37,646 a: 4 274**	**1,880**	**20,027**	**p: 37,646 a: 4,274**	**p: 0 a: 0**
Agrimonde GO	**ASIA**	4,427	3,703 Incl. 2,766 from plant	p: 10,764 a: 332	p:23,009 a: 4,188	476	46,416	p: 22,094 a: 4,189	p: -915 a: 0
	FSU	239	3,457 Incl. 2,091 from plant	p: 1,618 a: 53	p: 2,118 a: 363	187	12,825	p: 2,398 a: 363	p: +280 a: 0
	LAM	774	3,698 Incl. 2,758 from plant	p: 3,796 a: 145	p: 5,930 : 835	219	36,494	p: 7,992 a: 834	p: +2,062 a: 0
	MENA	632	3,457 Incl. 2,987 from plant	p: 2,288 a: 56	p: 4,176 a: 335	93	21,362	p: 1,985 a: 335	p: -2,190 a: 0
	OECD	1,066	4,099 Incl. 2,385 from plant	p: 8,396 a: 422	p:10,939 a: 2,159	401	33,507	p: 13,436 a: 2,158	p: +2,497 a: 0
	SSA	1,662	2,972 Incl. 2,667 from plant	p: 2,945 a: 57	p: 7,378 a: 527	263	23,133	p: 6,084 a: 528	p: -1,294 a: 0
	World	**8,800**	**3,588 Incl. 2,698 from plant**	**p: 29,809 a: 1,065**	**p: 53,551 a: 8,408**	**1,639**	**32,942**	**p: 53,990 a: 8,407**	**p: +440 a: 0**

[1] Feed, Seed, Waste and Other uses of food biomass
[2] for the low variant, presented in the Table 4

p: calories of plant origin
a: calories of animal origin (except aquatic products)

II.3 From quantitative scenarios to complete scenarios

Agrimonde 1 and Agrimonde GO: comparison, coherence, drivers of change

In this part we examine the quantitative scenarios built (see Table 6) with a view to describing their qualitative dimensions, which were not defined in the quantification. To this end, we consider the internal coherence of each scenario and draw conclusions from their comparison. We also explore actions that would enable one to reach the world of 2050 described in Agrimonde 1 in each region and at global level. This analysis makes it possible to identify six essential challenges for the Agrimonde 1 scenario: 1) agricultural and rural development; 2) innovations for ecological intensification; 3) management of natural resources; 4) levelling out of land-ownership inequalities; 5) changes to diet; and 6) world governance.

- **Agricultural and rural development is one of the main challenges of the Agrimonde 1 scenario.** The assumptions relative to food crop areas and yields in Middle East-North Africa, Asia and sub-Saharan Africa posit limited development of agriculture in these regions. This raises questions on the coherence of Agrimonde 1 in at least two respects. First, effective demand, especially in sub-Saharan Africa[45], might not be sufficient to guarantee the food consumption level supposed in this scenario, where it is constantly rising, per capita and overall. The increasing yields assumed in Agrimonde 1 (in the low variant) could turn out to be insufficient to allow for an adequate agricultural and economic take-off, which calls into question the yield potential of ecological intensification technologies in this region. Such technologies are currently only partially available, unlike classical intensification systems which are available and probably able, as Agrimonde GO foresees, to produce yields far greater than those envisaged in Agrimonde 1, at least at the beginning of the period. Hence, if the development of agriculture is the priority in sub-Saharan Africa, should a two-step trajectory not be envisaged for this region? The first phase would consist in generalizing classical intensification techniques, which would allow for an agricultural "take-off", and would be followed by a second phase of ecological intensification once the appropriate techniques have been developed and the environmental challenges become greater than the development ones. The choice of such a trajectory relates to the irreversibility of technological choices since the deployment of a technical system creates strong interrelatedness between technologies, infrastructure, training, players' strategies, etc., which can result in lock-in. This would be an obstacle to a change of technological paradigm even if the economic environment and the potentialities of new technologies made the switchover optimal.

In Middle East-North Africa and Asia, where agricultural development is limited due to a lack of potential cultivable land and to environmental constraints, especially water-related in certain areas, the agricultural sector might be unable to employ an increasing rural population, which would then massively migrate to towns. The accelerated artificialization of agricultural land[46] may lead to a vicious circle that does not allow for croplands to be kept at their 2000 level. Moreover, inequalities in living standards between urban and rural populations in these two regions could increase dangerously. The sustainability of Agrimonde 1 is therefore based on economic policies and regional development policies that should aim at curbing urbanization and the rural exodus by developing rural employment. This may concern management of the competition between urban activities and agriculture for land ownership, management of water resources, problems of congestion or social tensions, etc.

In Agrimonde GO, development through agriculture is less limited, owing to the assumption of high-growth yields. This assumption is strong because it implies, first, that rapid technological progress combined with a liberalization of trade is sufficient to trigger development and, second, that the impacts of climate change will have been overcome. In Middle East-North Africa this scenario could however result in more vulnerable agro-ecosystems, especially due to their dependence on fertilizers and pesticides (timing of nutrient supply and efficacy of active substances) and to an exacerbation of pressure on water resources.

- **Innovation and its diffusion are the second challenge of the Agrimonde 1 scenario.** Innovations likely to allow for ecological intensification of agriculture are less a matter of yield gains –

[45] Development is clearly the first challenge to meet in sub-Saharan Africa, irrespective of the scenario. It poses questions raised repeatedly on access to capital, techniques, land, training, markets, the development of infrastructure and the evolution of governance in this area, or on international agricultural trade regulations.

[46] For instance, in North Africa, the average space between towns shrunk from 66km to 21km between 1950 and 1995 in the coastal area, and from 66km to 32km in the interior (CIHEAM, 2008, *Mediterra - The Future of Agriculture and Food in Mediterranean Countries*, Presses de Sciences Po).

which are relatively weak in Agrimonde 1 compared to Agrimonde GO and past tendencies – than of the growing sophistication of production systems on the borders of traditional farming areas (agro-pastoralism and farming systems under shade in areas of woodland savannah, agro-forestry on the forest pioneer front, and peri- or intra-urban agriculture), playing on the complementarities among species in space and time. Yet the yield gains assumed in certain regions, even their stability in others, are considerable achievements, considering the deterioration of certain ecosystems and climate change. This phenomenon will worsen salinization, water scarcity and risks associated with extreme climatic events, whose effects are already accentuated by deforestation. The latter phenomenon furthermore raises the question of the mode of reproduction of soil fertility, that is, the fertilization techniques adopted. The former Soviet Union region calls into question the meaning of ecological intensification in an area where the rural population density is low and decreasing[47]. The doubling of yields assumed for this region in Agrimonde 1 could only be based on a highly automated type of farming that replaces crop observation and analysis with imaging and computer technologies. It would also be based on the development of precision farming techniques to limit chemical pollution.

- **Management of natural resources is a third challenge of the Agrimonde 1 scenario.** First, water resource management policies will have to have been strengthened decisively in most regions, especially in Middle East-North Africa, to rationalize the use and allocation of this resource. Even if, in Agrimonde 1, the impact of agriculture on farmed ecosystems is moderated by the limited increase of yields and production techniques that use few pesticides and fertilizers, the high level of conversion of pastures and forests, especially in sub-Saharan Africa and Latin America, is likely to have a considerable impact on the ecosystem services provided by these spaces, on the biodiversity of these ecosystems, on the water and carbon cycles, and so on. In particular, maintaining soil fertility in the Agrimonde 1 scenario is important, especially in areas reclaimed from the forest, where the interruption of former cycles of macro- and micro-nutrients make the soil highly fragile. In this respect, in Agrimonde GO, which assumes rapidly increasing yields, the pressure on agro-ecosystems is probably stronger. Moreover, in this scenario technological developments probably make it possible to cultivate former very marginal lands (steep slopes, deserts, etc.) which used to be warehouses of biodiversity. At global level, pressure on the forests is very much the same in the two scenarios. The creation of new cultivated land imagined in Agrimonde 1 actually corresponds to a substantial trend reversal since it would concern former pastures rather than forests. But pressure on forests is likely to be particularly strong since they contain water resources. Even if large-scale agro-forestry practices could be a solution, the Agrimonde 1 scenario is also based on the creation of ecological infrastructure for primary forests, which would allow for both the creation of croplands and the preservation of biodiversity. The development of incentives to preserve the forest, therefore a key point in this scenario, implies strong world governance.

- The high level of extension of croplands in sub-Saharan Africa and Latin America also raises questions on **the sustainability of the Agrimonde 1 scenario from the social point of view, which is the fourth challenge**. Territorial extensions imagined in this scenario could indeed exacerbate land inequalities that are already huge in these regions. In the former Soviet Union, to grasp opportunities for territorial extension in the North, afforded by global warming, it would be necessary to design a legal framework and a land policy governing the distribution of new, former permafrost lands. The coherence of the Agrimonde 1 scenario therefore strongly relies upon the conditions of access to the new agricultural areas, and the distribution of the rents derived from their exploitation.

- **The fifth challenge that the Agrimonde 1 scenario highlights concerns diet.** In Agrimonde 1, in 2050, the mean demand in calories per capita and per day tends towards 3,000 kcal in all the world's regions. Agrimonde GO, however, assumes a continuation of current trends in food consumption. For instance, whereas the calorie demand per inhabitant increases by 8% in Asia in Agrimonde 1, it increases by 30% in Agrimonde GO, driven by growing income, the generalization of urban eating habits, and consequently the rising proportion of calories of animal origin in people's diets. The possibility of containing the increase in mean food consumption is decisive in two respects in the Agrimonde 1 scenario: 1) the food resources-uses balance at world level depends heavily on it; 2) its sustainability from the health point of view also depends on it, if the growth in obesity that is currently accompanying the nutrition transition in developing countries intensifies. For the OECD-1990 region, the 25% reduction of per capita mean calorie consumption between 2000 and 2050 assumed in Agrimonde 1 is clearly a significant change. It relates to currently highly controversial nutrition

[47] The analysis of scenarios for this region highlights the strong regional contrast in population density among regions, which calls into question the very principle of construction of the scenario according to which, by 2050, regional migrations will not have exceeded previous levels.

policies, and their effectiveness, as well as the reduction of losses through less wastage and better recycling.

- **At global level, the main challenge to the Agrimonde 1 scenario concerns the regulations and inter-regional modes of governance that enable it to arise.** First, Agrimonde 1 supposes extensive trade between regions with surpluses and regions that cannot satisfy assumed food needs locally. The level of trade is even higher than in Agrimonde GO (although trade liberalization is a major driving force in this scenario). These possibilities of trade depend on regulations which have to: (i) avoid price distortions unfavourable to agricultural development; and (ii) reveal the environmental costs of farming, to encourage farmers to implement more sustainable systems. As noted above, Agrimonde 1 assumes that policies will have been implemented to slow down deforestation. The harmonization of policies for managing natural resources at global level, and the articulation of regional and global initiatives therefore appear to be important dimensions of the Agrimonde 1 scenario. Moreover, the effects of climate change on agriculture concern all of the world's regions and threaten the food security of some of them, notably Asia and Middle East-North Africa. Agrimonde 1 therefore calls for international regulations to combat climate change and to guarantee food security through development aid and mechanisms to secure supplies. It furthermore seems likely that foreign farm investments by countries with limited agricultural potential especially in Africa – which are still 'emerging' at the beginning of the 21st century –, will develop. In that case specific mechanisms of regulation and governance will have to be devised to guarantee the social and environmental sustainability of such investments and to ensure that they afford real development opportunities for the host countries.

The world in 2050 in the Agrimonde scenarios

The analysis of scenarios, in terms of coherence and action levers, and their comparison enabled us to identify certain qualitative assumptions for the Agrimonde 1 scenario. On this basis, the panel sought to identify the factors that had not yet been considered in the analysis but that were likely to have a decisive impact on the world's food and agriculture during the period leading up to 2050. These factors have been grouped into seven main themes: 1) the global context; 2) international regulations; 3) the dynamics of agricultural production; 4) the dynamics of biomass consumption; 5) the actors' strategies; 6) knowledge and technologies in the field of food and agriculture; and 7) sustainable development. By making assumptions on these different dimensions, with a concern for overall coherence and plausibility of the scenario, the panel obtained a complete scenario. A possible account of the Agrimonde 1 scenario is therefore proposed here, as well as that of Agrimonde GO which corresponds to the MA experts' storyline[48].

Agrimonde GO: Feeding the planet by making global economic growth a priority

In Agrimonde GO the world is preoccupied above all with the problem of employing and feeding a growing population. Huge investments in research and infrastructure, especially in developing countries, coupled with free trade, make it possible to meet steep increases in food demand. Economic growth is very intense, surpassing previous averages in several regions (mainly sub-Saharan Africa, Asia and the former Soviet Union), owing to the combination of trade liberalization, extensive economic cooperation, and the rapid diffusion of new technologies. Investments in education and health are moreover huge in all regions. Low trade barriers have facilitated the rapid diffusion of technologies, and multinational firms are deeply involved in innovation. This goes hand in hand with a powerful entrepreneurship dynamic but is not orientated towards protection of the environment.

In this rapid growth scenario a steep rise in energy demand has been experienced. The demand is mainly for fossil fuels but technical progress has substantially improved energy efficiency. Electricity is partially produced from renewable sources (10% of the total energy production in 2050) and biomass. Areas under agro-fuel crops have expanded considerably compared to the beginning of the century, driven by the rising prices of fossil fuels.

The conditions are met for environmental problems, especially those associated with climate change and fishing, to be addressed at global level through international cooperation. But since environmental problems are considered secondary to other priorities – economic growth, improvement of humans' material welfare –, they are taken into consideration only when they become unavoidable. Citizens

[48] Carpenter S. R., Pingali P. L., Bennett E. M., Zurek M. B. (eds), 2005, *Ecosystems and Human Well-being: Scenarios,* Volume 2, The Millennium Ecosystem Assessment, Washington DC.

tend to trust in the ability of science to solve them, and as a result no climate policy was developed during the first decades of the period under consideration.

The global availability of food calories, per day and per capita, has increased by 818 calories between 2000 and 2050. The steepest increases have been experienced in Asia, sub-Saharan Africa and Latin America, and the number of children suffering from malnutrition in developing countries was divided by 2.5 during the first half of the century. This tendency, stimulated by rapid economic growth and intense urbanization, is accompanied by a richer protein content of diets as people consume more meat and fish. This trend has resulted in the growth of the problem of obesity in many regions (Asia, Africa), which requires nutrition policies to be implemented.

Technological development has allowed for more intensive farming, as well as for an extended use of fertilizers and plant material, much of which is genetically modified. The vast majority of farms, both small and large, are highly mechanized and industrial. Local know-how is often replaced by standardized industrial methods and the variety of agricultural species is decreasing. Multinational firms are a predominant feature of this scenario; they have increased their control over plant and animal production, primarily through the development of new genetic strains.

Agrimonde 1: Feeding the planet by preserving ecosystems

From 2000 to 2050, global economic growth has been driven by the growth of the developing economies. Apart from the spread of ecological intensification practices, an infrastructure of regional planning and supply chains development has been put in place in these economies: transport, storage, industrial processing capacities, as well as services in health, education, training, and so on. The necessary investments have been made possible by improved income in rural areas. This is a result of the development of employment, a better distribution of added value throughout supply chains and the pooling of resources in various forms of cooperation. Public transfers implemented at national level, and international aid for development have been determining factors for initiating and securing investments. This massive aid was one of the answers, in the late 2010s, to the multiplication of periods of food crises threatening social and political stability.

Owing to the upsurge of opportunities for wealth creation in rural areas, the rural exodus in developing economies has slowed down. Urbanization nevertheless continues and sometimes encroaches on the best agricultural lands, despite the development of agriculture and agri-food activities in peri-urban and even urban areas, and efforts at densification of cities in countries that were emergent in 2000 (mainly China, India and Brazil). These efforts have taken the form of strong regional planning policies to limit the artificialization of the land and to deal with the energy crisis from the 2020s.

In 2050, trade in foodstuffs is regulated by the United Nations Organization for Food Security. To fulfil its mission of guaranteeing food security, rules designed to avoid distortions in competition are applied. They however provide for significant exceptions: a) to enable the least productive countries to develop a local market, and b) to take into account environmental issues. Moreover, this organization has to ensure a management of stocks and trade that protects countries which are highly dependent on food imports, from threats to their supplies. The tendency for agricultural prices to decrease in real terms, characteristic of the 20th century, has ended with strong population growth, coupled with the economic take-off of countries of the South. Faced with this new situation, the regulation of markets has therefore also aimed to avoid price volatility which was very strong at the beginning of the century and largely responsible for food crises.

Between 2000 and 2050 the systems of research, training and development in the agricultural and environmental fields have produced and diffused innovations for ecological intensification. These innovations are partially specific to local agriculture but also benefit from more generic scientific breakthroughs. Innovation is organized in an interactive and often participatory way, to promote the diversity of local know-how possessed by a variety of actors involved (farmers, other users of natural resources, NGOs, processors, etc.). This innovation effort on local, regional and global scales promotes diversity while capitalizing on it and pooling it. The emergence of highly internationalized epistemic and practice communities in research and ecosystem management has been decisive in this respect. Limits are placed on the appropriation of research results, to preserve the public nature of certain innovations and the dynamics of scientific accumulation.

Development policies, inspired by regional development policies implemented from the late 20th century in the European Union, contribute to structuring local and sector-specific food and agricultural systems in the form of clusters comprising processing, distribution and agri-supplies, as well as research, training and consultancy. In the richest countries, public funds are released not for production but for ecosystem management, to promote the multifunctionality of agriculture and to remunerate environmental services.

The growing scarcity of fossil fuels and the need to reduce greenhouse gas emissions has impacted on demand and renewed the energy offer by way of heavy investments in energy management, renewable energies and the fuel cell. The emphasis is on opportunities for distributed and decentralized energy production, waste recycling and by-products. Energy price increases at the beginning of the century triggered the search for energy autonomy on farms. It is in this framework, integrated into production as much as possible, that most of the production of agro-fuels in the world is developed.

The acceleration of climate change at the beginning of the century has been a decisive incentive for technological change in agriculture. Ecological intensification technologies make it possible to minimize the environmental impact of agricultural practices, primarily on water, biodiversity and the soil, and to make production more resistant to setbacks, through the reintroduction of greater domestic biodiversity. However, high prices and demand for food have created pressure to convert natural and semi-natural areas. As a result, deforestation in Amazonia and the Congo Basin, which was intense in 2000, has not been entirely stopped. Biodiversity conservation therefore goes hand-in-hand with a capacity for innovation and for developing production systems that are compatible with the preservation of a rich biodiversity and ecological infrastructure, especially for farmlands reclaimed from former forests. The role of agro-forestry systems is particularly important in this respect, even if in 2050 many environmental NGOs point out a high loss of biodiversity that justifies demands for more protected areas for wild biodiversity.

In 2050, diets in the various regions of the world have converged as regards calorie intake; they are situated at a mean availability of about 3,000 kcal/cap./day in each region. Cultural particularities have nevertheless maintained some diversity in the distribution of the various food sources. Increasing incomes have not led to a convergence of diets towards Western diets. Even though in certain regions, especially sub-Saharan Africa, food consumption trends were a result of economic development, they have also stemmed from behavioural changes in most regions. For instance, in a region like OECD-1990, the mean calorie consumption has declined from 4,000 to 3,000 kcal/cap./day. This steep downward trend is the result of less wastage by users or in catering systems, and more effective nutrition policies. The maintenance of diversity of diets also helps to solve problems of micronutrient deficiencies, primarily through the consumption of fruit and vegetables. The fast growth of the proportion of processed products compared to raw products, recorded at the beginning of the century, has levelled off. This is a symptom of the diversification of food systems. It also stems from regulations which have placed strong constraints on agri-food companies' information and communication on nutrition in the rich countries, encouraging them to limit the degree of product processing while continuing to sell innovative products in terms of practicality and variety.

From 2000 to 2050, the agri-industrial model, initially clearly dominant, merged with more local food and agricultural systems based on short circuits and on the diversity of small and medium-sized farms and processing enterprises, especially in developing countries. The tendency towards standardization, internationalization and concentration around a limited number of multinational firms has therefore declined. This change is facilitated by national and regional strategies to ensure food security, and by the considerable impact of CSR (Corporate Social Responsibility) on large firms' strategies. The agri-food sector has been strongly affected by CSR because consumers in the rich countries have proved to be more and more concerned about food issues, due to the spread of the sustainable food concept and following the "hunger riots". They pressurize agri-food firms, often via NGOs and consumer organizations, to take on their particular role in economic development and the reduction of malnutrition, as well as in the struggle against obesity.

III. Food behaviours, technological options and trade: first lessons from scenario exploration

After constructing two scenarios illustrating the variety of possible trends, we will now briefly consider the following question: which changes are feasible, necessary or desirable? The scenario exploration presented here does not generally enable us to provide clear-cut answers to these questions. It does however enable us to put forward structured arguments as to the most desirable, necessary or feasible options. The scenarios thus provide material for discussion on future trends and may also raise new questions which could be considered in greater depth. In this respect, this final section constitutes an opening. Starting with three major points, it proposes that we use the scenarios to structure discussions on the future of food and agricultural systems. To draw conclusions from the analysis and the comparison of two visions of the future, in Agrimonde GO and Agrimonde 1, this part presents a possible interpretation of the scenarios presented above, on three main points: diet changes and food behaviours; technological options; trade and regulations. This reading does not necessarily correspond to consensus within the panel. The panel's discussions about the scenarios have clearly shown how scenario building can revive the debate and raise new questions.

III.1 Food behaviours in question: are ruptures plausible?

The assumptions on diet used in the Agrimonde 1 scenario are strongly based on two changing trends. First, this scenario posits that the mean level of availability of food for consumption, measured in kilocalories, will decline in rich countries without this being due to a decrease in the mean per capita income. Second, it assumes that, notwithstanding the increase in the mean per capita income, it will increase moderately in emergent countries, so that the nutrition transition will not result in a higher risk of an epidemic of obesity, as in the Agrimonde GO scenario.

Income and supply permitting, food consumption is generally characterized by three phases[49]: 1) a phase of quantitative growth of consumption of all foods up to a level of calorie saturation; 2) a phase of qualitative change centred on the structure of rations: nutrition transition; and 3) a phase marked by stabilization of the macro-nutritional structure of rations. Hence, from a certain threshold, the wealth of countries is reflected by a ceiling in per capita food consumption. This non-linearity of the function linking consumption to income can be accentuated by other factors such as ageing of the population[50], given that the calorie needs of the aged are slightly lower than those of adults or of growing children, and the stability of certain diets even when household income rises, as in Japan, a typical example.

The transformation of food behaviours in terms of the Agrimonde 1 set of assumptions could also be based on other ruptures such as the reduction of the volume of consumption losses, or the application of new nutrition policies.

The Agrimonde 1 scenario assumptions on food consumption could, in the spirit of this scenario, reflect an effective struggle against waste by the final consumer. Certain behavioural trends, still marginal today, may be general by 2050. In recent years there has been a slow but growing individual and collective awareness of the sometimes harmful effects of each individual's actions in daily life, with regard to health and the environment. A more responsible attitude, entailing sustainable behaviours, is encouraged by actors in civil society and public authorities who try to raise public awareness.

Finally, nutrition-related non-communicable diseases are gradually becoming a topical subject which is a cause for concern among citizens and governments alike, in all regions of the world. The rapid increase in health expenditures and the economic and social costs of these diseases are worrying. In 2005, 1.3 billion adults in the world were overweight, and of them 400 million were obese[51]. If recent trends continue, in 2030 these figures could reach 3 billion and 1 billion, respectively[52]. The Agrimonde 1 assumptions and the behavioural changes that they imply correspond to a scenario in which the struggle against these diseases is not only a top priority but is also successful. However, in

[49] Duquesne B., Matendo S. and Lebailly P., 2006, "Profiling food consumption: comparison between USA and EU", USDA and AIEA2 International Meeting, *Competitiveness in Agriculture and in the Food Industry: US and EU Perspectives*, Bologna, 15-16 June ; Combris P, 1990, "L'évolution du modèle alimentaire en France de 1949 à 1988: continuité et ruptures", Annales de Gembloux 96, pp.279-304.

[50] People over 60 will account for 21% of the world's population in 2050, against 10% in 2000 (UNO, 2006, *World Population prospects: The 2006 Revision Population Database).*

[51] The WHO website: www.who.int/

[52] Kelly T., Yang W., Chen C-S., Reynolds K. and He J., 2008, "Global Burden of Obesity in 2005 and Projections to 2030", *International Journal of Obesity*, 32(9).

this respect public interventions in developed countries, generally scarce until now, have focused primarily on information, education and communication. They do not seem to have had any meaningful effect on the consumption habits of citizens, the majority of whom have not changed their diet. One of the challenges of the Agrimonde 1 scenario is therefore to find more effective forms of action to trigger the change imagined in food consumption trends in Agrimonde 1. To that end, decisive progress in our knowledge is required, especially to better understand the complexity of food behaviours and their relationship with health, and to identify what is likely to change them.

III.2 Options for ecological intensification

Today the concept of ecological intensification essentially refers to technical options to develop, rather than a prescribed set of processes that can be applied everywhere. It may therefore very quickly appear that, as in fields other than agriculture, these so-called technical options encompass social, economic, spatial and political options which are not incidental and have probably not been sufficiently explored. We do however know enough about the options that have accompanied the process of rationalization ('modernization') of North American and European agriculture, since their effects are now visible. This knowledge enables us to clarify the conditions required for a particular option.

From ecological intensification as a technical option…

First, let us revert to ecological intensification, as such[53]. It can be defined as a technical alternative to the steady development of an agriculture based on the substitution of labour by capital by means of mechanization and heavy consumption of energy, as well as an artificialization of conditions of production aimed at freeing farmers from the constraints of natural processes through the use of manufactured inputs (fertilizers, pesticides, animal fodder, etc.), genetic selection of plant varieties (distinct, homogeneous and stable) and improved animal strains, etc. The idea of ecological intensification is to go back on some of these choices, and to conceive of a type of agronomy that is closer to steering ecological processes than to an attempt to control the production process as tightly as possible. This new agenda also implies: lower consumption of fossil fuels; better use of the soil's ability to mobilize organic matter (by associating or sequencing certain crops and using new tillage techniques); integrated pest management (biological control organisms, mixing species and varieties, organization of fields, crop rotation, etc.); better resistance to diseases by relying on diversified populations, etc. Of course, all this has not yet been well established and requires research and experimentation, by researchers as well as farmers. For the advocates of this approach it does not mean reverting to an archaic type of agriculture; on the contrary, the idea is to use modern techniques to attain its objectives: marker-assisted selection, biotechnologies, tillage techniques, matching of technological recommendations with the micro-local ecological conditions, mechanization as well as animal traction, etc. It is difficult today – without a precise inventory of available test results – to know what yields can be obtained. The Agrimonde 1 scenario proposes targeted yield objectives, beneath which this type of approach remains utopian.

… to ecological intensification as an option of social and spatial organization

The question of the agrarian frontier, which seemed to have been forgotten somewhat, is back on the agenda. To the first frontier, well-known since the Neolithic, that of forest clearing and the cultivation of 'virgin soil', a second frontier has inexorably been added over the past century or more, that of urban and infrastructure development. Here, regulations and the property market set the rules, and agricultural profits are rarely able to withstand other types of speculation or decisions made in the general interest. It is therefore probably high time to reason differently as to what a real peri-urban and urban agriculture is, one that is not a rival of residential or industrial expansion, vanquished in advance. Finally, the new environmental and social issues suggest the existence of a third frontier, within the agricultural world and based on the way of conceiving of crop and stock farming techniques.

We can thus distinguish a first model, qualified as 'segregationist', separating those areas that can be farmed from those that must not be farmed from an environmental protection point of view, but in which it will nevertheless be necessary to manage 'natural' processes. This situation is clearly

[53] From the book by Michel Griffon which illustrates a scenario of ecological intensification (Griffon M., 2006, *Nourrir la planète – Pour une révolution doublement verte*, Odile Jacob). See also Griffon M. and Weber J., 1998, "Economic and Institutional Aspects of Double Green Revolution". Development of Research Network for Natural Resources, *Environment and Ecology* (USA). 1998/12:9(4), pp.39-42.

illustrated in the Agrimonde GO scenario for the Latin America region, where a stabilization of forest areas is compensated for by high yields on cultivated areas. In the OECD-1990 region, characterized by reforestation, Agrimonde 1 presents a more qualified version of this model, in which the reduced possibilities of intensification of crops lead to a whittling away of pastures.

This variant of ecological intensification in traditional farming areas requires innovations to make agricultural practices less environmentally harmful. Proposals usually concern new pest-control or tillage conservation techniques in which biotechnologies, precision agriculture and so on can play a large part. In any case, environmental challenges are considered as being met elsewhere, in the spaces devoted to them, consisting of reserves, corridors and 'natural' areas which fulfil this function for the entire planet and are justified by the services that the ecosystems concerned render to humankind.

While performance criteria are still those usually practised (yields, weight gains, labour productivity, etc.), even under certain environmental constraints, they will favour farms that apply the recommended technologies the most efficiently, and which are able to make big investments and to benefit from appropriate technical support. In this type of model, so-called 'commercial' farms that are sufficiently large to be efficient, and those in the process of becoming so (through an investment and technology acquisition effort), are distinguished from others which will never become like that and are destined to disappear or to be treated 'socially'!

From another point of view, combining the ecological and productive functions of agro-ecosystems in the same area corresponds to a model that can be qualified as 'integrationist'. It is based on the combination, in the same territory, of different types of productive systems, adapted to the ecosystems constituting the territory, in such a way as to maintain it in the form of a mosaic of ecosystems producing a diversity of services (purifying and regulating water resources, soil conservation, maintenance of landscape structures and biodiversity, carbon fixation, etc.). This involves different types of farming (livestock, forestry, crops, etc.) in the same territory, on the same farm or on different farms, overlapping to differing degrees (see the mode of ecological intensification in the Agrimonde 1 scenario for the Middle East-North Africa, sub-Saharan Africa, Latin America, and Asia regions).

In the Agrimonde 1 scenario the agricultural performance criteria are no longer limited to technico-economic indicators. They encompass a range of indicators, on the scale of a territory, which inform on the efficiency of agricultural practices as regards water quality, biodiversity and soil quality conservation, as much as on commodity products. In this schema, the types of productive systems described above are no longer exclusive; they are complementary by allowing for efficient management of the diversity of the ecosystems involved. The Agrimonde 1 scenario is a fine illustration. For instance, to caricaturize, in Latin America forests are devoted no longer to clearing for land use or to protection, but to intermediate forms corresponding to various agro-forestry models. In Asia humid areas are not all drained; rather they are valued as a source of grazing land in dry seasons or for combined agricultural and aquaculture projects. In Middle East-North Africa and in sub-Saharan Africa, rangelands with low forage productivity become key elements in grazing routes that use a diversity of environments and biological corridors enabling the fauna and flora to circulate. The same applies to hedges, small woods and orchards, habitats for many crop auxiliaries and course substances that preserve the soil and low-lying vegetation from the effects of wind and rain. In the Agrimonde 1 scenario, farms with a low level of efficiency in terms of exclusively technico-economic criteria play an important role in this respect in 2050. They make the multifunctionality of agriculture fully meaningful, that is, not only a farming activity that provides goods and services apart from agricultural goods, whether for food or not, but also one of the activities practised in a territory by some of the households living there. In this sense it is both the territory and the households that are multifunctional, as agriculture as such represents only one of these functions.

Ecological intensification, performance criteria and (ir)reversibility of choices

In this sense, the Agrimonde 1 scenario integrates a change of viewpoint on the multifunctionality of agriculture, assessed as essential both by the recommendations of the IAASTD and by the World Bank 2008 report on agricultural issues[54]. One of the first tasks to make it meaningful would consist in producing performance criteria to evaluate the accomplishment of these different functions, if only to frame them politically and administer them, and not to remunerate them. We would then see that in

[54] McIntyre B.D., Herren H.R., Wakhungu, J, Watson, R.T., 2009, *Agriculture at a Crossroads*, Synthesis Report, International Assessment of Agricultural Knowledge, Science and Technology for Development. World Bank, 2008, *World Development Repot: Agriculture for Development.*

such a schema the different types of agriculture mentioned above complete one another rather than having to conform to a single model. Finally, in both cases, but more so in the integration model, the question arises of the real capacity for new technological choices (and therefore also social, economic, local development, spatial organization etc.) to emerge. It could prove difficult to break away from past choices which are embedded not only in current technical solutions (mechanization, fertilizers, pesticides, genetic engineering, etc.) but also in cognitive systems (knowledge and know-how, representations of nature, pollution, landscapes, etc.) and in the values of the main actors involved. Are we not trapped in technical rationalization, a sort of lock-in that other sectors have also experienced – except we cannot do without agriculture!

III.3 Regulations for trade and sustainable agriculture

One of the main findings of the Agrimonde foresight study is probably the necessity for accelerated development of international trade in food and agricultural products during the next few decades. The transfers forecast in balancing out food calorie resources and uses are not a direct projection of the volume of international trade involved in the different scenarios. A good aggregated indicator of the trade necessary to ensure that needs are met is nevertheless the sum of regional shortages in plant calories.

Despite certain limits[55], note that the cumulated shortage of regions in the Agrimonde 1 scenario is 9,415 Gkcal/day whereas it is only 4,399 Gkcal/day in Agrimonde GO (see Table 6). Agrimonde GO is nevertheless a scenario that is supposed to represent an open world based on growing international trade, whereas the Agrimonde 1 scenario is more concerned with long-term sustainable development. This same indicator also highlights intense growth of international trade, as in 2003 it was situated at around 1,400 Gkcal/day[56].

Therefore, whereas the Agrimonde 1 scenario was built on a normative basis as regards the estimation of food needs and environmental protection (notably in the choice of assumptions on surface areas and yields), it implies strong growth of inter-regional and therefore international trade. Of course one has to examine the likelihood of these assumptions. The low-yield variants in the regions with a shortage, in the Agrimonde 1 scenario, are relatively weak (lower than the past trend), whereas the consumption assumptions, especially in animal calories, are high[57]. The necessity for growth in international trade nevertheless seems real, as indicated by the comparison with the Agrimonde GO scenario and with other forecasts or scenarios.

What regulations of trade can promote this required growth of international trade? It is not possible to answer this question precisely. However, it seems clear that a strong dose of protectionism, especially in regions with shortages, would not be advisable. Too much protection could impede the necessary growth of imports into such areas. Conversely, the assumptions of the Agrimonde 1 scenario, relative to surface areas and yields in particular, imply an economic viability of local agriculture, especially that which is based on many small semi-subsistence farms. But this economic viability could be undermined by competition from massive imports at cut prices, especially when exports are subsidized, as the developed countries did on a large scale in the past. We therefore reach a conclusion that may seem surprising. We see that many poor countries, in regions with shortages, would have gained from a positive conclusion to the Doha Round. Most importantly, we need to emphasize the necessity for a growth of imports into regions with shortages, and the danger of any ideological dogmatism as regards the regulation of international trade. Moreover, one has to bear in mind the necessity for international regulations concerning the environment, especially the fight against global warming. The articulation between environmental and commercial regulations will therefore be necessary. Implicitly, the assumptions of the Agrimonde 1 scenario assume such an articulation, but we know that this is a difficult undertaking that is only just being tackled. This is evidenced by the decision taken at the recent Poznan conference (2008) to include changes in land use – especially actions to protect forests – in the future agreement following the Kyoto Protocol, even though the modalities of how this will be taken into account are by no means clear.

[55] The sum of regional deficits does not include deficits related to intra-regional trade. Nor does it take into account the fact that some countries are net exporters of plant products and net importers of animal products or vice-versa.
[56] The results for 2003 are not however directly comparable to those of the 2050 scenarios since they concern both animal and plant products, and also include simultaneous exports and imports of one or the other by the same region, which is not the case of figures from 2050 scenarios. There is therefore an under-estimation of the need for more imports by regions with deficits when one compares the results of the 2050 scenarios with the results from 2003.
[57] Especially in sub-Saharan Africa where they are even higher than in Agrimonde GO.

Directions for further inquiry

During the exploration of the two scenarios, several assumptions were not explored in depth. The analysis nevertheless revealed particularly important directions for further investigation.

The impact of climate change on cultivable land potential and future yields has been taken into account only qualitatively, leading to the expectation that the growth of yields could be lower than certain other studies suggest. Research currently under way to quantify the future arable land potential under climatic constraints, according to various greenhouse gas emission scenarios, could be used in the quantitative module. More generally, it would be necessary to examine the articulation between the impact of climate change in the different regions and the various trajectories of technological progress.

The quantitative tool would also allow for more in-depth analysis of important issues for the future of food and agricultural systems. In particular, past trends and scenario assumptions on labour productivity could be linked to the technologies used and their energy consumption, and to the demography of rural spaces, to further test the scenarios under consideration. The impact of the scenarios in terms of water resources and energy autonomy of agricultural systems could also undergo quantitative analysis. Finally, the avenues opened by the elaboration of functions of animal production could serve to formulate more precise assumptions on the future characteristics of breeding systems, and to test differentiated assumptions on international trade in animal products and concentrates for animal feed. In a region with shortages in animal products, would it be better to import such products directly, or to import vegetal concentrates to add to local animal production?

Other priority questions and issues appeared during this scenario exploration and could lead to new research questions. For instance, the possibility of marine aquaculture being an important source of food and energy biomass in the future is based on a number of conditions that would need to be explored (possibilities of domestication, conflicts of uses at sea, animal feed, environmental impacts). Moreover, it would be necessary to explore the conditions under which emergent or as yet non-existent supply chains using agricultural biomass for non-food purposes could grow considerably. These assumptions were not included in the two scenarios presented here. Finally, it appears that in several regions and under various impetuses, forms of urban or peri-urban agriculture could develop or emerge. These would need to be studied in their full diversity.

Agrimonde®

By exploring possible futures of the world's agricultural and food systems up to 2050, the Agrimonde project seeks to identify the fundamental challenges that agricultural research will have to face. Its objective is firstly to enable both CIRAD and INRA to design orientations and strategies. Secondly, it aims at promoting the participation of French experts in international debates on food security and environmental issues, through the process of scenario building.

Under the responsibility of a Steering Committee, the Agrimonde project was carried out by a Task Force consisting of a Panel of Experts and a Project Team who met regularly between June 2006 and December 2008.

Expert Panel

Bernard Bachelier, FARM (Foundation for World Agriculture and Rural Life)
Danielle Barret, CIRAD*
Pierre-Marie Bosc, CIRAD*
Jacques Brossier, FI4IAR***
Jean-Pierre Butault, INRA**
Jean-Christophe Debar, AGRI US Analyse
Francis Delpeuch, IRD (Research Institute for Development)
Fabrice Dreyfus, SupAgro Montpellier (International Center for Higher Education in Agricultural Sciences, Montpellier)
Gérard Ghersi, MSH Montpellier (Social Sciences and Humanities Research Institute, Montpellier)
Michel Griffon, CIRAD*
Christian Hoste, CIRAD*
Bernard Hubert, FI4IAR***
Denis Lacroix, IFREMER (French Research Institute for Exploitation of the Sea)
Marie de Lattre-Gasquet, CIRAD*, ANR (French National Research Agency)
Jacques Loyat, MAP (French Ministry of Agriculture and Fisheries)
Michel Petit, IAM (Mediterranean Agronomic Institute of Montpellier)
Jean-Louis Rastoin, SupAgro Montpellier (International Center for Higher Education in Agricultural Sciences, Montpellier)

Steering Committee

Patrick Caron, CIRAD*
Catherine Esnouf, INRA**
Hervé Guyomard, INRA**
Bernard Hubert, FI4IAR***
Alain Weil, CIRAD*

Project Team

Sébastien Treyer, (Project Head), AgroParisTech (Paris Institute of Technology for Life, Food and Environmental Sciences)
Maryse Aoudaï, INRA**
Rémi Barré, INRA** and CNAM
Jean-Marc Chaumet, INRA**
Bruno Dorin, CIRAD*
Isabelle Karcher, INRA**
Tristan Le Cotty, CIRAD*
Sandrine Paillard, INRA**
Laurent Parrot, CIRAD*
Tévécia Ronzon, INRA**

The Agrimonde report, summarized here, was written by Jean-Marc Chaumet, Francis Delpeuch, Bruno Dorin, Gérard Ghersi, Bernard Hubert, Tristan Le Cotty, Sandrine Paillard, Michel Petit, Jean-Louis Rastoin, Tévécia Ronzon, Sébastien Treyer. The full report will be published in English by Editions Quae, beginning of 2010.

* French Agricultural Research Centre for International Development.
** French National Institute for Agricultural Research.
*** French Initiative for International Agricultural Research.

INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE
147, rue de l'Université • 75338 Paris cedex 07
Tél : + 33(0)1 42 75 90 00 • Fax : + 33(0)1 47 05 99 66
www.inra.fr

AGRICULTURAL RESEARCH FOR DEVELOPMENT
42, rue Scheffer • 75116 Paris
Tél : + 33(0)1 53 70 20 00 • Fax : + 33(0)1 47 55 15 30
www.cirad.fr

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