Agrimonde-Terra: Foresight land use and food security in 2050

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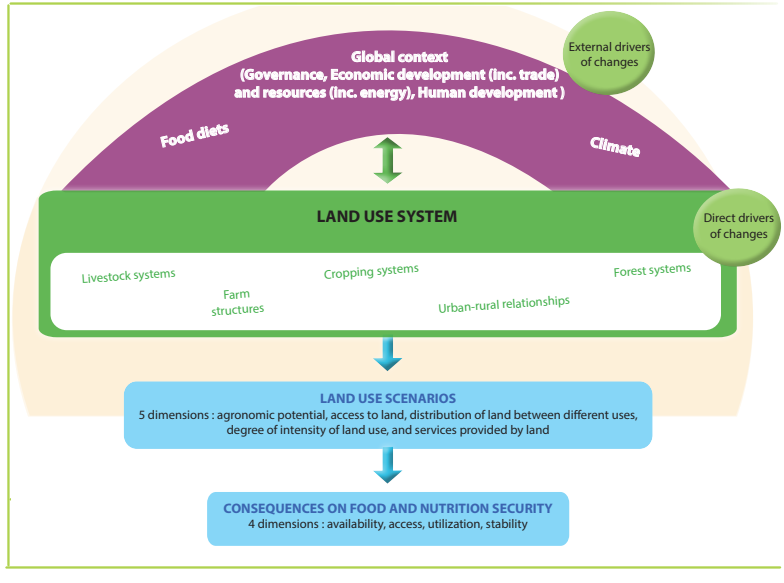
Over the past 50 years, the world's arable and permanent crop land area has grown by 12% while the area dedicated to permanent meadows and pastures has grown by 9%. In 2015, there were about 570 million farms (35% of these farms in China and 24% in India) contributing to the production of food, feed and energy for 7.3 billion people, and there were still about 795 million people undernourished, 600 million obese and 1.9 billion overweight adults across the planet. Concerning current land use and the potential for expanding the agricultural land area in the various world regions, this differs widely according to their land endowment. North Africa, the Near and Middle East and China already exceed their cultivable area. India and the European Union are reaching the limit of their cultivable area and larger regions such as Canada/USA, the Former Soviet Union and East, Central and South Africa remain far below their potential cultivable area, part of which is therefore threatened by deforestation. The expected growth in the world population, which is set to reach 9.7 billion in 2050, and land availability clearly raise the question of the future of land-use patterns and of their interactions with food security. What are the main drivers of land-use changes and how do they interact and influence food and nutrition security? How will the agricultural land area change over the next 40 years, at the world level and in the different regions? What tensions will there be between food and nutrition security and mitigation of climate change in 2050? In order to answer these questions, to contribute to the highlighting of policy levers that could modify ongoing land-use patterns for improved food and nutrition security and to provide decision makers with a tool for dialogue between stakeholders, Cirad and Inra decided, following their previous foresight study on "World food and agricultural systems in 2050"[1], to conduct Agrimonde-Terra, a new foresight exercise on "Land use and food security in 2050".

The Agrimonde-Terra's scenarios point out a diversity of pathways of change for agricultural land use and food security in 2050. They highlight the fact that we are entering a period of great uncertainty and instability, which finds its origin in the dynamics and the interconnectedness between trend factors (demography, urbanization, climate change…), uncertainty and risk factors (economic growth, employment, eating patterns, climate change mitigation…), private actions and public policies at local, national and international levels. Agrimonde-Terra's scenarios also suggest that ensuring world and regional food and nutrition security in a context of climate change is a difficult, long and narrow path.

Uncertainties about the capacity of the planet to feed a growing population in a context of climate change and on-going debates within the scientific community regarding land-use change trajectories led Cirad and Inra to conduct a new foresight study on ''Land use and food security in 2050". A morphological analysis method, which highlights systemic relations, was used for scenario-building in order to explore different futures for land use and food security.

This process was accomplished by mobilizing around 80 international experts during thematic workshops, and a Scenario Advisory Committee that provided guidance on scenarios building. The first step of the approach consisted of analyzing the long-term dynamics of the ''land use and food security" system (Fig. 1), with a focus on the five dimensions of land use: agronomic potential, access to land, degree of intensity of land use, distribution of land between different uses and services provided by land. By identifying a range of variables influencing each driver of the system and its dynamic of change, hypotheses on how each driver might evolve in 2050 were elaborated. In the second step, five contrasted scenarios were built by combining one or several hypotheses per driver, respecting causal relationships, seeking consistency of the hypotheses and plausibility of the scenario. Each scenario describes a situation of land use and food security in 2050 and has been translated into a narrative. In the third step, the impacts of the scenarios in terms of land use, agricultural production and trade in the 14 regions under consideration and at the world level (Fig. 2) have been assessed through quantitative simulations conducted with the biomass balance model GlobAgri-AgT (Box 1).

Figure 1. The Agrimonde-Terra land use and food security system



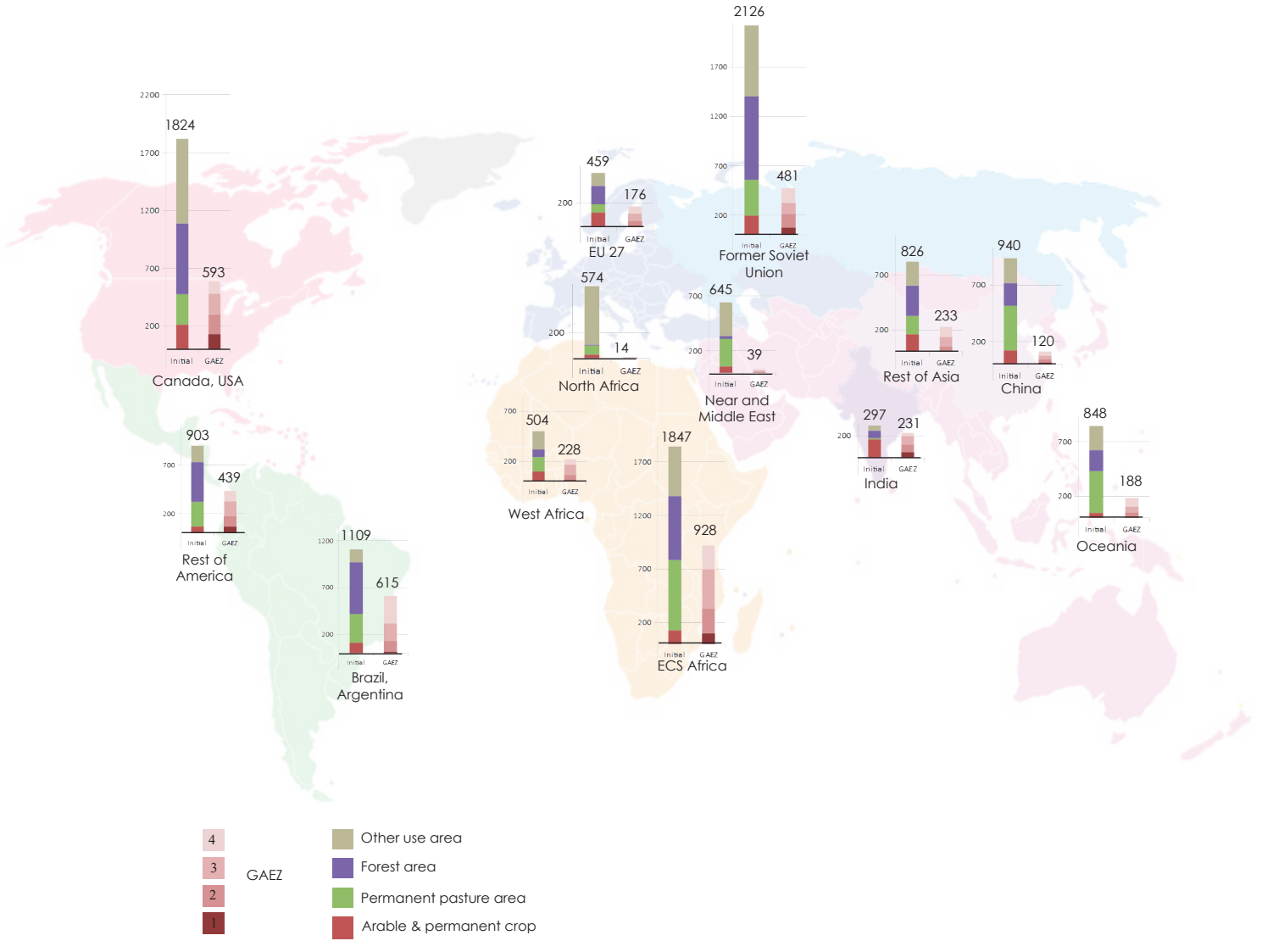
DRIVERS OF LAND USE AND FOOD SECURITY AND POSSIBLE CHANGES BY 2050

In the "land use and food security" system (Fig. 1), Agrimonde-Terra considers that land-use changes result from complex interactions between diverse drivers and have an impact on food security at different scales ranging from household to global. A first category of drivers are direct drivers of the land-use system: urban-rural relationships, livestock systems, cropping systems, farm structures and forest systems. A second category of drivers encompasses the external drivers that influence both the land-use system and food security: global political, economic and social context, climate change and food diets. Direct and external drivers have been studied in detail with the objective of identifying past and emerging trends as well as potential disruptions. On this basis, alternative hypotheses about future changes by 2050 have been built for each driver[2]; they are the "building blocks" of each scenario (Fig. 3).

1 - Paillard S., Treyer S. and Dorin B. (coordinators), 2011. Agrimonde: Scenarios and Challenges for Feeding the World in 2050. Paris: Quae.
2 - All the quantitative hypotheses used in simulations are described in the working paper Le Mouël *et al.* , 2016 "*Hypotheses about the future of drivers of the "land-use and food security" system and their translation into quantitative hypotheses".*

Sources: GlobAgri-AgT, adapted from GAEZ database, adapted Zabel et al. (2014) and additional data provided by Zabel.

Figure 2. World Map of Agrimonde-Terra regions with observed land use (arable land, pasture, forest and others) and maximum cultivable area in 2010 (millions ha)



Global context

Land-use systems are strongly influenced by political, economic and social events outside the agricultural and forestry sectors at the global, regional and domestic levels. Agrimonde-Terra's hypotheses on the future changes of the global context are different from the IPCC Shared Socio-economic Pathways (SSPs) but two of our hypotheses are directly inspired by SSP: Conventional development (from SSP5) and Sustainable and cooperative world (from SSP1). In our analysis of future pathways, we focused on three aspects: political (conflicts, main actors and alliances, trade policies), economic (growth and income distribution, energy and climate policies, R&D) and social contexts (population, social climate, health, education, culture). As far as the population variable is concerned, Agrimonde-Terra used the median projection provided by the United Nations in the 2015 revision, where the world population reaches 9.7 billion people in 2050, with regional changes between 2010 and 2050 ranging from stability in the European Union (EU 27), Former Soviet Union (FSU) and China, to strong increases in West Africa and East, Central and South Africa (ECS Africa) (+192% and +155%, respectively), North Africa and the Near and Middle East (NME) (+72% and +70%, respectively), and to a lesser extent India (+45%). Assuming that world and regional population would be similar by 2050 in all the alternative futures, we designed five pathways for the global context:

• **Sustainable and cooperative world**: strong commitments towards mitigation of climate change, regulation of the nutritional quality of food products, health, and a shift to a green economy; states cooperate amongst themselves and with businesses, civil society organizations and international institutions; moderate economic growth (average world Gross Domestic Product per capita of $20,000 in 2050) and liberalized trade; carbon as the cornerstone of energy markets, decrease of energy consumption; inequalities are reduced.

Box 1. The GlobAgri platform and GlobAgri-AgT

The GlobAgri platform has been set up by CIRAD and INRA to generate consistent databases and biomass balance models using data from FAOStat as well as data shared by colleagues from different institutions.[1] The databases generated are balanced and account for the links between products (through animal feed or oilseed crushing for instance). Biomass balance models provide a balance equation between resources (domestic production plus imports minus exports) and utilization (food, feed, other) for each region and each agri-food product. In each equation, imports are a linear function of domestic total uses and exports are a linear function of the world market size. A world trade balance equation ensures that world imports equal world exports for each agri-food product. The system of balance equations can simulate land-use change in each region induced by changes in the uses of agri-food products, provided hypotheses on changes of a set of variables (such as plant and animal yields, maximum available cultivable land, trade conditions etc.).

The GlobAgri platform has been used to generate a database and a biomass balance model specifically customized for Agrimonde-Terra (specific product and country aggregation, specific rules of co-product handling, specific rules of model closure). The resulting tool is named GlobAgri-AgT. It encompasses 32 aggregates of agri-food products (25 plants and 7 animal aggregates) and covers 14 broad regions (Fig. 2). The balance model works with a maximum cultivable area for each region. When in one region the cultivated land area cannot expand because the maximum cultivable area is reached, as there is no price mechanism in the model, it uses trade to achieve the balance between resources and utilization for all agri-food products: exports are first evenly reduced for all agri-food products, then if necessary imports are increased, according to a set of rules allowing for differentiated rises across agri-food products. GlobAgri-AgT is described in detail in the technical report "Hypotheses about the future of the drivers of the 'land use and food security' system and their translation into quantitative hypotheses".

GlobAgri-AgT has been used to simulate the impacts on world and regional land use of the five Agrimonde-Terra scenarios. The morphological tables (Fig. 3) indicate that for most scenarios several hypotheses of change pattern may co-exist for several drivers. This means that for these drivers, the world's regions can follow different development paths, some prevailing in some regions, others being prominent in other regions. For the quantitative analysis, however, one hypothesis is chosen for each driver and applies to all regions. When relevant, the same scenario is simulated using alternatively different hypotheses of change for one or two drivers. In such cases, the simulation results of the scenario variants may be interpreted as boundaries for that scenario as a whole. The variants of the different scenarios are described in Table 1.

Given that the main specificities of the "Households" scenario are rather qualitative features (networks, mobility, multi-activity, plasticity, agility) which cannot be dealt with by GlobAgri-AgT, we do not provide quantitative results for this scenario.

Land-use changes as well as changes in domestic production and international trade of each agri-food product in each region between the initial situation and 2050 are the outputs of the model and they are used to assess the ability of each scenario to ensure world food availability: agricultural land area expansion and deforestation suggest increased tensions over land, which in turn put into question the food availability equation at the world and regional level. The other three dimensions of food security (access, utilization and stability) are dealt with through a qualitative analysis, based on information provided by the scenario narratives.

1 - *These colleagues are warmly thanked as well as their institutions: Center for Sustainability and the Global Environment (SAGE), Commonwealth Scientific and Industrial Research Organisation (CSIRO), International Institute for Applied Systems Analysis (IIASA), Institute of Soil Science of the Chinese Academy of Sciences, Joint Research Centre (JRC), Princeton University, World Fish Institute, World Resources Institute (WRI) and Woodrow Wilson School of Public and International Affairs.*

• **Regionalization and energy transition**: States joining in large regional blocs to face together financial crises, unemployment, pollution, high rates of non-communicable diet-related diseases; principle of "food sovereignty and subsidiarity" at the regional blocs level based on regional food supplies and supported by businesses and civil society organizations; moderate economic growth (average world GDP per capita of $20,000); high level of biomass energy; strong intra-regional trade.

• **Economic and political fragmentation:** series of crises (economic, energy, geopolitical and ecological) amplifying each other; severe geostrategic tensions, weak access to energy in some regions; low economic growth (average world GDP per capita of $18,000) with huge differences between countries; highly developed informal economy, trade limited to neighbouring countries.

• **Conventional development led by market forces:** alliance between multinational corporations, investments funds and international institutions; steady economic growth (average world GDP per capita of $24,000) based on low-cost fossil fuel, low trade barriers, confidence in science above all to overcome natural resources' limits, education and Information and Communication Technologies; large inequalities.

• **Non-State actors:** highly globalized world; economic networks based on NGOs, associations, multinational companies, foundations and academic institutions; failure of sovereign States to take up the challenges of climate change and poverty; government endeavouring to coordinate hybrid and agile coalitions; decentralized energy production; economic situation of groups dependant on their capacity for networking; large inequalities.

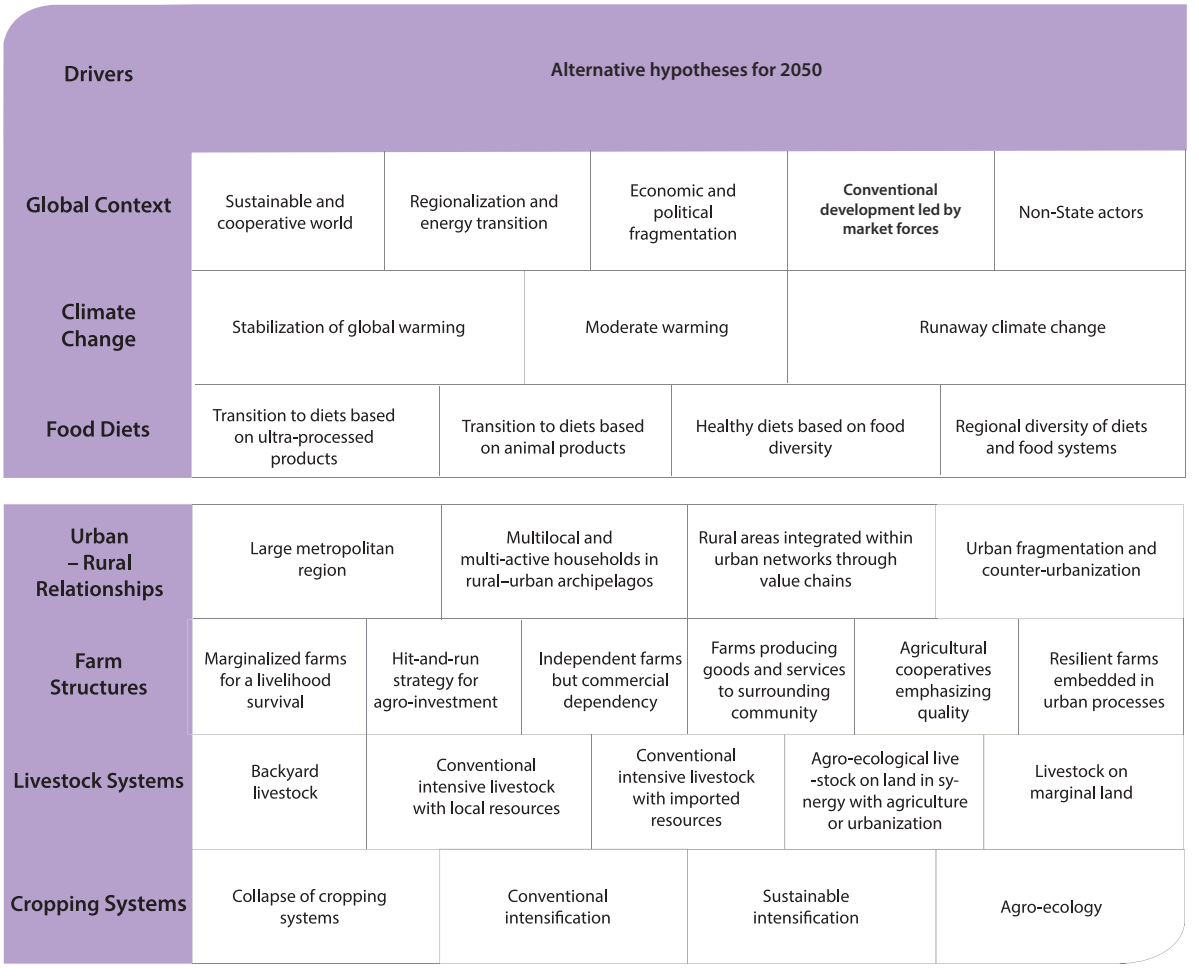
The global context pathways influence climate change, food diets (through household incomes), urbanization processes and cropping and livestock systems (through R&D).

Climate change and mitigation

Land use is at the forefront of the climate issue as it is both concerned by its impacts and will be a major actor in its mitigation. It is responsible for just under a quarter (~10 – 12 GtCO2eq per year) of anthropogenic GHG emissions, mainly from deforestation and agricultural emissions from livestock, soil and nutrient management, and among economic sectors has one of the largest potentials for mitigation. There is evidence of the impacts of historical and recent climate change on food production, with a global net loss in average wheat and maize yields of 3.8% and 5.5% respectively relative to what would have been achieved without the climate trends of 1980-2008[3]. Extreme weather events played an important role in the food crisis of 2007-2008 and continue to multiply.

3 - Lobell D.B., Schlenker W. and Costa-Roberts J., 2011. Climate trends and global crop production since 1980. *Science*, 333(6042): 616-620.

Figure 3. Drivers and alternative hypotheses for 2050



We described climate change patterns to 2050 through three pathways, inspired by the Representation Concentration Pathways (RCP) of the fifth assessment report of the IPCC (Intergovernmental Panel on Climate Change):

• **Stabilisation of global warming:** in a context of strong commitment towards mitigation of climate change combined with relatively low climate sensitivity, global temperature changes are maintained well below +1°C to 2050 and changes in precipitation remain limited (<+0.05mm/day in 2100); crop yields in both temperate and tropical zones are not significantly affected by climate change; cultivable area does not notably change; all mitigation options adapted to local situations are considered, including carbon storage in agricultural soils and resource use efficiency measures, to create synergies with yield increases and the limitation of land degradation.

• **Moderate warming:** mitigation is considered only as a co-benefit of adaptation measures, as well as reduced food and energy consumption due to lower economic activity and/or energy independency strategies; global temperature changes reach +1°C in 2050 and changes in precipitation amount to +0.08 mm/day in 2100; by 2050, modest 60 million ha increase in moderately suitable to very suitable lands for plant production, unevenly distributed: rise in the Northern latitudes (+69 million ha for instance for the three regions Canada/USA, FSU and China) and decrease in tropical regions (-11 million ha for both regions Brazil/Argentina and Rest of America for example); frequency of extreme climatic events (heat waves, floods, etc.) increases, leading to a moderate rise in the inter-annual variability in crop yields.

• **Runaway climate change:** in a context of strong dependence on fossil energies, greenhouse gas emissions continue to rise sharply positioning the climatic system in a scenario corresponding to the IPCC RCP 8.5; global temperature changes reach +2°C in 2050 and changes in precipitation amount to +0.15 mm/day in 2100; land area suitable for crop production increases by approximately 600 million ha by 2100[4] which corresponds to an increase of 120 million ha for moderately suitable to very suitable-lands in 2050; mainly concerns Northern latitudes while the land area suitable for crop production decreases in tropical regions; average quality of the potentially cultivable land decreases; on average at the global scale, per-hectare cereal yield decreases range between -13% and -30%[5]; extreme climatic events become more frequent leading to increased inter-annual variability in crop yields.

For the quantitative simulations, hypotheses on the future of climate change influence regional maximum cultivable areas and crop yields. Deforestation-afforestation is evaluated *ex-post* as an outcome of quantitative simulations and is used to test mitigation hypotheses.

4 - Zabel F., Putzenlechner B. and Mauser W., 2014, Global agricultural land resources – A high resolution suitability evaluation and its perspectives until 2100 under climate change conditions. *PLoS ONE* 9(9): e107522. doi:10.1371/journal.pone.0107522

5 - Müller C. and Robertson R.D., 2014. Projecting future crop productivity for global economic modeling. *Agricultural Economics*, 45: 37–50. doi: 10.1111/agec.12088

Food diets

Diets together with demography determine food consumption of agricultural products and thus act indirectly on land use. Currently, a nutrition transition is occurring in developed and developing countries, increasing caloric availability, and reducing undernutrition in most regions. It is based on: the edible plant oil revolution; a shift towards increased consumption of animal products; increasing consumption of sugars and sweeteners; and declining consumption of legumes, whole-grain cereals and vegetables. This change in diet is linked with the diffusion of energy-dense, refined and ultra-processed foods through global food value chains[6]. These changes led to a dramatic increase in overweight and obesity and diet-related non-communicable diseases (cardiovascular diseases, type II diabetes, cancers). Developing countries increasingly face a double burden of malnutrition with under- and overnutrition occurring simultaneously. Based on food transition patterns, health outcomes, food value chain and food and nutrition policies, we have elaborated four global dietary changes by 2050 (Fig 4.):

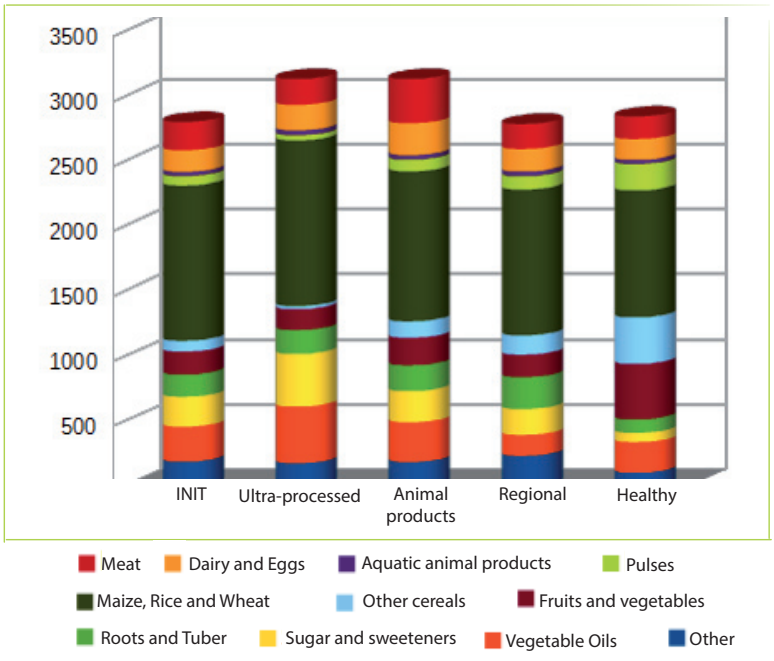
• **Transition to diets based on ultra-processed products** and transnational value chains: rapid nutrition transition in developing countries driven by "modern" value chains (supermarkets and transnational food companies); dietary convergence toward a diet based on the consumption of ultra-processed foods; consumption of vegetable oil, refined cereals, processed meat, salt and added sugars (especially sodas); strong impact of diets on public health, obesity or overweight, with non-communicable diseases being a major cause of mortality worldwide.

• **Transition to diets based on animal products** and urban lifestyle: nutrition transition based on food supply and on urban lifestyle changes, through higher incomes and higher consumption of meat; increasing consumption of animal products, fat and added sugars and salts and decreasing consumption of coarse grains, legumes, and vegetables; significant increase in calorie intake and reduced diversity of foods; increasing overnutrition and persistence of undernutrition in remote rural areas and poor urban settlements.

• **Healthy diets based on food diversity**: implementation of public health policies to tackle the persistent issue of malnutrition and reorient diets toward healthier and more diversified food consumption; global measures for limiting the trade in energy-dense, ultra-processed foods with low nutritional values; national health education and policies targeting key players and products of the food systems; more balanced and diversified diets with increased consumption of fruits and vegetables, of pulses, a diversity of seeds and coarse grains and a moderate intake of animal products.

• **Regional diversity of diets and food systems:** diverse and heterogeneous pathways of food diets, reinforcing their regional specificity; reconnection of regional supply chains to regional food crops; food value chains mixing regional agri-food industries and traditional food supply,valuing culinary culture; consumption of cereals, coarse grains, pulses or tubers and roots with the importance of each product depending on region; limited increase in the rates of overweight and obesity and diet-related non-communicable diseases.

Figure 4. Average world food diets in the initial 2010 situation and by 2050 under the various hypotheses for the future of food diets(kcal/capita/day)



Changes in food diets impact cropping and livestock systems (through food demand) and farm structures (through organization of food supply chains).

For quantifying hypotheses on food diets, we made differentiated assumptions on changes in calorie availability per capita and in shares of product groups in diets over the 2010-2050 period. These assumptions resulted in an average world diet significantly different according to diet future pathways (Fig. 4). Differences are even more marked at the regional level. Under each pathway, the extent of change in diet from 2010 to 2050 differs widely from one region to the other: for instance, under the pathway "Transition to diets based on animal products", the share of meat increases sharply in most developing regions while it is unchanged in most developed regions (Fig. 9).

Rural-urban relationships

Changes in the relationships between urban and rural areas have an impact on land use and food security. Urbanization concentrates individuals and jobs, attracts rural migrants, influences individual diets and increases the disconnection between agricultural production and food consumption. On the other hand, rural areas are still based on agriculture activities in most part of the developing world and are often experiencing a development of non-farming activities.
We have elaborated four hypotheses of change in urban and rural areas interactions:

• **Large metropolitan region** with a spatial break with rural hinterlands: massive rural migration in large metropolitan centres, strong urbanization dynamics; development of global trade; standardisation of lifestyles based on consumerism; spatial and economic break between large urban areas and rural areas.

• **Multi-local and multi-active households in a rural-urban archipelago:** increase of temporary migration to cities; development of rural households' multi-activity strategies; significance of non-farm activities in rural development.

6 - Monteiro C.A., Moubarac J.C., Cannon G., Ng S.W. and Popkin B., 2013. Ultra-processed products are becoming dominant in the global food system. *Obesity Review* 14 (Suppl. 2): 21–28.

• **Rural areas integrated within urban networks through value chains:** multipolar urbanization process; increasing role of medium-size cities as intermediate between rural areas and large cities; rural development based on agri-food activities.

• **Urban fragmentation and counter-urbanization:** crisis of large cities; redeployment of population growth to medium-size cities and small towns; increase in rural population and agricultural workers in some developing countries.

Changes in urban-rural relationships impact food diets (changes in eating environments and lifestyle), income levels in rural areas (depending on the nature of the links between rural and urban areas), the insertion of farm structures within food systems, rural migration and the number of farm workers in rural areas, the mode of development of rural areas (based on agriculture, on the agri-food sector, or multi-sectorial).

Farm structures

Farm structures are the basic units for production and major users of land. Agricultural structures are extremely diverse ranging from small family farms to large-scale farms. International reports tend to underline the economic and social importance of small farms based on family labour, and their potential productivity gains. Large-scale farming is based on financial investment capacities. Farm structures are characterised by a combination of factors relating to the land, capital and labour used in production and by their integration into social and economic dynamics. Access to land is a major issue for farm structures, for women in particular. Taking these issues into account, Agrimonde-Terra has identified six pathways for future farm structures:

• **Hit-and-run agro-investments:** large agro-projects raising financial funds, hiring labour and farmland; emerging temporary farming structures; decision making in the hands of brokers and engineers.

• **Independent farms but commercial dependency:** family farms contracting with industrial private or public enterprises that organize collection, processing and marketing of standardized products; farmer's responsibility for labour.

• **Farms producing goods and services to surrounding communities:** farmers providing services to users through the mediation of local governments and communities; innovations in tune with agroecology and the circular economy.

• **Agricultural cooperatives emphasizing quality:** commercial farms connected with either local or international markets; added value based on collective action and voluntary quality standards.

• **Resilient farms embedded in urban processes:** family farms coping with disruptions; farming that guarantees a minimum income and access to food; new multi-active strategies based on farms.

• **Marginalized farms for livelihood survival:** farmers poorly connected to markets because of their isolated location or because of their exclusion from development policies; development of subsistence farming.

Farm structures impact cropping and livestock systems, as well as agricultural employment and incomes.

Cropping systems

Future cropping systems must contribute to food and nutrition security, animal feed, and the supply of biomass for energy and materials; they are part of the environment and of rural livelihoods. In the past, in Northern countries and a few regions in the South, green revolutions have led to the separation of crops and livestock, regional specialization, globalization and mechanization. Other developing regions have increased their yields through an intensification of labour. These diverse intensification processes lead to a degradation of natural resources which puts their sustainability into question. At the same time, a number of developing regions have experienced stagnation or poor increases in yields. Agrimonde-Terra examined how farmers, in interaction with other components of the food system, public policies and research and extension, could modify cropping systems while taking into account local bio-physical and socio-economic conditions, and making the best use of productive and human resources. Four distinct pathways for the evolution of cropping systems and an impasse have emerged, each addressing current challenges in different ways:

• **Conventional intensification:** increasing yields *via* simplified cropping systems relying on industrial inputs; end-of-pipe approaches to the negative impacts generated; uncertainty regarding the capacity to overcome or respond to a variety of socio-economic pressures.

• **Sustainable intensification:** intensification of production combined with the reduction of environmental impacts; input substitution or maximizing input efficiency thanks to new technologies.

• **Agroecology:** major redesign of systems emphasizing crop diversification, agroforestry and mixed crop-livestock farms relying on self-generated biological regulation and local recycled inputs to produce economic and agro-ecosystemic resilience.

• **Collapse of cropping systems:** evolution based on conventional intensification towards a number of potential impasses resulting from cropping system weaknesses: climatic, biotechnical or linked to the socio-economic context such as lack of labour, land access insecurity, lack of access to inputs, to credit etc.

For the quantification of hypotheses on the future of cropping systems, we made differentiated assumptions on changes in average crop yields for groups of crops (cereals, protein seeds, other crops) and on changes in individual crop yields within groups. For the latter we assumed that following changes in food diets, crops increasingly (decreasingly) demanded at the world level would likely benefit from increasing (decreasing) R&D efforts resulting in more (less) technical change (induced technical change theory) and above-group average (below-group average) change in per-hectare individual yield. These assumptions resulted in higher average yield increases in the pathway "Conventional intensification" than in the pathway "Sustainable intensification", the latter showing greater yield increases than the pathway "Agroecology".

Livestock systems

Livestock systems are major users of land either directly through grazing or indirectly through the production of animal feed. At the world level pastures cover about 2.2 times more land than arable and permanent crops (Fig. 2). In the past 40 years, meat and other animal products have been significant elements of the nutrition transition in developed and emerging countries; demand increased in connection with rising incomes and was a major driver of deforestation. But during the past two decades a number of countries in the developing world have seen their animal products consumption remaining low. At the same time, a shift from ruminant to monogastric meat has reinforced the demand for animal feed crops, with the share of poultry meat rising from one-sixth of world meat production in 1970 to one-third today[7]. Based on trends in animal feed, efficiency of animal systems, crop-livestock synergies, and herd mobility, four hypotheses for the future of livestock systems were produced:

• **Conventional intensive livestock:** almost unlimited availability of key production factors (land, capital, labour, water and other inputs); specialization of activities, genetic improvement, use of antibiotics, medications;
- **With imported resources:** global availability of key production factors, imports of resources (feed, genetics, medication etc.).
- **With local resources:** availability of key production factors at a regional scale; regionally-produced feed (forage, concentrates and by-products).

• **Agro-ecological livestock on land in synergy with agriculture or urbanization:** strong autonomy in terms of feed and input use; feed and protein autonomy through associations of livestock and crops; local land used for feed and pastures; production of hardy animals.

• **Livestock on marginal land:** small and large ruminants raised on extensive or pastoral systems; grazing herds on land with medium to low agronomic potential; livestock management techniques (production schedule, birth and density).

• **Backyard livestock:** synergies between production and the environment, low dependency on inputs and feed (using urban or industrial waste) and labour intensity; vital role in households' food and nutrition security.

Hypotheses concerning the future of livestock systems apply to five livestock sectors (dairy, beef, small ruminants, pork and poultry), each comprising different production systems.[8] They were translated into quantitative hypotheses through differentiated assumptions on changes in feed-to-output ratios (quantity of dry matter feed by unit of output produced) and on shares of the different production systems in the total production output of the sectors under consideration. Such assumptions resulted, in average, in larger improvements in the production performances of livestock systems under the "Conventional intensive livestock" pathway than under the "Agroecological livestock" pathway.

THE FIVE SCENARIOS OF LAND USE AND FOOD SECURITY BY 2050

Five contrasting scenarios of land use and food security by 2050 were developed. They are based on a morphological table (Fig. 3) with each line devoted to a driver. Within a line, each cell contains one of the hypotheses for the future of the concerned driver. Each scenario is characterized by a specific combination of hypotheses and by a colour. The first three scenarios are based on current competing trends identified in most regions of the world (Fig. 5). The last two scenarios involve potential breaks that could change the entire land use and food security system (Fig. 7).

• The first scenario ("Land use driven by metropolization") links the development of megacities at global level with a nutrition transition led by global agri-food companies selling ultra-processed foods, in a global context of development through market forces and rapid climate change, leading to marginalize small farmers.

• The second one ("Land use for regional food systems") relates the increase of medium-size cities and their networking with rural areas to the emergence of regional food systems based on family farming and traditional foods, and a set of regional agreements.

• The third scenario ("Land use for multi-active and mobile households") links strong individual mobility between rural and urban areas and a development of non-farm employment to the emergence of hybrid diets based on traditional and modern value chains, in a globalized world where family farms and cooperatives are major actors in land use.

• The fourth scenario ("Land use for food quality and healthy nutrition") assumes that due to the increasing cost of malnutrition, a radical move towards healthy diets occurs fuelled by global cooperation and public policies in a context of climate change stabilization, implying a re-configuration of agricultural system backed by new alliances between stakeholders.

• The fifth scenario ("Land as commons for rural communities in a fragmented world") assumes that in a context of repeated multiple crises, development based on small towns and rural communities occurs focusing on managing common property in agriculture in order to ensure food security.

Land use driven by metropolization ["Metropolization" scenario]

By 2050, two-thirds of the world's population live in cities and more than 15% of the urban population lives in megacities (over 10 million inhabitants). Urbanization is part of global economic growth, which emerges out of conventional development. The world economy is built upon a network of "global cities" in which most of the activities and jobs are located. Value creation within these megacities is mainly based on the concentration of activities in services, industry, knowledge and finance. Urban growth is fuelled by high levels of internal migration from rural areas.

7 - Alexandratos N. and Bruinsma J., 2012. *World agriculture towards 2030/2050*: the 2012 revision. ESA Working Paper N°12-03. Rome, FAO.
8 - Herrero *et al.,* 2013, Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences 110(52)*: 20888-20893.

Table 1. The scenarios and their variants simulated with the GlobAgri-AgT model

Scenario	«Variants» (assumptions used)	Running name
Metropolization	**With ultra-processed products:** Transition to diets based on ultra-processed products	Metropolization_Ultrap
	With animal products: Transition to diets based on animal products	Metropolization_Animp
Regionalization	**With agricultural technology A:** Sustainable intensification for cropping systems + Conventional intensification with local resources for livestock systems	Regionalization_A
	With agricultural technology B: Agroecology for cropping systems + Agroecological livestock	Regionalization_B
Healthy	**With agricultural technology C:** Sustainable intensification for cropping systems +Agroecological livestock	Healthy_C
	With agricultural technology D: Agroecology for cropping systems + Agroecological livestock	Healthy_D
Communities	**With agroecology:** Agroecology for cropping systems + Agroecological livestock	Communities_AE
	With collapse: Collapse of crop production + Backyard livestock	Communities_Collapse

Note: The scenario "Land use for multi-active and mobile households" has not been quantitatively simulated within the GlobAgri-AgT model. This scenario has only been qualitatively analyzed.

While environmental concerns have taken a back seat with the emphasis on conventional development, climate change has significant effects, especially in agriculture. Processing, retailing and wholesaling transnational corporations control the greater part of food markets in both urban and rural areas. They provide the connections between rural production sites and mainly urban consumption zones. Two dynamics in diet change are occurring: one driven by the expansion of globalized value chains providing low-price ultra-processed foods (variant Ultrap), and one variant supported by the major consumption of animal products, meat in particular (variant Animp), based on the increasing demand of an emerging middle class (Tab. 1). Compared to 2010, diets in 2050 are higher in edible plant oils, refined cereals, sugars and sweeteners (through soft drinks), salt and animal products (including processed meat fats) and lower in coarse grains and pulses.

Intensive conventional agriculture based on a high level of inputs has developed *via* private capital from investment funds, companies, and the urban middle class. They invested in production areas tightly linked to urban food markets, in specific and specialized regions, which can be remote. Agricultural production only takes account of environmental issues after the fact (end-of-pipe), leading to severe soil degradation, entailing the displacement of agricultural areas (to select land best suited to this form of intensification) and greenhouse gas emissions. The emergence of global interlinked urban archipelagos has excluded vast expanses of the world from economic growth. In rural areas distant from large cities, which are difficult to access and isolated from global markets, poor farmers seek to carry on their farming practices in arduous economic and environmental conditions (degraded soil, unsecure access to land, poor access to water and to markets).

As a result of the evolution of the food system, unhealthy diets developed in lower and middle classes, leading to a dramatic increase in diet-related non-communicable diseases in developed and developing countries, while growing inequalities within urban areas and between urban and rural areas have led to problems of undernutrition. The dynamic of the global food system led to an international specialization in production with Brazil/Argentina and North America doubling or tripling their exports, and the Former Soviet Union and EU 27 increasing their exports, with the Rest of Asia increasing both exports and imports (Fig. 11). Other regions became highly dependent with imports tripling in West Africa, ECS Africa, North Africa and the Near and Middle East, and even bigger increase in India. Both importing and exporting regions (except China) experience an increasing pressure on arable land and the most significant pressure on pasture arises in ECS Africa (Fig. 6). Here, diet type is of major significance for land pressure as the ones based on animal products put much more pressure on land compared to diets based on ultra-processed food goods (Fig. 4 and Fig. 9). Despite the increase in global trade and because of strong pressure on agricultural land, the considerable impact of climate change on agricultural production has made the food supply system more vulnerable, triggering occasional food crises, especially for low-income households.

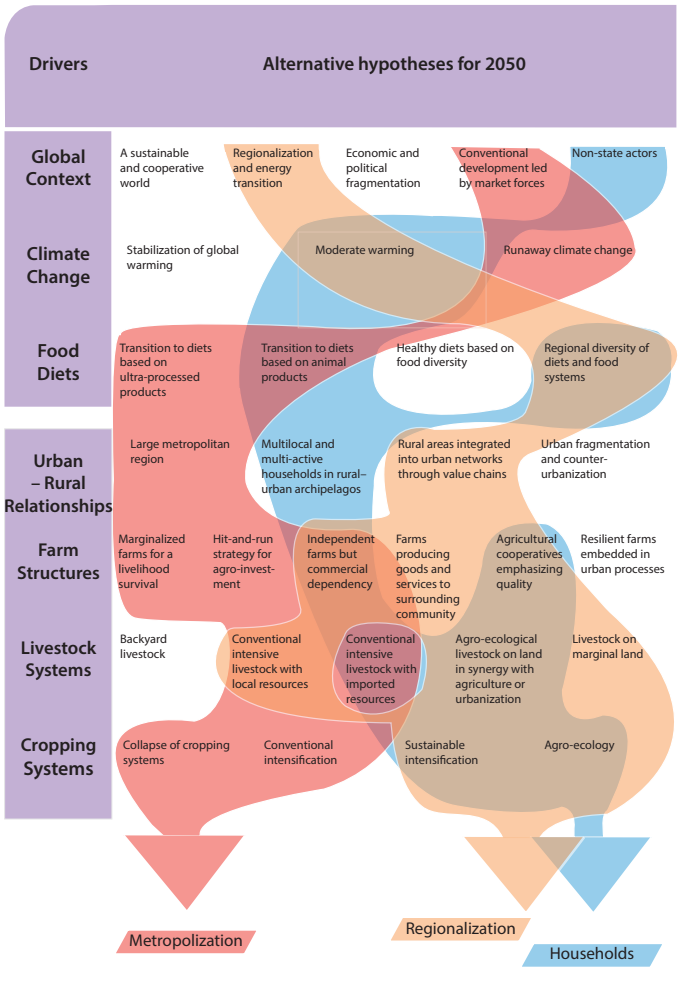
Land use for regional food systems ["Regionalization" scenario]

By 2050, States have joined together in supranational regional blocs. Political and economic governance in regional blocs arose as a way to address a series of issues such as financial crises, unemployment, pollution and high rates of non-communicable diet-related diseases. This led to a shift in urbanization from large cities to medium-size cities and small towns. The latter became part of regional development playing a significant role as intermediates between rural areas and larger cities. Within these blocs, States are managing energy transition and improving food diversity. They seek greater energy autonomy by increasing the production of renewable energy and by using regionally available fossil fuel resources.

Regional blocs shaped food systems by investing preferentially in traditional regional foods and by reconnecting the food industry to regional production. Regions applied the concept of "food sovereignty" and subsidiarity, wherein as much food as possible is produced within the region and recourse to imported products is only made when regional production is not sufficient (such as in North Africa and the Near and Middle East, for instance). This process involved major changes in land use in regions where agriculture had been largely shaped to supply international markets such as in the Brazil/Argentina region 40 years ago. Traditional diets have been promoted, thanks to a reconfiguration of supply chains and value chains at the regional level, with medium-size cities and small towns concentrating industrial and small-scale food processing. Each region has now broadened the range of foods on offer by supporting diverse food industries based on regional food cultures. The production and consumption of roots and tubers, coarse grains, pulses, fruit and vegetables has increased dramatically. Systems of agricultural cooperatives and contract agreements with downstream partners such as agri-food industries had a positive knock-on effect for agriculture and rural development. With the development of regional food value chains, nutrition transition towards the consumption

of ultra-processed foods was limited together with its potential negative impact on public health, and food access for rural population was improved. In a context of moderate climate change, renewed diversity in production has transformed crop and livestock systems. Diverse crop and livestock systems co-exist, from conventional systems to sustainable intensification agriculture or agroecology. Diversification led to the increasing production of legume crops, thereby making cropping systems more agroecological, while also strengthening ties between crop and livestock systems. Depending on the region, cropping systems evolved toward sustainable intensification agriculture or agroecology. Animal feed is expressly sourced from regional plant production, and trade in organic fertiliser between livestock and crop farms is organised at small and medium scales. In general, farmers have favoured the use of varieties suited to regional agri-climatic conditions. We then built two variants (A and B) according to agricultural technologies (Tab. 1).

Figure 5. Alternative combinations of hypotheses describing scenarios of land use and food security by 2050



These evolutions have generated either slight increases or decreases in arable land (Fig. 6) for both exporting regions such as North America, Brazil/Argentina, Oceania or the Former Soviet Union and importing regions such as the Rest of Asia or ECS Africa. But four regions have experienced high pressure on agricultural land: EU 27 and India where arable land increased, West Africa where both arable land and pastureland grew strongly, and ECS Africa where pastureland expanded very importantly. Globally the regionalization of diets and food systems has limited international trade which, nevertheless, remains a major concern for net importing regions such as the Near and Middle East, North Africa and West Africa (Fig. 11).

Land use for multi-active and mobile households ["Households" scenario]

In a highly globalized, mobile and hybrid world, non-State actors including civil society groups, international NGOs, local authorities, multinational companies, academic institutions, foundations and cities shaped social, economic and geopolitical transformation processes. They have organized themselves to form *ad hoc* networks that play a key role in trade and are gradually superseding sovereign governments. These networks are fuelled by public debates and steered by concerned groups structuring both consumption and production through new forms of disintermediation of food value chains. Their strategies are jointly defined with citizens, consumers, residents and other relevant groups who express their concerns regarding health, biodiversity, the environment and climate change. In this dynamic but unstable economic context, households have improved and diversified their incomes by being much more mobile. Reversible, temporary, short- or long-distance mobility have driven social networks and economic strategies. Circular migration between rural and urban areas is now a normal way to gain access to employment.

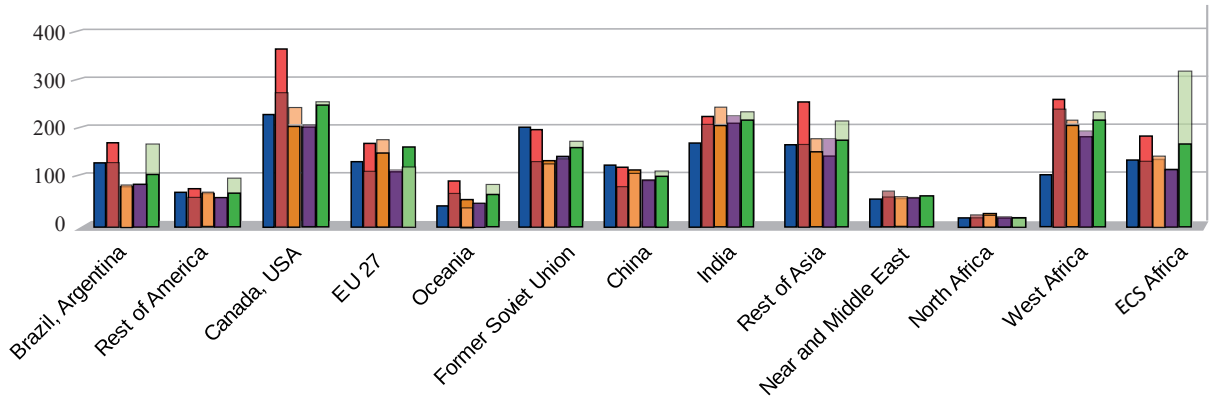
Diverse demands have drawn public attention to farm practices and farmers' groups. Farming households are driving organizational and technical innovations in food value chains, networking with each other *via* numeric platforms that disintermediate and shorten traditional supply chains. Access to these platforms and their modes of regulation have become central to food governance in urban and rural areas. As these networks diversified ranging from local, regional or national scales to international, they became the basis for the development of agriculture and contributed to a relative improvement in farm incomes.

Regarding these changes, households played a key role as places in which work, exchanges and solidarity were organized, and which are enmeshed within various networks of production, consumption and social activities. Thanks to resources generated by mobility, households increased and diversified their incomes by being located in both rural and urban areas and carrying out farming and non-farming activities in the food trading and processing sectors, in industry, in the building sector or in services.

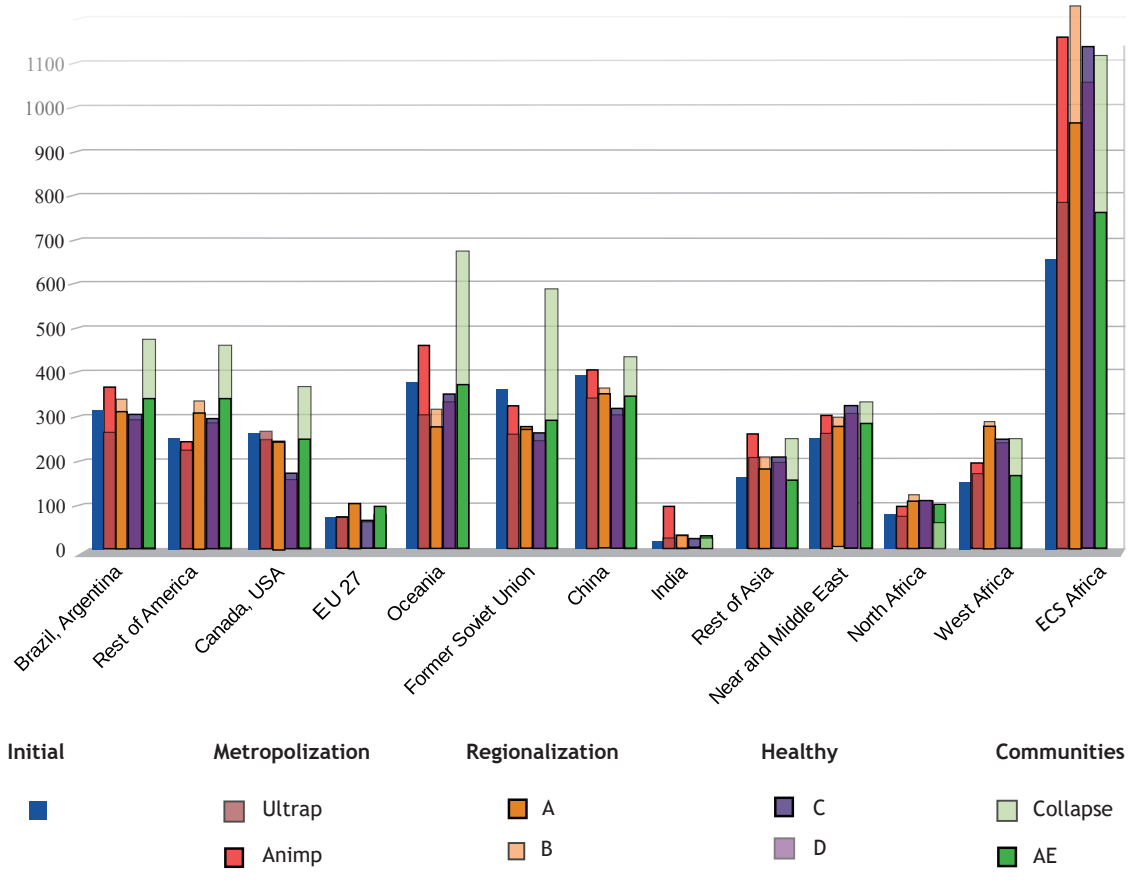
Farm structures within these food networks are diverse, ranging from small farms with family labour to large, highly-capitalized farms. But, in general, multi-activity systems contribute to ensuring food and nutrition security for rural and urban households by diversifying their income and guaranteeing direct access to foodstuffs. Pressure on land in this scenario is quite similar but a little lower than in the "Regionalization" scenario due to more active international markets that ease specific regional pressure on agricultural land.

Figure 6. Agricultural land areas in the initial 2010 situation and by 2050 in the various scenarios (million ha)

6a. Arable and permanent crops area



6b. Permanent pasture area



Land use for food quality and healthy nutrition ["Healthy" scenario]

In the 2020s, as healthcare systems were saddled with the considerable costs associated with diet-related non-communicable diseases and, more generally, as the consequences of malnutrition on public heath were increasingly felt, most States were compelled to implement a raft of policy measures aimed at shifting consumption patterns towards healthier diets. These policies were aligned with international measures to fight climate change. They focus on energy, transport, construction, food systems and carbon storage. In this context, synergy across multiple scales (national, regional and international) on food, agriculture, and climate policy was sought so that agricultural and food policies simultaneously generated widespread, positive impacts on both diets and climate change at the global level. Global soil improvement policies have also led to the rehabilitation of degraded land (25% of the world's productive lands were degraded in 2006) for agricultural use and carbon storage. National states and urban authorities shaped more inclusive development processes linking rural to metropolitan areas, improving transport and communication infrastructures, land planning and favouring efficient food value chains.

To meet nutrition targets, food chains have been reshaped to give access to diverse and high-quality products such as fruits and vegetables, coarse grains and pulses, and improving the quality of industrial processing in order to preserve micronutrients and fibres. Compared to 2010, the diets of 2050 in emerging and developed countries are lower in animal products, fats, ultra-processed foods, sugars and

sweeteners. In specific developing countries, as a response to the continued incidence of undernutrition, the share of animal products in diets has increased. Access to fresh food in urban and rural areas has improved with the development of a large range of distribution channels such as outdoor markets, small retailers and large supermarkets. To meet the challenges posed by under- and overnutrition, both crops and cropping systems have diversified, incorporating techniques from agroecology, while livestock systems are now re-associated with crop production in order to improve mineral cycles. Depending on the availability of capital and the situation in the agricultural labour force, cropping systems have evolved towards sustainable intensification (variant C) or agroecology (variant D; cf. Tab. 1). These changes contributed to both limiting agricultural greenhouse gas (GHG) emissions and increasing carbon storage in soil, raising per-hectare yields in instances where yield potential was previously far from being reached. Organized in cooperatives, farmers are part of healthy food chains, producing quality foods based on standards and contracts with agri-food industries, or selling high value fresh products to urbanites. Better-organised food systems have also reduced food losses and waste, in particular by improving the food storage and preservation capacities of countries in the Southern hemisphere.

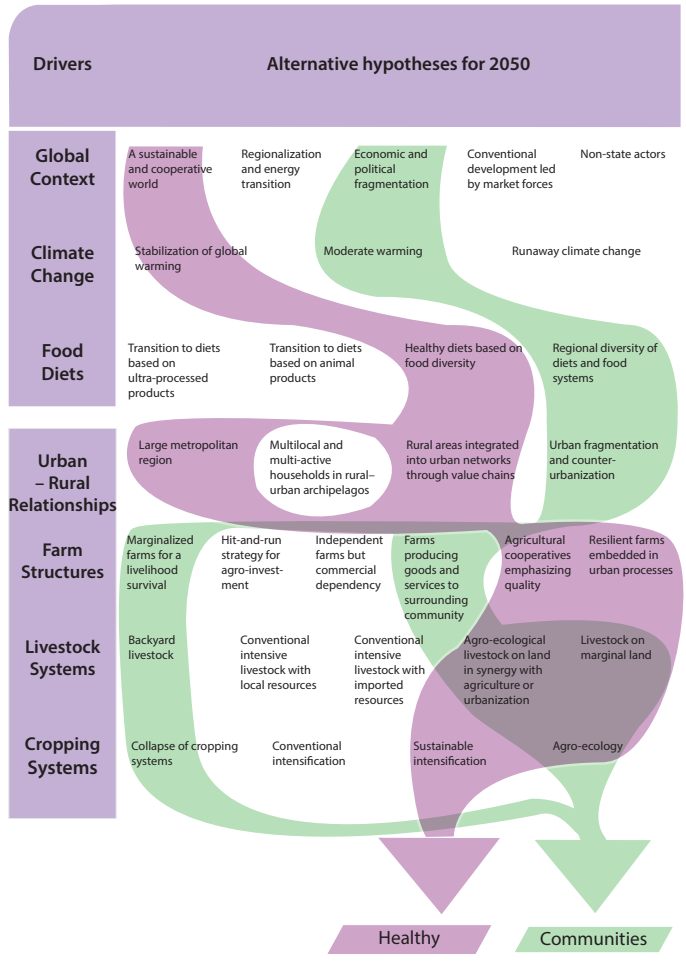
Worldwide shifts in land use reflect this crop diversification, limiting globally the expansion of the agricultural area. Most regions have seen a decrease or a stabilisation in their arable land area. But three regions, where in the past consumption levels of animal products were inadequate, have experienced an expansion of agricultural land (Fig. 6) with an increase in arable land in West Africa and India, and a major increase in the pastureland area of East, Central & South Africa.

As a result of the mixed cross-sectoral policies reshaping food markets and agriculture, global diet is much healthier than 40 years ago. The increase in unhealthy food consumption has been halted, and undernutrition has decreased due to food diversification and better resilience of farm systems. International trade has remained significant (Fig. 11) and has strengthened in importing regions such as the Near and Middle East and North Africa, Sub-Saharan Africa and the Rest of Asia, with products coming from exporting regions such as North America and to a lesser extent the EU 27 and Former Soviet Union.

Land as commons for rural communities in a fragmented world ["Communities" scenario]

In 2050, simultaneous financial, energy, ecological and geopolitical crises have shaped a world situation that is fragmented not only politically, but also economically. States have reduced public expenditure to basic functions. Unemployment increased thereby impeding metropolitan growth. This process slowed down population and economic concentration in large urban areas, generating an urban de-concentration. Reduced migration from rural to metropolitan areas has led to the growth of smaller towns and fragmented urban development. Rural populations have increased in South Asia, Sub-Saharan Africa and Oceania where birth rates remain high. By 2050, food supply chains in urban areas are based on formal and informal markets providing staple foods and on networks between urban communities and rural ones.

Figure 7. Alternative combinations of hypotheses describing scenarios of land use and food security by 2050



Urban and peri-urban agriculture provides incomes and food for poorer urban households, especially women active in markets. Faced with this situation, two evolutions have prevailed (Tab. 1).

In order to cope with the multiple crises, in some places farmers have succeeded in organizing themselves within their community to develop agro-ecological farms (variant "Agroecology"). Cooperation and collective management have served to co-construct and manage common land to provide sustainable production of foodstuffs, energy and environmental services. Agro-ecological agriculture is regarded as both an agricultural system based on biological self-regulation and a central element of the food system and of social organization, ensuring the food sovereignty of rural and urban communities. Synergies between communities have been developed to relink livestock and cropping systems and therefore to improve soil fertility management and ensure self-sufficiency in animal feed.

In other places, where farmers failed to organize themselves, subsistence farming has developed against a backdrop of declining farm sizes resulting from the growing rural and farming population and the absence of economic development in urban areas (variant "Collapse"). The process of conventional intensification in cropping systems encountered two types of pitfall, depending on the region and access to inputs: over-exploitation of the soil and over-intensification of small-scale farming generating strong adverse impacts on the environment. These processes have generated collapse and stagnation in cropping yields (Fig. 10).

By 2050, changes in land use are highly diversified from one region to another, according to the different challenges they face (energy, climate, soils and water) and the collective ability of farmers to bring about a transition to agro-ecology in their community. Through self-governing institutions and local food systems, local communities ensure a certain level of food and nutrition security in an extremely negative global context by turning to agro-ecological practices. Conversely, due to the vulnerability of technical systems and the lack of a resource management strategy, regions with subsistence farming face repeated instances of food insecurity and have contributed to deforestation.

These evolutions have increased the pressure on agricultural land especially when the collapse pathway prevails. In this case, North America, Brazil/Argentina and Oceania have expanded strongly both their arable land and pastureland, as well as the Rest of Asia, West Africa, ECS Africa and India (Fig. 6). But the levels of trade dependency in the regions have been maintained (Fig. 11). The consequences for food and nutrition security vary. Undernutrition is still significant, especially in regions where calories availability remains low such as India and ECS Africa (Fig. 9).

LESSONS ON LAND USE AND FOOD SECURITY FROM THE SCENARIOS

Ensuring world food availability in 2050 will involve expanding the world's agricultural land area to the detriment of forests, but with major differences between scenarios

Most Agrimonde-Terra scenarios lead to an expansion of the world's agricultural land area (Tab. 2). Hence, according to our hypotheses, the land-using effects of increased world food consumption (following increased world population, either reinforced or alleviated by changing food diets) tend to exceed the land-saving effects of increased performances in world agricultural production (following increased crop yields and improved livestock feed-to-output ratios).

However the extent of ***world agricultural land*** expansion varies widely across scenarios. It is particularly high for scenarios involving either stagnation of crop yields and deterioration of livestock production performances (+2 billion ha or +41% for "Communities with collapse") or a huge increase in animal product consumption (+1.3 billion ha or +27% for "Metropolization with animal products"). It is far more limited, even close to zero, for scenarios involving either reduced calories availability in food regimes (+142 million ha or +3% for "Communities with agroecology") or a limited increase in consumption of animal products joined with the substitution from ruminant to monogastric meat in meat consumption (+ 29 million ha or +0.6% for "Healthy with agricultural technology C" and -54 million ha or -1% for "Metropolization with ultra-processed products").

All Agrimonde-Terra scenarios, apart from "Healthy with agricultural technology C" (Healthy_C) imply an ***enlarged cropland area*** at the world level (Tab. 2). The higher the share of animal products in food diets, the larger the expansion of the world's cropland area (+620 million ha or +40% for "Metropolization with animal products", Metropolization_Animp). The lower the increase in crop yields or the improvement in livestock feed-to-output ratios, the stronger the need for cropland area at the world level (+555 million ha or +36% for "Communities with collapse"). It is interesting to note that the "Metropolization with ultra-processed products" scenario (Metropolization_Ultrap) induces a significant increase in the world's cropland area (+243 million ha or +16%). In practice, in this scenario, we have assumed a steady process of substitution of ruminant with poultry meat in food diets. Hence world poultry meat consumption and production increase significantly (+201% in 2050 compared to 2010), requiring more feed and contributing to the rise in the world's cropland area needed. This adjustment mechanism is particularly marked in regions such as India or ECS Africa and, to a lesser extent, West Africa where the share of meat in food diets is particularly low in the initial situation, so that transition in diets even when based on ultra-processed products induces a significant increase in meat consumption (Fig. 9). On the contrary, it is also interesting to note the "cropland saving" nature of the scenario "Healthy" (from -56 million ha in the variant C to +50 million ha in the variant D). In this scenario, the increase in world production and consumption of meat and animal products more generally is limited because of both the decrease in daily calories available per capita in most regions and the substitution of pulses for animal products in regions where the share of animal products in food diets is initially high (developed and emerging regions, see EU 27 for example in Fig. 9).

In most Agrimonde-Terra scenarios, the change in the world's agricultural land area is mainly explained by ***the change in the world's pastureland area*** (Tab. 2). Once again, the lower the increase in crop yields or the improvement in livestock feed-to-output ratios, the larger the world pastureland area in 2050 (+1.46 billion ha or +43.5% for the "Communities with collapse" scenario). The higher the share of animal products in food diets, the larger the world pastureland area required (+698 million ha or +21% for Metropolization_Animp). The "pastureland using" nature of the "Regionalization" scenario (+517 million ha or +15.5% for "Regionalization with agricultural technology B", Regionalization_B) partly relates to the higher share of small ruminant meat in food diets involved in this scenario. Because in Africa and the Near and Middle East, traditional diets are based on small ruminant meat, the "Regionalization" scenario implies a significant increase in small ruminant meat consumption in these regions. Overall, the small ruminant sector is less efficient than monogastric sectors in transforming feed into meat, so the additional pastureland area required at the world level is significant.

Only the scenarios "Metropolization with ultra-processed products" and "Healthy with agricultural technology C" are able to produce sufficient food for the expected growing population up to 2050 without further major deforestation at the world scale (+11 million ha and -62 million ha forest area, respectively, Fig. 8). Under all the other scenarios, ensuring food availability in 2050 would require large areas of deforestation all over the world. In some cases, deforestation is so huge that the corresponding scenarios may be considered clearly unsustainable in 2050: the Communities_Collapse and Metropolization_Animp scenarios for example.

But one could also question the feasibility of the scenario "Regionalization", which induces significant deforestation: 352 million ha and up to 733 million ha in the A and B variants respectively.

Table 2. Changes in agricultural areas at the world level over 2010-2050 in the different scenarios (million ha and % with respect to base period levels)

	Total agricultural land area	Arable and permanent crops (cropland) area	Permanent meadows and pastures (pastureland) area	Forest land area
"Metropolization"				
- Metropolization_Ultrap	-54 (-1%)	+243 (+16%)	-297 (-9%)	+11 (+0.3%)
- Metropolization_Animp	+1318 (+27%)	+620 (+40%)	+698 (+21%)	-1297 (-32%)
Regionalization				
- Regionalization_A	+249 (+5%)	+70 (+4.5%)	+179 (+5.5%)	-352 (-9%)
- Regionalization_B	+691 (+14%)	+174 (+11%)	+517 (+15.5%)	-733 (-19%)
Healthy				
- Healthy_C	+29 (+0.6)	-56 (-4%)	+85 (+2.5%)	-62 (-1.5%)
- Healthy_D	+269 (+5.5%)	+50 (+3%)	+219 (+6.5%)	-279 (-7%)
Communities				
- Communities_AE	+142 (+3%)	+277 (+18%)	-135 (-4%)	-154 (-4%)
- Communities_Collapse	+2013 (+41%)	+555 (+36%)	+1458 (+43.5%)	-1863 (-46%)

Sources : GlobAgri-AgT

Although more limited, induced deforestation under the "Healthy with agricultural technology D" (Healthy_D) scenario (-279 million ha) puts into question the feasibility of this scenario given that it involves strong mitigation objectives aimed at stabilizing climate change. There is clearly a consistency issue in this Healthy_D scenario between the deforestation induced and mitigation objectives at the world level.

The two scenarios which involve the largest land expansion ("Metropolization" and "Communities with collapse") are also those where the political context leads to unsecure access to land. In the first case, farm structures evolve towards "hit-and-run agro-investments" or "independent farms" contracting with agri-food companies. Land expansion will be stimulated by these farm structures, either by renting or grabbing the land of small farmers who will be displaced and may push the agricultural frontier further, or by expanding themselves. In the second case, farm structures evolve towards "marginalized farms" that practice subsistence farming in a degraded environment with high competition for access to land as a consequence of the increased rural population. It will be these farm-type structures which contribute to land expansion and it will not have the same impact on the rural population as in the first case. In the other three scenarios, the political context favours security in access to land and land expansion is more limited.

Ensuring world food availability in 2050 without significant further deforestation will imply a major increase in the performances of agricultural systems in some regions, notably in India, West Africa and ECS Africa

There are three regions where the agricultural land area expands significantly under all scenarios: India, West Africa and ECS Africa. This is not the case for other regions where agricultural land may expand or decrease according to the scenarios (Fig. 6).

Beyond the historical social, economic and political differences between India as a continent-wide country and Africa as a 45 country-continent, there are ***three main factors which explain this specific situation for India, West Africa and ECS Africa.***

The first relates to our hypotheses regarding dietary changes under the various scenarios. These three regions show initial food diets where both the daily calories availability per capita and the share of animal products (especially meat) are the lowest in the world: 2390 kcal/cap/day including 6% of animal products and less than 1% of meat for India; 2663 kcal/cap/day including 3% of animal products and 2% of meat for West Africa; 2225 kcal/cap/day including 9% of animal products and 4% of meat for ECS Africa. Hence, as all our hypotheses about the future of food diets result in increasing up to 2500 or 3000 kcal the daily calories available per capita and increasing up to 10% or 16% the share of animal products for those regions which are below these levels in the initial situation, ***India, West Africa and ECS Africa all experience changes in diets which are little differentiated across scenarios (except for the share of meat in ''Metropolization_Animp") and which induce a rather large increase in the share of animal products in diets*** (Fig. 9). However, in India, due to traditional vegetarian diets, meat consumption remains stable in all scenarios apart from ''Metropolization_Animp" which assumes a huge increase in meat consumption, notably poultry meat; in the ''Healthy" scenario, Indian consumption of animal products is replaced by consumption of pulses.

Strong population increases over 2010-2050 are the second factor explaining the specific situation of India, West Africa and ECS Africa. West Africa and ECS Africa are the two regions where the population is expected to increase the most in the world: +192% and +155% respectively. The expected population increase is lower in India (+45%) but remains very substantial in absolute numbers given the current size of the Indian population.

The combination of these first two factors implies huge consumption increases, notably for animal products, in the three regions in all scenarios. In this regard it is interesting to emphasize the contrasting positions of India and China regarding diet and population change on the one hand, and the resulting expansion in agricultural land on the other. In contrast to India, the Chinese population is expected to stop growing and remain stable from 2010 to 2050. Furthermore in the case of China where the share of animal products in daily caloric availability is initially 19%, our hypotheses for the future of food diets result in stable or decreasing daily calories availability per capita as well as a fall in the share of animal products in diets in all scenarios except Metropolization_Animp. Hence it is not so surprising that while both regions are initially already using nearly all their cultivable area (Fig. 2), in most scenarios China experiences a reduction in its agricultural land area while India expands its agricultural land area (Fig. 6) and is increasingly constrained by its cultivable area.

The third factor explaining the specific position of India, West Africa and ECS Africa is ***the rather weak performance of their agricultural production systems in the initial situation.*** This third factor is particularly significant in the two African regions (e.g., Fig. 10) where the acceleration in the growth of crop yields and in the improvement of livestock feed-to-output ratios, which is assumed in most scenarios, closes only partially the initial gap observed with the average performance of developed and emerging regions. Other factors should be considered such as population density, irrigation capacity and agrarian systems.

Therefore it is not surprising that all three regions are among the largest contributors to the expansion of the world's agricultural land area in all Agrimonde-Terra scenarios (except the "Metropolization" one), either through an expansion of the cropland area (India and West Africa) or through the expansion of pastureland (ECS Africa). As a direct consequence, it is no surprise that all three regions are also among the largest contributors to world deforestation observed in most Agrimonde-Terra scenarios (Fig. 8). Hence, it is clear from Figure 8 that under our quantitative hypotheses, all of our Agrimonde-Terra scenarios are unsustainable for India, West Africa and ECS Africa, which would all experience a severe reduction or even disappearance of their forest area.

In other words, given the strong expected population increase in West Africa, ECS Africa and, to a lesser extent, India and assuming that promoting healthy diets in these regions would require a significant increase in consumption, especially animal products consumption, ensuring world food availability in 2050 without major deforestation around the world would certainly require limiting the expansion of the agricultural land area in these regions either by increasing imports or through improving the performances of their agricultural production systems, especially livestock production systems.

Increasing Indian, West African and ECS Africa imports would make it possible to save some agricultural land area, avoiding some of the deforestation in these regions. Such an adjustment would not induce more deforestation at the world level provided that the available agricultural land in other regions is sufficient for producing these additional imports. ***Increasing the agricultural performance of Indian, West African and ECS African production systems, particularly livestock systems, would be also a land-saving lever***, making it possible to reduce deforestation. Our hypotheses on the future of cropping and livestock systems result in a sharp improvement in performance of the agricultural production systems in the three regions, especially in the African ones, in most scenarios.

Figure 8. Changes in forest land areas in the different scenarios (in million ha with respect to 2010)

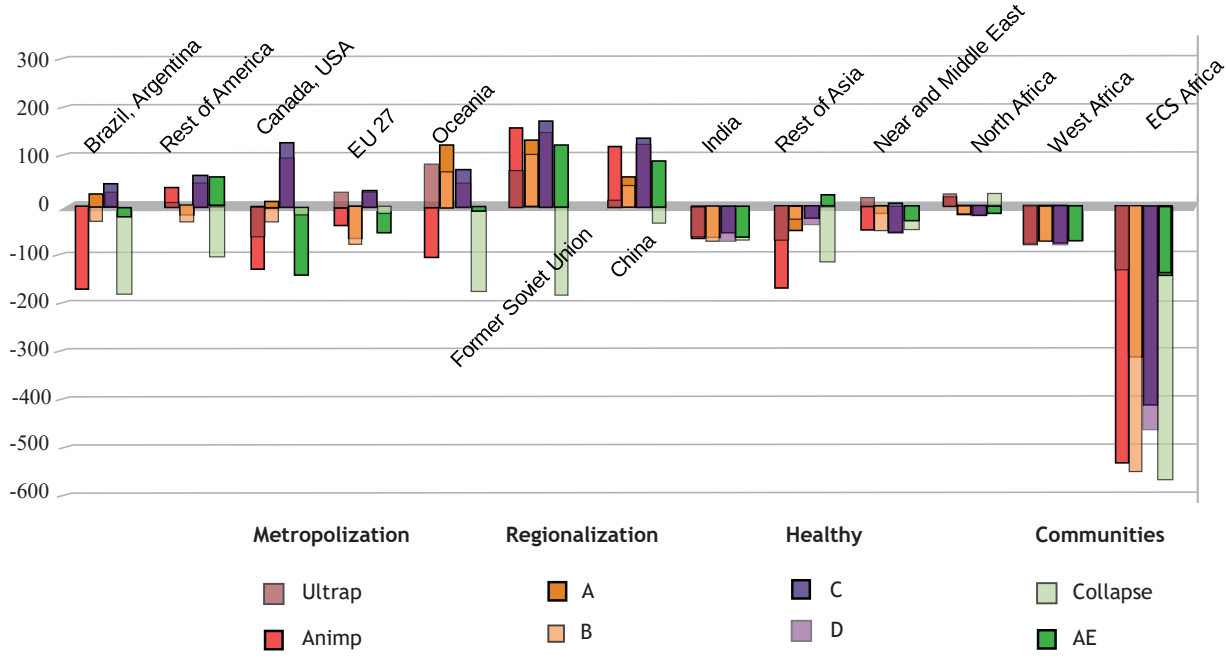


Figure 9. Regional food diets in the initial 2010 situation and by 2050 under the various hypotheses for the future of food diets(kcal/capita/day)

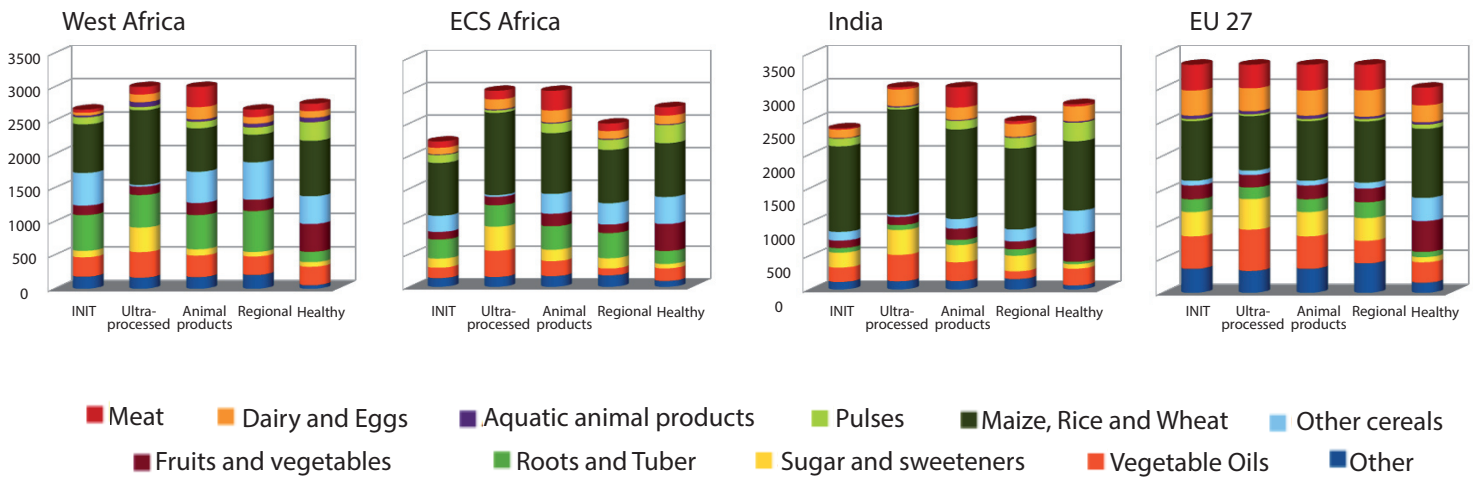
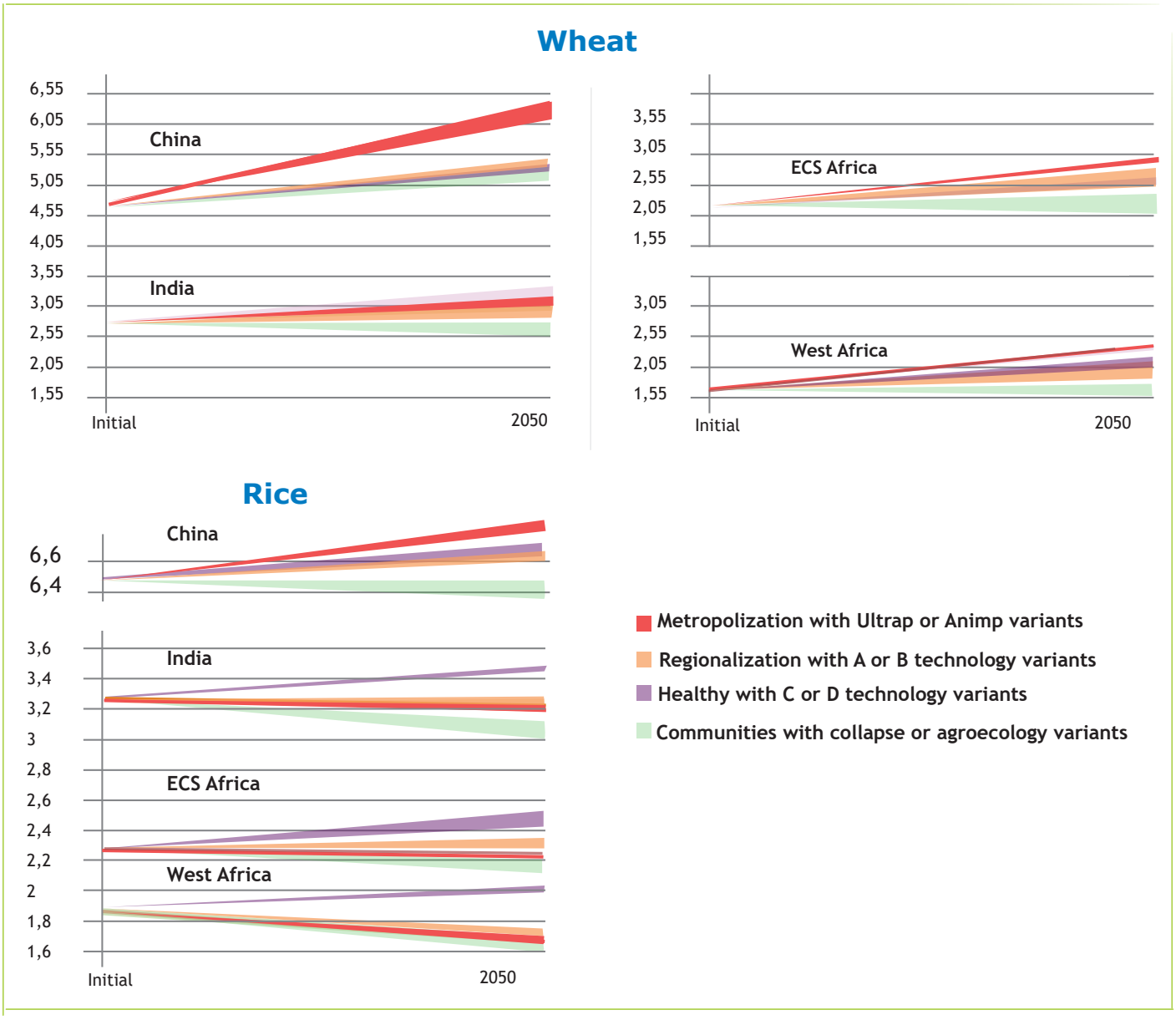


Figure 10. Regional wheat and rice yield in the initial 2010 situation and by 2050 under the various hypotheses for the future of cropping systems (tonne per hectare)



There is, however, significant uncertainty regarding the potential for increased performance in all three regions.

Let us underline at this stage that West Africa and ECS Africa are the two world regions exhibiting the lowest initial performances in terms of livestock feed-to-output ratios, especially in ruminants. For instance, in the initial situation, the feed-to-output ratios of the mixed systems in the dairy sector and in the beef sector in the two African regions is 5 (dairy sector in ECS Africa) to 15 (beef sector in West Africa) times higher than those of the EU 27 (one of the world's best performers in dairy and beef meat production). This means that producing 1 tonne of dairy or bovine meat in ECS Africa or West Africa requires 5 to 15 times more dry matter feed than in the EU. Of course, there are great uncertainties regarding the initial livestock feed-to-output ratios data, notably in West Africa and ECS Africa. There are also significant uncertainties regarding the room for manoeuvre in the two regions for improving these feed-to-output ratios. To this regard it is worth noting the roles of livestock in West and ECS Africa (and in India) where mixed crop-livestock systems and pastoralism are very common and livestock provide nutrient-rich food products but also draught power, organic manure and domestic fuel; livestock also serve as a source of income, as a means for capital accumulation and insurance against income shocks, generate employment and play a role in the security of territories. Despite huge uncertainties, one may assume however, notably on the basis of literature and experiences, that there exist rooms of manoeuvre for improving livestock feed-to-output ratios in all three regions.

Whatever the scenario, international trade will play a key role for ensuring world food availability in 2050

World trade increases in all scenarios, apart from "Regionalization" (Fig. 11). Unsurprisingly, "Metropolization" is the scenario inducing the highest increase in world trade (from 2010 to 2050, world exports in kcal would increase by +151% under the variant "Animal products" and by +71% under the variant "Ultra-processed products"), while the "Healthy" and "Communities" scenarios result in far smaller rises (from +20% to +30% according to scenarios and variants). In contrast, the regionalization of food systems involved in the "Regionalization" scenario logically leads to a reduction in world trade (-15% in both variants).

Beyond these global figures, the ***Agrimonde-Terra scenarios lead to far different world trade configurations and positioning of regions in international trade*** (Fig. 11). "Metropolization" relies on international trade and specialization. Hence in this scenario, world agricultural production concentrates both on a few products and in the few of the most competitive regions. Regions with lower comparative advantages become more dependent on imports. In such a situation, ensuring world and regional food availability requires increased trade flows between exporting and importing regions. In "Metropolization" agricultural production and exports are clearly concentrated in Brazil/Argentina and Canada/USA, two regions benefiting from large area of available cultivable land. In contrast, North Africa, the Near and Middle East, India, West Africa and ECS Africa experience dramatic rises in their agricultural imports, increasing their dependence on world markets to ensure their food availability. Interestingly, one will notice that concerning exports, the concentration process is more marked in the "Animal products" variant than in "Ultra-processed products".

In the "Animal products" variant, Brazil/Argentina and Canada/USA share the leadership on world agricultural export markets because they are the both largest exporters of animal products and feed ingredients. In the "Ultra-processed" variant, both regions must share the leadership on world agricultural export markets with the Rest of Asia due to the significance of this region in palm oil exports and the central role of vegetal oils in the diet based on ultra-processed products.

World trade also increases under the "Healthy" scenario but to a significantly lesser extent and without the concentration process specific to "Metropolization". "Healthy" is one scenario allowing net importing regions to alleviate the increasing trend in their food import dependence, in addition with higher quality standard for products on international markets. Reducing the dependence on international trade is part of the spirit of "Regionalization" but world trade would be far from finished and would continue to play a key role regarding food availability.

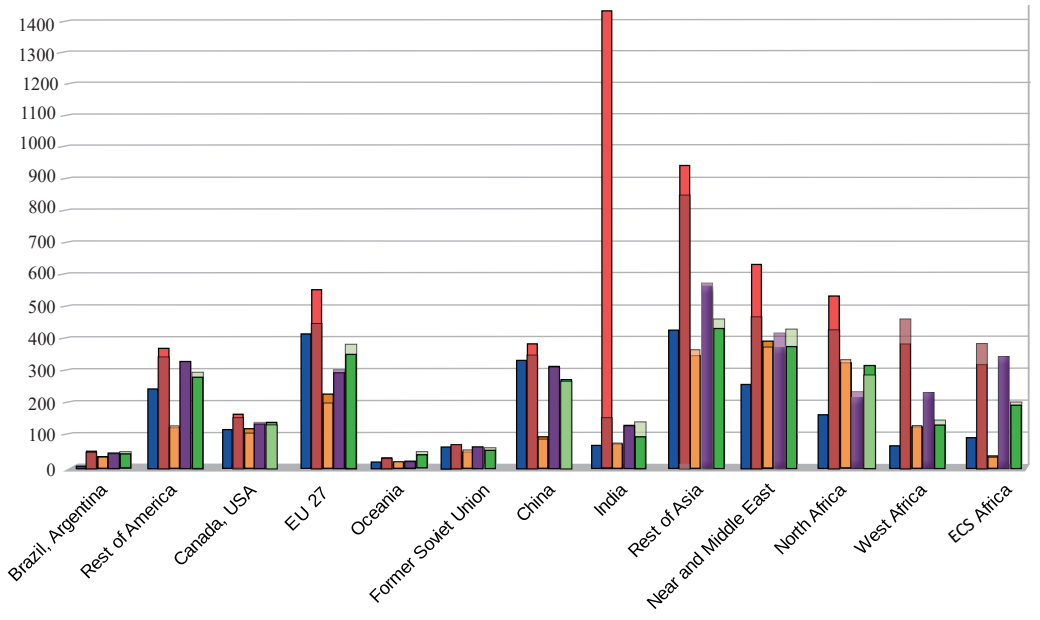
According to our hypotheses, some regions are likely to become highly dependent on imports for their food whatever the scenario. This is clearly the case for ***North Africa, as well as the Near and Middle East,*** with both regions initially strongly dependent on imports, a situation which worsens in all scenarios. This also seems to be the case for ***West Africa*** and to a lesser extent ***India***. These four regions experience strong population growth pushing up food demand, but are either constrained or almost constrained by their cultivable land area, which limits the potential for an increase in domestic production in most scenarios. In this regard, the almost 80% net import dependence that North Africa reaches in the "Metropolization" scenario (meaning that in 2050 80% of North African food needs are covered by imports) is due, at least partly, to the loss of half its cultivable area induced by the strong climate change hypothesis involved in this scenario.

In all scenarios, apart from "Regionalization", India and West Africa would experience a significant increase in their import dependency, which is often double or even four times greater than in the initial situation. Both these regions have small reserves of cultivable land for meeting the increase in domestic consumption. Hence they start to increase their imports. The case of India under "Metropolization" whereby food diets change towards an increased share of animal products is particularly striking: facing the upper limit of cultivable land, India starts to import both feed ingredients (essentially maize and cakes) and monogastric meat.

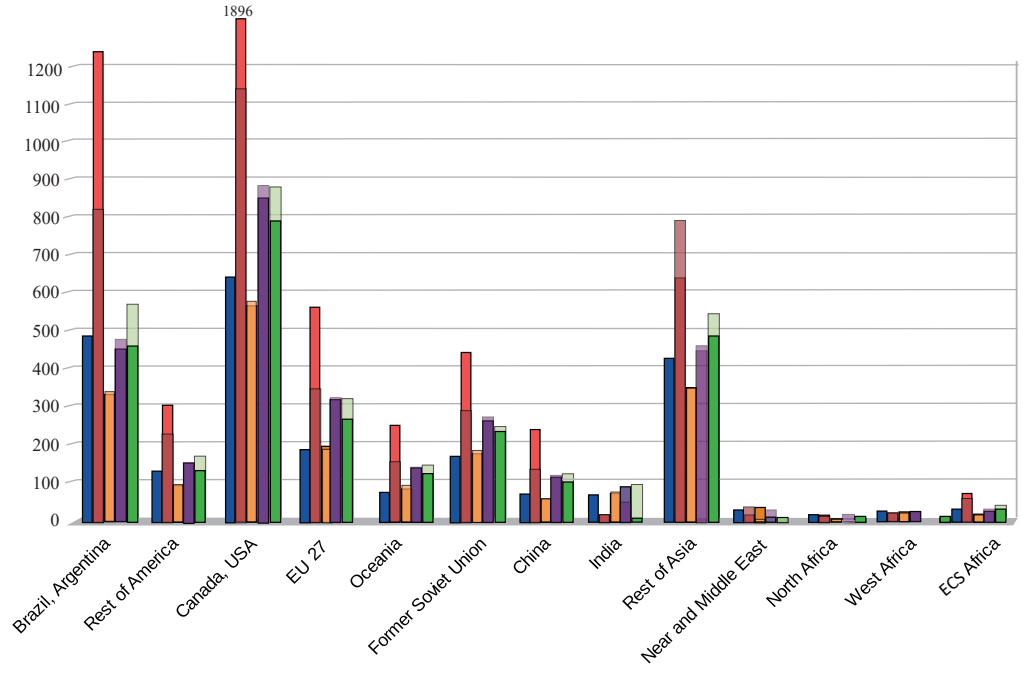
Over-reliance on food imports can increase the risk of disruption to supply and access caused by global production fluctuations and price volatility, as well as trade wars. Over-reliance on food imports also places a significant burden on state budgets.

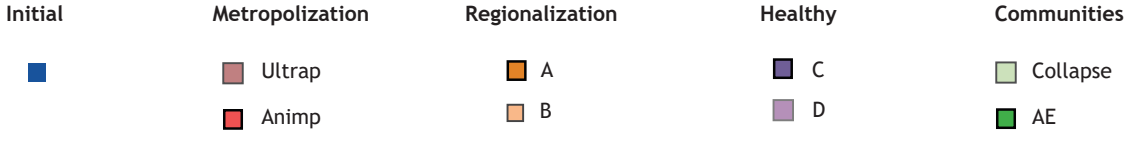
Figure 11. Agricultural trade in the initial 2010 situation and in 2050 in the various scenarios (in 1000 Giga cal)

11a. Gross agricultural imports



11b. Gross agricultural exports





Increasing food and nutritional diversity towards healthier diets in 2050 while limiting agricultural land expansion and deforestation will require changes in cropping and livestock systems towards greater diversification

Among Agrimonde-Terra scenarios, two involve increased food and nutritional diversity in 2050: the "Healthy" scenario and, to a lesser extent depending on regions' traditional diets, the "Regionalization" scenario. According to our hypotheses, both these scenarios lead to an expansion in agricultural land and further deforestation at the world level, but to a very different extent depending on the scenarios and the variants within each scenario.

First of all, ***increasing food and nutritional diversity through the "Healthy" scenario would use significantly less land than increasing food and nutritional diversity through the "Regionalization" scenario*** (Tab. 2 and Fig. 6). In addition to the differences between the "Healthy" and the "Regional" food diets (Fig. 4 and 9), implying differentiated changes in the regions' food consumption of various products, the decrease in inter-regional trade in the "Regionalization" scenario also contributes to greater land use. By favouring the substitution of imported products with local ones, the "Regionalization" scenario also leads to increasing production in regions which are less productive, resulting in a greater requirement for agricultural land at the world level. All in all the land-use changes induced by both scenarios exhibit significant discrepancies, the "Regionalization" scenario achieving increased food and nutritional diversity at a far greater cost in terms of the global expansion of agricultural land area and deforestation than the "Healthy" scenario: + 249 million ha agricultural land (+70 million ha cropland and +179 million ha pastureland) under Regionalization_A and +29 million ha agricultural land (-56 million ha cropland and +85 million ha pastureland) under Healthy_C for instance.

Secondly, among the possible development paths for cropping and livestock systems, the A and C variants would demand significantly less land than the B and D variants whatever, the scenario. This is not surprising and is closely related to the adopted quantitative hypotheses, which make changes in crop yields up to 2050 more favourable in the variants Healthy_C and Regionalization_A than in the variants Healthy_D and Regionalization_B, the same being observed for the average livestock feed-to-output ratios in the "Regionalization" scenario only (Tab. 1). Beyond the quantitative hypotheses which may be questioned, given the lack of empirical evidence on input-to-output performances of crops and animals in agroecological systems compared to conventional systems, both scenarios suggest the ***unavoidable need to for the appropriate diversification of cropping and livestock systems (mainly regarding the composition of animal rations) together with an increase in food and nutritional diversity if we wish to limit the expansion of agricultural land and deforestation around the world.***

An illuminating illustration is the situation of Brazil/Argentina in both scenarios. In Brazil/Argentina, the increased food and nutritional diversity involved in both the "Healthy" and the "Regionalization" scenarios (as well as the reduced inter-regional trade in the latter) contradicts the development path the region had previously adopted, at least for an important chunk of its agriculture: openness on international markets, simplification of production systems and specialization in products at the heart of the nutritional transition (vegetable oils, sugar, poultry meat). Hence these scenarios would lead to tremendous changes for Brazil/Argentina's agriculture, which would experience a decrease in agricultural land area (from -5 to -12% according to variant and scenario) following the -25% ("Healthy") or -50% ("Regionalization") decrease in domestic soybean production, the -10% decrease ("Healthy") or quasi-stagnation ("Regionalization") in domestic production of sugar plants and products and the quasi-stagnation in the production of animal products in both scenarios. Of course, given the assumptions in the scenarios, the production of some diversified products would increase substantially (nearly +350% increase in fruits and vegetable production in the "Healthy" scenario; nearly +150% increase in roots and tubers production in the "Regionalization" one) and, according to our quantitative hypotheses, their yields per hectare as well. This faster increase in per hectare yields of diversified products (resulting from induced technical change) avoids an expansion in agricultural land in Brazil/Argentina in both scenarios. Hence, these results suggest that ***for some regions, such as Brazil/Argentina, increasing food and nutritional diversity all over the world would imply huge changes in their production systems and a total redesign and adaptation of production systems aimed at diversity.*** This could take some time and in the meanwhile it is likely that following increased food and nutrition diversity, agricultural land would expand in these regions.

Only the "Healthy" scenario is likely to be able to ensure world food and nutrition security in 2050

Among the Agrimonde-Terra scenarios, at least two are clearly not able to ensure sustainable world food and nutrition security in 2050: the "Metropolization" and the "Communities" scenarios, notably under the "Collapse" variant. Furthermore, two have ambiguous results: the "Regionalization" and the "Households" scenarios. Only the "Healthy" scenario seems likely to be able to meet the objective of world food and nutrition security in 2050.

Box 2. Global regionalized land use scenarios and their impact on food security: The case of Sub-Saharan Africa (SSA)

As for all the world's regions, the Agrimonde-Terra team conducted a retrospective analysis of the direct and the external drivers of land-use change and of the food security situation. Qualitative experts' analyses and quantitative data[1] gave complementary insights. The analysis not only revealed intra-regional differences but also common challenges for the land-use system, which are highlighted below:

** The population of SSA, the last of the world's regions to make its demographic transition, will double between 2010 and 2050. SSA has also the highest urban population growth rate in the world (3.6% per year), with an increasing number of metropolitan areas, new emerging large cities as well as networks of regional smaller towns. Most cities are characterized by insufficient basic infrastructure, particularly in low-income areas, and high proportion of slum dwellers.*

** In SSA, besides pastures (34% of the total area) and forests (28% of the total area), arable and permanent crops represent 9% of the total area. There are still vast amounts of land that are not used intensively, especially pasture areas, degraded soils, and primary forests or forests which are barely exploited. The rights of land users are not properly secured; much of the land in rural areas may be formally owned by the government but with complex combinations of property rights and users' rights. Competition for land is growing –sometimes leading to land grabbing– in a number of countries, especially Sudan, Mozambique, Tanzania, Ethiopia, Madagascar, Zambia, and DRC.*

** Agriculture in SSA accounts for about one-third of the gross domestic product, but since it involves 65% of labour force, it will play a key role in development. Agricultural productivity is low; input use is low; over 95% of its area is cultivated under rain-fed conditions; fallow practices for regenerating fertile soil are disappearing; and infrastructures are insufficient. Farmers with two hectares or less represent 80% of all SSA farms and contribute up to 90% of the production in some SSA countries. These evolutions put heavy burdens on cropping and livestock systems which need to become more productive while neutralizing soil degradation and facilitating the adaption of agriculture to climate change.*

** Import dependency for agricultural products is increasing.*

** SSA is affected by undernutrition and there are simultaneously emerging overweight problems. Over the past 10 years, the calorie intake levels from cereals have increased, while calorie intakes from animal products and fruits and vegetables have remained constant at a lower level than the recommended intake. Thus, for healthier diets, consumption of these products must increase.*

** The weakness of many public institutions and of agricultural policies impairs the sustainable development of agricultural production, the evolution of farm structures and organizations, as well as access to education, health, clean water and agricultural services in rural areas.*

With the support of the Scenario Advisory Committee, the Agrimonde-Terra team identified the on-going trends and weak signals in SSA related to each of the Agrimonde-Terra scenarios (Tab. 3) and found out that no dominant pathway(s) toward a specific scenario in SSA could be singled out because of the diversity of situations.

Table 3. On-going trends and weak signals in SSA related to each Agrimonde-Terra scenario

Metropolization	Regionalization	Households	Healthy	Communities
- Development agencies promote liberalization and privatization. - Increased land grabbing in some countries. - Little state sovereignty and increased food imports. - Economic growth linked to exports of natural resources. - Deforestation, land degradation by foreign enterprises in Central Africa. - Growing over nutrition	- Active regional and civil society organizations. - Autonomy in energy sources (fuel reserves, hydropower). - Consumption of local foods and hunted animals. - Informal trade between countries. - Farmers' knowledge of natural resources management. - Agroecology promoted through participatory approaches.	- Inefficient governmental services in most countries. - Development agencies, foundations, NGOs, academic institutions and multinational firms are all active in SSA and form networks. - Agricultural families depending on off-farm incomes.	- Democratization process in some countries. - High potential for renewable energy (hydropower, solar, wind, biomass). - Potential for carbon sequestration. - Networks of cities, especially in West Africa. - Growing investments on irrigation. - Assisted natural regeneration to restore degraded forests. - Mixed farming systems form the backbone of agriculture and provide most of staples food.	- Political instability and poor governance in some countries. - Mostly unsecure land and property rights. - Conflicts over resources. - Agriculture, fruit picking, hunting, forest management are major sources of revenues and employment. - Active communities, especially in West Africa. - Low yields.

Ensuring food and nutrition security will require systemic analysis and will thus differ from one country to the other. Agrimonde-Terra indicated that the following drivers of the land-use and food security system are of particular importance for SSA stakeholders when considering land use and food security at regional or national levels:

*• **Food diets:** The diets of the 'Regionalization' and 'Healthy' scenarios (Fig. 9) point to the need to increase the consumption of animal products (meat, dairy, eggs and aquatic products), fruits and vegetables, pulses and local cereals. Strong public policies and consumer mobilization as in the 'Healthy' scenario and the reconfiguration of food supply chains and value chains as in the 'Regionalization' scenario could play an important role.*

*• **Cropping and livestock systems:** In both West Africa and ECS Africa, the two variants in cropping and livestock systems of the 'Healthy' and 'Regionalization' scenarios (Tab. 1) lead to the smallest increases in arable and permanent crops (Fig. 6.a). However, it is not the case for permanent pastures (Fig. 6.b) which increase less with the 'Metropolization' scenario with ultraprocessed diets and conventional intensification. In any case, the resulting challenges in crop and livestock productivity and efficiency will have to take into account the special role of livestock in SSA production systems as discussed in the lessons from the scenarios. They reveal the need for further research on cropping and livestock systems.*

*• **Urban-rural relationships:** In the coming period of demographic transition, the spatial evolution of the population will be very important. The overwhelming concentration of population and activities in large cities will drive the 'Metropolization' pathway whereas integration of rural areas into urban networks through value chains contribute to the 'Regionalization' and the 'Healthy' scenarios, and multi-active households in rural-urban archipelago contribute to the 'Households' scenarios.*

*• **Political, economic and social contexts:** In the future, some local SSA communities could continue to innovate in the 'social wild' as in the 'Communities' and 'Households' scenarios. If land tenure is still insecure, there will be evictions of small farmers as in the 'Metropolization' scenario. The reinforcement of land institutions and policies (for example, regulating access to land, security of transhumance pastoralism, farmers' access to agricultural services, setting up producers' organizations and cooperatives) could change the pathway to the 'Regionalization' or 'Healthy' scenarios.*
Regarding the major challenge of generating employment, scenario analyses identified opportunities through growing territorial markets ('Regionalization') or food exports of healthy products ('Healthy') and multiple activities and mobility ('Households').

1. FAO (2009) report entitled "How to feed the world in 2050. High Level Expert Forum. The special challenge of Sub-Saharan Africa" considered that only 2 of the 44 countries in Africa have high standards in data collection.

"Healthy" is the scenario which contributes most to reducing not only overnutrition and related diseases, but also undernutrition. This is also the one scenario allowing world food availability to be achieved at the cost of a rather limited expansion in agricultural land area at the world level. There are some regions, however, where promoting healthier diets induces an increased consumption of animal products, such as in India, West Africa and ECS Africa. In these regions, even the "Healthy" scenario is likely to induce an expansion in the agricultural land area and significant deforestation. As the "Healthy" scenario also involves a strong commitment from governments, corporations and international institutions to mitigating climate change, requiring the production of renewable energy and the maintenance of world forest cover as far as possible, there are potential tensions between the objectives of food security and climate change stabilization, resulting in increased competition for land between agricultural and forest uses, and farmers' interests. Agroforestry and farming practices that contribute to improved soil quality and the storage of organic carbon in soils (thus yield potentials) could be very interesting options in this case, since they simultaneously work towards the objectives of for food security and climate change stabilization.

Conversely, "Metropolization" is the scenario which contributes most to the expansion of overweight, obesity and diet-related non-communicable diseases all over the world, with considerable impacts on public health and economic activities. In setting up a kind of race between changing food systems, increasing yields, deteriorating natural resources and propagating diet-related non-communicable diseases, "Metropolization" induces a series of effects which work against food and nutrition security at various levels. Firstly, as far as food availability is concerned, previous analysis has clearly shown that the propagation all over the world of animal rich-food diets is unsustainable both at the world level and for some regions. However, the expansion of agricultural land area and deforestation could be significantly reduced if transition in diets was based on ultra-processed products all over the world. Secondly, "Metropolization" relies on crop and livestock systems which are sensitive to climate change and contribute to natural resource degradation (notably soil and water). This throws into question the future performances of such systems and therefore world food availability in the longer term. Thirdly, this uncertainty, combined with the international specialization process involved in the "Metropolization" scenario, is likely to result in increased price instability on world agricultural markets, which is likely to put into question the stability dimension of world and regional food security. Fourthly, as "Metropolization" involves increased spatial and economic inequalities, a large section of the rural and urban population is marginalized with poor access to food due to low incomes.

"Communities" is a multi-crisis scenario in which the deterioration in agricultural production performances would create a reduction in food availability at the world and regional level. Because every region needs more land to meet its food needs, there is a struggle for resources, with very serious tensions over land and a degradation of natural resources, including soils. Long-term world food availability is put into question. World food availability and accessibility can be ensured only if communities are able to re-build collectively local food systems based on agro-ecological cropping and livestock systems. But even in this case, the smaller expansion in agricultural land area corresponds to a -10% decrease in daily calories availability per capita in most regions. In developed countries, this reduction in food availability could contribute to reducing overnutrition and related diseases. In developing countries however it could cause increased undernutrition, affecting women and children. In addition, as the "Communities" scenario involves sluggish economic growth all over the world, households are likely to see their incomes stagnate or even decrease and therefore they could face difficulties in accessing food, mainly in urban areas. On the other hand, re-built local food systems could facilitate food access for rural populations as well as contributing to increased food and nutritional diversity through the crop diversification involved in agroecological cropping systems.

The "Regionalization" scenario induces a series of changes that work in favour of world and regional food and nutrition security, but at the same time leads to ambiguous results regarding world food availability. "Regionalization" is a scenario opposing the global convergence of diets towards a few standardized products through the promotion of traditional diets and products. It therefore favours food and nutritional diversity and contributes to limiting the development of diet-related non-communicable diseases in world and regional populations, mostly by reducing the global diffusion of ultra-processed foods. This scenario also involves the development of agri-food industries in small and medium-sized cities acting as intermediaries between rural areas and urban centres. These industries positively affect rural development, rural employment and rural incomes for men and women. Hence "Regionalization" may improve access to food for rural populations. However, "Regionalization" is only able to ensure world and regional food availability at the cost of a significant expansion of the agricultural land area and considerable deforestation at the world level. Land area expansion and deforestation by farmers may even be dramatic in regions poorly endowed with land and sometimes poor in other natural resources (water, for instance) such as North Africa, the Near and Middle East, India and West Africa, or better endowed with land but exhibiting poor agricultural productivity such as ECS Africa. In such regions, the "Regionalization" scenario appears rather unsustainable.

Finally, "Households" appears as an intermediate scenario, contributing to a decrease in undernutrition but with the opposite effects on overnutrition. Changes are induced by a wide variety of actors (groups of citizens, associations, NGOs, enterprises etc.). Regarding food and nutrition security, "Households" is an intermediate scenario which has common elements with three other scenarios. It shares with "Healthy" a major public interest in nutrition, but State regulation is not involved.

It shares with "Regionalization" the idea that local food systems could respond to demands from consumer groups; the food diversification implied could have a positive impact on overnutrition. However, the main question raised by such a scenario is the extent to which changes in demand towards healthier foods from various consumers' groups are able to induce the transformation of food systems, without a regulatory framework. It therefore seems plausible that ultra-processed foods retain non-negligible shares in both food diets and food systems in the "Households" scenario, contributing to an increase in overnutrition.

Finally, "Households" is a scenario in which households use mobility to diversify their sources of incomes, accessing non-farm jobs in urban or rural areas. This income diversification is likely to improve food access and result in reduced undernutrition.

Box 3. Agrimonde-Terra, a tool for dialogue tested in Tunisia

Foresight is meant to lead to change through "a systematic, participatory and multi-disciplinary approach to explore mid- to long-term futures and drivers of change" (FTP, 2014). [1] Land-use' stakeholders are more inclined to become proactive and provoke desired changes for improved food security when they participate in discussions on possible future land use, and when consensus is built around the necessary changes and their interplay. The ability of Agrimonde-Terra's outputs to be used as a 'tool for dialogue' for the construction of national land use scenarios was tested in Tunisia in March 2015. A two-day workshop was organized at the initiative of the Institut National de Recherche Agronomique de Tunisie (INRAT) and part of the Agrimonde-Terra team, with the Syndicat des Agriculteurs de Tunisie (SYNAGRI). Twenty Tunisian coming from the Ministry of Agriculture, the Ministry of Environment, agricultural development groups, farmers' associations, Bizerte agro industrial hub, and representatives from three development agencies participated.

The Agrimonde-Terra land use and food security system and hypotheses were the basis for building land use scenarios specific for Tunisia. The following method was used:

(1) A shared diagnosis of land uses in 2015 in Tunisia. A retrospective analysis prepared by the Agrimonde-Terra team formed the basis for discussions. Land access is marked by inequality and insecurity; there is a dichotomy between smallholder farms (54% of Tunisian farms are less than 5 hectares and access to water, inputs, and credit is limited) and a capitalist model based on land concentration and a high use of agricultural inputs. Agricultural lands are scarcer while food needs are rising due to rapidity in population growth. Net food trade dependency is high (40%) and nutritional quality is falling.

(2) Discussion of the Agrimonde-Terra hypotheses for all drivers and, when necessary, proposals for new ones in order to achieve a better fit with the Tunisian situation.

(3) Construction of Tunisian land use scenarios. Four Tunisian scenarios were built; they share some similarities with the Agrimonde-Terra scenarios. The Tunisian scenarios were entitled: (a) 'Agroecological land use' which is close to the Agrimonde-Terra 'Regionalization' and 'Heathly' scenarios; (b) 'Dual land use' which resembles the 'Metropolization' scenario; (c) 'Use of virtual land' which resembles the Metropolization scenario with the ultraprocessed products variant; and (d) 'Land use for subsistence' which has similarities with the 'Communities' scenario with the collapse variant.

(4) Selection of the preferred Tunisian scenario. On the basis of their expertise, the Tunisian group evaluated its four scenarios by rating possible changes in crops yields, livestock production, use of inputs, autonomy for seeds, employment in agriculture and agriculture-related activities, imports dependency, and growth of agricultural land. The Tunisian scenario 'Agro-ecological land use for territorial food systems' was preferred because it offers more sustainability in land use and food security.

The group recognized however that the Tunisian baseline scenario ('Dual land use') could last until 2050. If the Tunisian government favors food imports, industry and services at the expense of agriculture and rural development, the Tunisian scenario 'Use of virtual land' will develop. The scenario 'Land use for subsistence' will be due to pressure groups' influence on the governance of land-use. Conversely, the Tunisian 'Agroecological land use' scenario will develop if consumers chose healthier diets and local foods, while government look for increased autonomy in food, and agricultural production is targeted to local markets with however some "niche products" for exports, and also attention is given to the preservation of local resources.

The ease of ownership by the participants of the Agrimonde-Terra hypotheses for future evolution of drivers and adaptation to the local situation, as well as their capacity to build their own land use scenarios for Tunisia suggest that the Agrimonde-Terra approach can be a tool for discussion on land use and food security at national or regional levels. One year later, Mohamed Elloumi, from INRAT, stated that "the workshop discussions play a role in the preparation of the national agricultural research strategy for the next two decades" and Leïth Ben Becher, chairman of SYNAGRI declared that "the workshop's outputs are used for discussions on the consequences on a possible agreement between Tunisia and the European Union".

1. FTP (2014). 'A Glossary of Terms commonly used in Futures Studies'. Rome: Forward Thinking Platform.

CONCLUSIONS

The Agrimonde-Terra scenarios show that there is no given pathway to food and nutrition security while simultaneously addressing other major challenges, notably climate change, biodiversity preservation and energy transition. Because the scope of the challenge is complex, with many overlapping and interlinked issues that cut across sectors, territories and actors, changing the course of ongoing trends requires systemic transformation, public policies and consistent actions from a wide range of actors. Each region and each country will have to find its own pathway related to its initial situation, but in coherence with common responsibilities in facing global challenges.

Building global governance for land use and food security implies a cross-sectoral and multi-stakeholder approach

It is crucial to build global governance on land use and food security to prevent food crises, land grabbing and degradation and to mitigate the effects of climate change. Global governance should take into account regional specificities, and involve governments as well as civil society organizations (especially famers' organizations), private companies (from the agroindustry, energy and chemistry sectors), donor agencies and international institutions. Achieving zero hunger and halting the spread of diet-related non communicable diseases while mitigating climate change can only be effective if the existence and experience of the 570 million farms as well as the diversity of the supply chains actors are taken into account, and if all stakeholders recognize the limits of world resources, the need for healthier diets and the necessary socio-technical transformation of agriculture. Collective action and cooperation could give the issue of food security the status of a global public good, as has been done for the environment (climate change and biodiversity).

Changes on both the demand and supply sides are necessary for transition towards diversified and healthy diets and the reduction of waste and losses

Attaining food and nutrition security for all, and especially for the most vulnerable households, implies a transition from current diets to healthier and more diversified diets, as well as a reduction in waste and losses at all stages of the food chain, from field to plate. The evolution of diets will vary according to initial situations, but generally it means more coarse grains, legumes, fruit and vegetables, and less animal products in diets in most regions of the world, with the exception of Africa and India. It also means better quality products which are more nutritious and contain fewer residues from chemical agricultural inputs. On the demand side, public policies, including price and subsidy policies, and education are essential to accelerate progress towards healthy diets and the reduction of consumption waste and losses. On the supply side, farming techniques and work organization should lead to improvements in the use of inputs and to crop diversification, while improving the quality of soils and water, enriching biodiversity and guaranteeing adequate and stable returns on investments. Changes should also target the reduction of production losses in the fields and at the farm gate with minimal negative effects on the environment. Changes in processing (such as the choices made concerning technological processes, additives and ingredients, and packaging), marketing (distribution channels, improvements in labelling with regard to nutrition, and the diminution of marketing pressure for food goods rich in energy, saturated fats, trans-fatty acids, free sugars or salt; gradual redrawing of products), waste treatment and secure contracts between farmers and buyers will also contribute to healthy diets and the reduction of waste and losses.

Future cropping and livestock systems are a cornerstone issue for food security and further research is needed on their economic, environmental and social performances

The economic, environmental and social performances of cropping and livestock systems determine the impact of agricultural activities on food security. Besides the current dominant conventional intensification path, which has demonstrated its strengths and limits, Agrimonde-Terra has analyzed two alternative pathways for cropping systems -"Sustainable intensification" and "Agroecology"- and three alternative pathways for livestock systems -"Agro-ecological livestock", "Livestock on marginal land" and "Backyard livestock"- with different combinations. These alternative systems are clearly subject to controversy; their performances are very difficult to compare because they respond to different logics, with very different outputs and outcomes and a lack of retrospective data; they cannot be reduced to yield or input use levels. However, the five scenarios show that their implementation needs to be examined at the crossroads of four factors: knowledge and investment capacities of farmers and land access, changes in food supply chains and markets, rural development and urbanization dynamics, and ecosystem constraints. The importance of these four factors varies between regions, but pathways for the transformation of agricultural systems are generally driven by factors of different economic sectors, both in rural and urban areas. The transformation of cropping and livestock systems, as a diversified mosaic of pathways, will be embedded into the current dynamics of the transformation of food chains, rural development and urbanization, household strategies and environmental changes and should be based on regional challenges.

The importance of trade and the roles of new actors require a rethinking of its organization

Even if only around 13% of agricultural production is officially traded, multilateral trade seems absolutely essential for national and household food and nutrition security. International trade has evolved and become far more competitive; new financial actors and intermediaries have emerged putting pressure on traditional actors; transport routes and harbours have become strategic for world security; norms and standards are rapidly evolving; governments are increasingly wary of intervening in markets, leaving unresolved the question of how best to address rural market failures. Given these circumstances and the importance of trade for food access and stability and, more generally, global security, it is very important to have discussions about the multilateral trading system to facilitate its evolution towards clear rules and increased openness and transparency and to link trade agreements to environment, food security issues etc.

All the above imply securing access to land for all types of farming structures and caring about rural development

Rural development will depend on the capacity to link up with urban and peri-urban areas and to attract younger generations to become active in farming or in agriculture-related activities. Policies and actions are necessary to secure access to land for all types of farming structures at different geographical scales, to involve rural inhabitants in decision-making about land policy development at national and territorial levels, to protect the "global commons", in other words the land that women, men, indigenous peoples and local communities traditionally use collectively, and to improve legal frameworks for contracts.

Agrimonde-Terra organization

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The scientific coordinators of the thematic workshops:
(i) Francis Aubert (Agro-Sup, Dijon) and Frédéric Lançon (Cirad) for the workshop on "Urban-rural relationships"; (ii) Jacques Marzin (Cirad) and Laurent Piet (Inra) for the workshop on "Structures of production"; (iii) David Makowski (Inra), Florent Maraux and Eric Malézieux (Cirad) for the workshop on "Cropping systems"; (iv) Philippe Lecomte and Alexandre Ickowitz (Cirad) and Philippe Lescoat (AgroParisTech) for the "Livestock systems" workshop.

The steering committee: Pierre Fabre (Cirad), Hervé Guyomard (Inra), Etienne Hainzelin (Cirad) and Bertrand Schmitt (Inra).

For further information

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