INRAE

Role of European agriculture in world trade by 2050

Balancing climate change and global food security issues

Summary report of the study conducted by INRAE - February 2020

Climate change affects agricultural production, with ripple effects on food security, global trade and the environment. Consequences are manifold and, in more ways than one, uncertain. In a shifting geopolitical context, instability could exacerbate as a result of climate change and respective regional contributions to global food security could change while regional agricultural policies and trade strategies could undergo significant transformation.

In Europe as in other parts of the world, agriculture faces the double challenge of having to reduce its environmental impacts while ensuring a sufficient level of production to meet evolving domestic and global demands for agricultural products. Along with changes in the production conditions, significant variation in diets may also affect the demand for agricultural products. Beyond their effect on consumers' health, these transitions could also be significant factors accelerating or mitigating climate change. In this context, the Pluriagri association[1] has mandated INRAE to examine the role that European agriculture could play on global agricultural markets by 2050, given the uncertainty around the consequences of climate change and technological progress on yields, the possible pressures exerted by farmland expansion, and impacts of changes in diets.

This modelling work showed that by 2050, the need for cropland in some European regions – mostly Eastern Europe, Poland and Germany – could diminish compared to current levels due to changes in domestic demand for agricultural products and plant yields. The "land surplus" thus emerging in these areas would, however, be much smaller than that which could appear in the former USSR (and in Canada-USA provided world diets evolve towards healthier patterns). It would also be too limited to offset the significant increase in farmland needs in some regions – including sub-Saharan Africa – with likely detrimental impacts on natural ecosystems. However, this could be an opportunity for Europe, either to develop oil and protein seed crops – thereby reducing its reliance on plant-based protein imports and limiting the deforestation induced by soybean production (especially in Latin America) – or to transition towards agroecological cultivation systems while maintaining adequate production levels to meet demand. There would be a lot less margins left in France, the United Kingdom and in the rest of Europe (North-European countries, Benelux and Ireland). Southern Europe would also likely be limited, with increased water stress affecting yields. Finally, the expansion of permanent grassland areas could limit the wiggle room, in Europe as in the rest of the world.

A biomass balance model to make projections to 2050

This study builds on existing foresight work on global food security trends – carried out by Inra, Cirad, the FAO, the IIASA and the IFPRI[2] – with a specific emphasis on Europe. Although the literature on global food security generally considers Europe as a single entity, this study divided the continent into eight regions to reflect the diversity of European agricultural systems (Figure 1). The potentials of how these agricultural systems evolve, both in terms of their contributions to global food security (proxied by *food availability*) and of the environmental issues associated to the *expansion of agricultural areas* at the expense of natural and forest areas, were examined.

Box 1. Organisation of the study

This study was carried out by INRAE at the request and with the support of the Pluriagri association, following the principles and method set out by INRAE's Directorate for Expertise, Foresight and Advanced Studies (DEPE) for the management of collective scientific assessments. These principles are described in a guide available on INRAE's website[3].

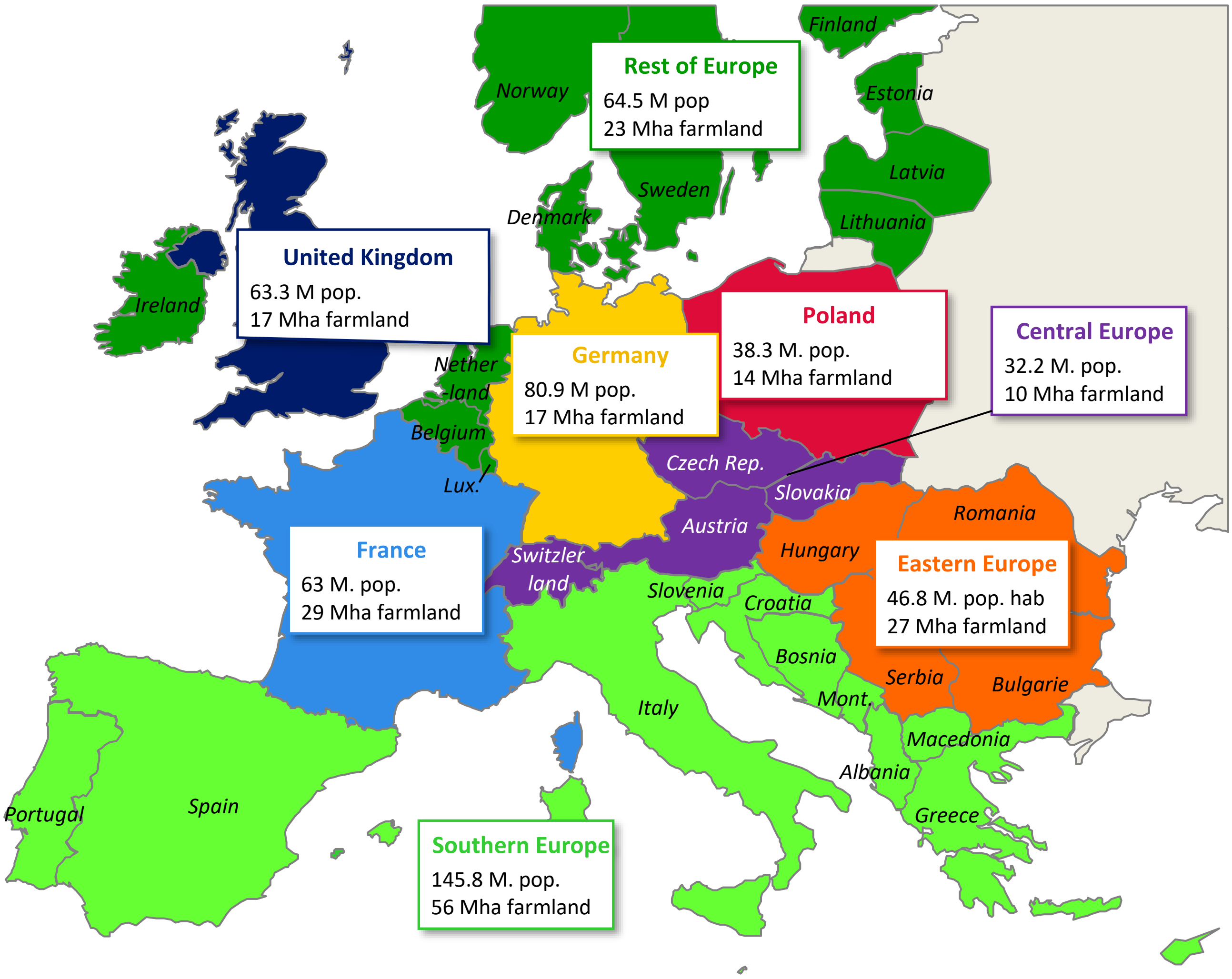
The INRAE project team, with Anaïs Tibi (as project manager), Philippe Debaeke, Hervé Guyomard and Bertrand Schmitt (as scientific leaders), Agneta Forslund and Elodie Marajo-Petitzon (in charge of modelling), led the project. INRAE mobilised a group of some twenty experts and scientific contributors from different institutions and different disciplines (climatology, agricultural and animal sciences, genetics, ecophysiology, pedology, plant pathology…) for the analysis of the international scientific literature. INRAE and Pluriagri also formed a Scenarios group comprising operators and scientific experts, to assist the project team in designing the assumptions for key variables and constructing the scenarios.

[1] Pluriagri is an association formed by some stakeholders of the large crops industry (Avril, confederation Générale des planteurs de betteraves, Unigrains) and Crédit Agricle S.A.

[2] Respectively, United Nations Food and Agriculture Organisation, International Institute for Applied Systems Analysis and International Food Policy Research Institute.

[3] https://www.inrae.fr/en/news/guidelines-collective-scientific-assessments-and-advenced-studies

Figure 1. Composition, population (in millions) and farmland (in million hectares) of the eight European regions



Source: FAOSTAT, 2017

The purpose of the scenarios in this study was not to "predict" the future, nor even to reflect the likeliest trends. Their goal is to identify the wiggle room available to European and global agricultural systems if they are to ensure food security while limiting pressure on natural and forest lands, in a hypothetical world in which the *current* economic, social and political mechanisms would still prevail in 2050.

Based on this general context, which reflects the "middle of the road" socio-economic pathway (SSP2) defined by the IPCC for its 5th Assessment Report[4], the critical variables for the global agricultural and food systems were projected between the baseline year, "2010" (average 2009-2011) and the 2050 projection horizon: the demand for agricultural products (mostly driven by demographics and changes in diets), plant and animal yields, cropping intensity (ratio between harvested and cultivated areas), and cultivable land availabilities. The projections were based on trends of the past two decades, adjusted for uncertainties that may affect these variables in the future.

A series of simulations were made based on these assumptions using a biomass balance model, GlobAgri-AE2050 (*see Box 2*), to translate these scenarios in terms of change in acreage, agricultural production and trade levels for each region. This model, first constructed for the Agrimonde-Terra foresight exercise conducted by Inra and Cirad (Le Mouël *et al.*, 2018) and further developed for the purpose of this study, simulates the balance between supply (production and international trade) and demand (food and feed, non-food needs) for each agricultural product (38 products, including five types of fodder) in the 21 regions considered (including eight regions in Europe).

[4] This scenario is similar to the Representative Concentration Pathway (RCP) 6.0 for greenhouse gas emissions (+6.0 W/m²) radiative forcing for year 2100), or "business as usual".

IPCC: Intergovernmental Panel on Climate Change.

Box 2. GlobAgri-AE2050: a biomass balance model for agri-food products at the global level

GlobAgri-AE2050 is a source/utilisation model for agricultural and agri-food products. For each of the 21 regions and each product (and fodder), the model defines a balance in which domestic production plus imports equal domestic utilisations (food, feed and other uses), plus exports, inventory change, losses and waste. Domestic productions are assessed so as to meet food and non-food demands, plus demand for agricultural products intended for feed. Demand for feed is driven by demand for animal products in human diets and is computed within the model as a linear function of production, combined with changes in animal feed efficiencies (quantity of feed necessary to obtain one unit of each animal product).

Establishing the source/utilisation equilibrium in each region for each product at the given time-horizon (in this case, 2050) will depend on the quantity of available cultivable land in the region. *In cases where cultivable land constraints offer enough flexibility to accommodate any desirable expansion of cultivated areas in 2050,* the model is balanced by equalising, for each product, total sources to total utilisation, in each region and at the global level. Harvested areas are calculated based on productions *via* crop yields. Cultivated areas are obtained by using cropping intensity ratios. Based on defined domestic supply and demands, gross imports and exports can then be computed with the appropriate methods in the model. The dynamics change *when one or several regions reaches a point where arable areas are saturated in 2050* (the need for cultivated areas exceeding available cultivable acreage). In this case, the equilibrium is obtained by first reducing the regions' market share in gross agricultural exports, then, if this initial adjustment mechanism fails to bring the cultivated area in the region below arable acreage, by increasing gross agricultural import rates.

Scenarios incorporating diet changes and factoring in uncertainties on crop yields by 2050

Diet patterns and crop yields, as two of the main variables driving the evolution of global agricultural and food systems, were subjected to different scenario-based assumptions, to assess their weight on farmland needs, agricultural production and global trade outcomes by 2050. Several definitions were also explored for maximum available cultivable areas, used as a constraint in the model[5].

Two alternative assumptions for diets: "trend-based" and "healthy"

Demand for food, which results from a combination of demographic and dietary factors, is the key driver of the domestic need for agricultural products[6]. Echoing the debate on health and environmental impacts of dietary patterns, two alternative pathways were considered, based on the assumptions adopted by the FAO (2012) and in Agrimonde-Terra. Figure 2 shows the change in total global demand for food by 2050 based on those two assumptions.

So-called "trend-based" diets for 2050 are an extension of past regional trends. Individual calorie intakes level off in developed regions and increase in emerging and developing regions. Note that this increase is however too modest to close the nutrition gap in Sub-Saharan Africa.

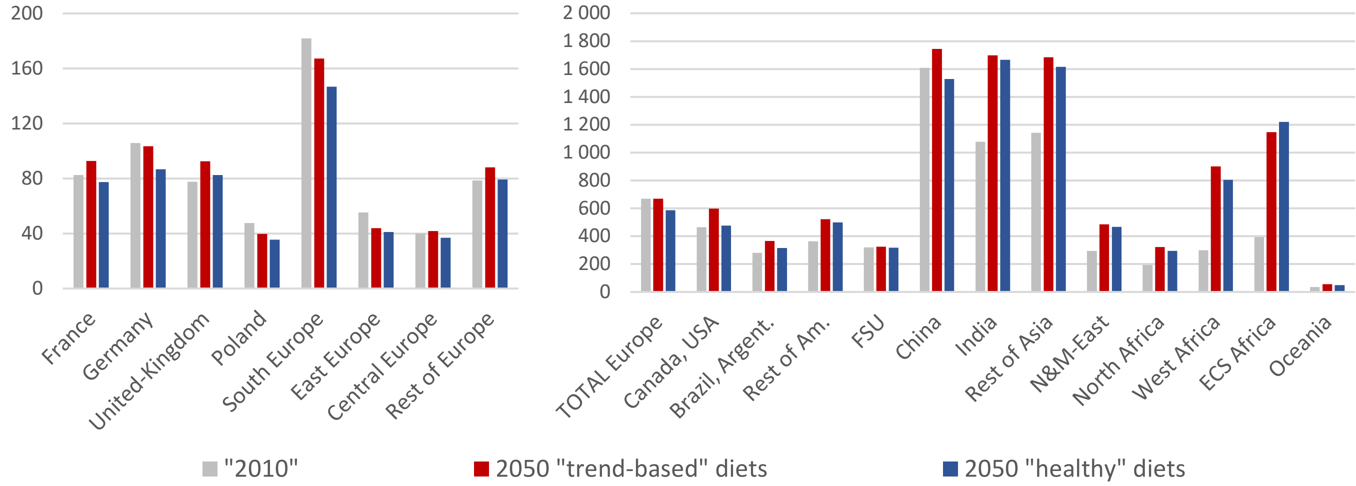
So-called "healthy" diets illustrate a radical and generalised transition towards healthier diets (as recommended by the WHO). These diets are characterised both in terms of meeting daily individual energy needs and of achieving a better-balanced and more diversified diet: consumption of animal-based products would decline in Europe and other developed regions compared to "2010"; it would increase in sub-Saharan Africa, India and, more moderately, in North Africa. With the generalisation of "healthy" diets, regional disparities would diminish whereas they would persist with "trend-based" diets.

No matter what assumption is used for diet outcomes by 2050, food demand in sub-Saharan Africa, India and the rest of Asia would soar, given their demographic dynamics. In most other regions, trend-based development of consumption would lead to an increase in food demand that would be mitigated or cancelled by the adoption of "healthy" diets (China, Canada-USA, Brazil-Argentina). Due to the demographic decline in Poland, Eastern and Southern Europe, Europe's total food demand would plateau in the "trend-based" diets assumption and diminish in the "healthy" diet assumption.

[5] Two additional exercises were performed: one to project the utilisation of agricultural inputs for energy, the other to improve consistency in animal feed efficiency measurement.

[6] Total demand for agricultural products includes animal feed, which derives from food demand, and is therefore an endogenous variable in the model (*see Box* 2).

Figure 2. European (left) and global (right) demand for food in "2010" and 2050 (in TKcal[7])



Incorporating the uncertainty related to crop yields

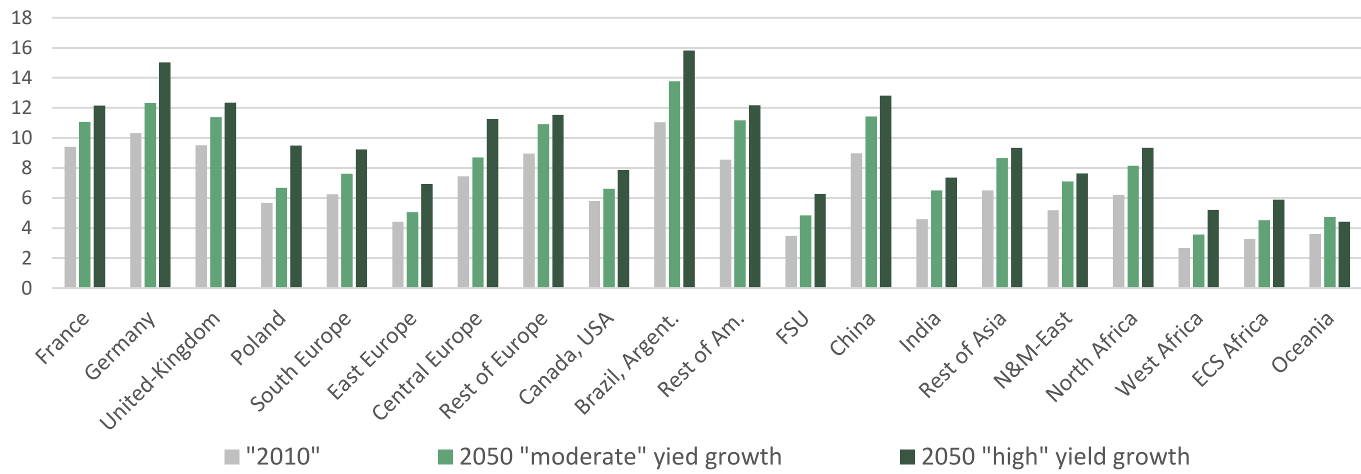
Crop yields, which are drivers of each region's capacity (or incapacity) to cover its needs, are another important parameter in the global food equation in 2050. In this study, the focus was on characterising the uncertainties related to crop yields in 2050, under the combined impacts of climate change and technical evolutions (plant breeding, technological advances, agricultural practices, etc.).

The impact of climate change was estimated through a statistical relationship established based on a meta-analysis exercise consisting of a quantitative analysis of scientific literature (Makowski *et al.*, 2020). It incorporates the effects of changes in annual average temperature, annual average precipitation, and atmospheric CO_2 concentration. Impacts of technical change on yields were assessed based on FAO projections for 2050 (2012, 2018) as part of the FAO's work on global food security.

Two major uncertainties loom over future yields. On the one hand, the dynamics of technical progress until 2050 is difficult to predict. On the other hand, the capacity of crops to benefit from CO_2's fertilising effect "in the field"[8] depends heavily on how well the plants' nitrogen and water needs are met, and on their genetic makeup – and the outcome of those two factors is also challenging to characterise.

To reflect these uncertainties, the simulations were made based on two sets of projections (Figure 3). In the "high" yield growth assumption, with a steady pace of technological progress and plants reaping the full benefit of the CO_2 effect, the slowdown in the average yield growth observed in the past two decades persists until 2050. In the "moderate" yield growth assumption, the rate of technical progress is more moderate, and plants do not benefit from the CO_2 effect.

Figure 3. Average regional yields (t/ha) in « 2010 » and 2050 (all non-fodder crops)



[7] 1 TKcal (for Terakilocalorie) corresponds to 10^{12} kilocalories.

[8] Photosynthesis rates in plants increase with CO_2 atmospheric concentrations.

Minimal effect of climate change on available cultivable areas by 2050

The definition chosen for cultivable areas is important in the GlobAgri-AE2050 model because they are the limiting factor for potential expansion of cultivated areas. The cultivable land availabilities were projected based on the *Global Agroecological Zones* procedure implemented by IIASA and the FAO, factoring in the impacts of climate change on the soils' agro-climatic potential. The definition used in the simulations assumes that an area is cultivable if its agro-climatic potential can accommodate a crop (annual or perennial), no matter how it is currently utilised.

In these assumptions, global cultivable acreage would remain relatively stable by 2050 compared with "2010", hovering at around 5 billion ha, as losses in the two Latin American regions, the three African regions, and Oceania would be offset by gains, mostly in the former USSR, USA-Canada and, to a much lesser extent, China and the "rest of Europe" region.

The baseline scenarios show some wiggle room in certain European regions

For each world region, GlobAgri-AE2050 (see Box 2) assesses the cropland and pastureland needs (i) to meet domestic demand in agricultural products (ii) while, if possible, maintaining export market shares and import rates and (iii) within exogenously defined sets of technical conditions for plant production (yields, cropping intensities), animal production (feed efficiencies), and cultivable area availability. If a region does not have adequate cultivable acreage to meet these conditions, the model adjusts trade levels as needed, first by reducing the region's exports, then by increasing its imports. The resulting change in the region's weight on global markets then reverberates on regions with cultivable acreage headroom. It should be noted that no normative assumption was formulated as to how international trade strategies and alliance might evolve.

Two so-called baseline scenarios, based on the two alternative dietary patterns observed by 2050, were each simulated with the two yields assumptions ("moderate" and "high" growth). The results of these four simulations are summarised below.

The simulations allow us (i) to break down the effects of each variable in the system and (ii) to identify those regions that may have cropland wiggle room or, conversely, those that are at risk of facing tensions in land utilisations, notably when considering the combined evolution of cropland and pastureland needs.

Based on our assumptions for food demand and agricultural supply, and using the fairly flexible definition of maximum cultivable area, the North Africa and Middle- and Near-Eastern regions (which already experienced substantial pressures on land utilisations in "2010") are the only ones that are limited by land availability. This applies to all baseline scenarios simulations. All the other regions have enough cultivable land availability to expand their cropland as needed, including those dedicated to cultivate fodder. As a result, the model estimates production quite "mechanically", disregarding possible adjustments linked to fluctuations in agricultural product prices.

Varying trends in cropland needs across regions

When diets evolve following current trends, simulations suggest that **global cropland need tends to increase.** The amount of this expansion, however, hinges on yields dynamics: between the "high" and "moderate" yield growth assumptions for 2050, it would vary between **+223 and -11 million hectares (Mha) respectively, from the 1 540 Mha of cultivated land in "2010".** These evolutions are consistent with the figures derived from work on global food security, that factor in impacts and challenges associated with climate change (from 0 to +200 Mha from « 2010 » levels, according to the studies considered in the 2017 review by Le Mouël and Forslund). However, these are aggregated values, and the situation varies considerably between regions (Figure 4).

Cropland needs could increase in some regions by 2050, sometimes by a considerable measure. Sub-Saharan African regions are extreme cases, due to the sharp growth of their demand for food, which results from the combined effects of the demographic boom and the closing of the nutrition gap (albeit still incomplete in the « trend-based » diets assumption). Given the current low level of crop yields in these regions, even these optimistic assumptions would be enough to face the surge in demand only at the cost of a considerable expansion of cultivated land (up to a doubling of current acreage in the "moderate" assumption for yield growth). India's situation would be similar but somewhat less acute: the growth of the different components of food demand would be more moderate, hence more easily offset by yield improvements. However, given India's geographic conditions, its need for cultivated areas would come very close to its arable land constraints in 2050, in particular in the "moderate" yield growth assumption. Finally, the two Latin-American regions (Brazil-Argentina and the rest of America), as well as the Rest of Asia (excluding China) and Oceania would also need to increase their cultivated acreage.

Conversely**, in other regions, the need for cultivated land could decrease compared to "2010", creating what can be called "land surplus".** This is the case of the former USSR, which could diminish its cropland by a third, essentially due to its stagnating population.

Both situations could also prevail in Europe (Figure 5). Land surpluses would appear in Eastern Europe, Poland in Germany (and, to a lesser extent, in Central Europe). France and the rest of Europe, on the other hand, would need more cultivated acreage, whereas the United Kingdom would stay at the "2010" level.

The cases of Southern Europe and China, both net importers in « 2010 », should be considered separately. Based on GlobAgri-AE2050, these two regions should reduce their cropland needs compared to « 2010 », while maintaining high levels of imports. However, it is possible or even likely, if economically preferable and provided their water resources allow it, that these regions keep their cultivated acreage at the "2010" level in an attempt to reduce their dependency to agricultural imports.

Figure 4. Cropland needs for each region by 2050 (in millions ha)

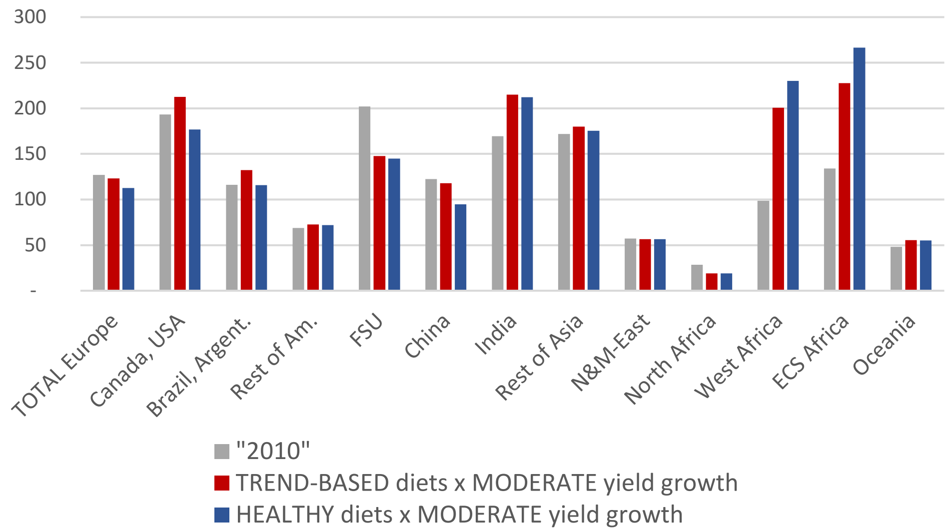
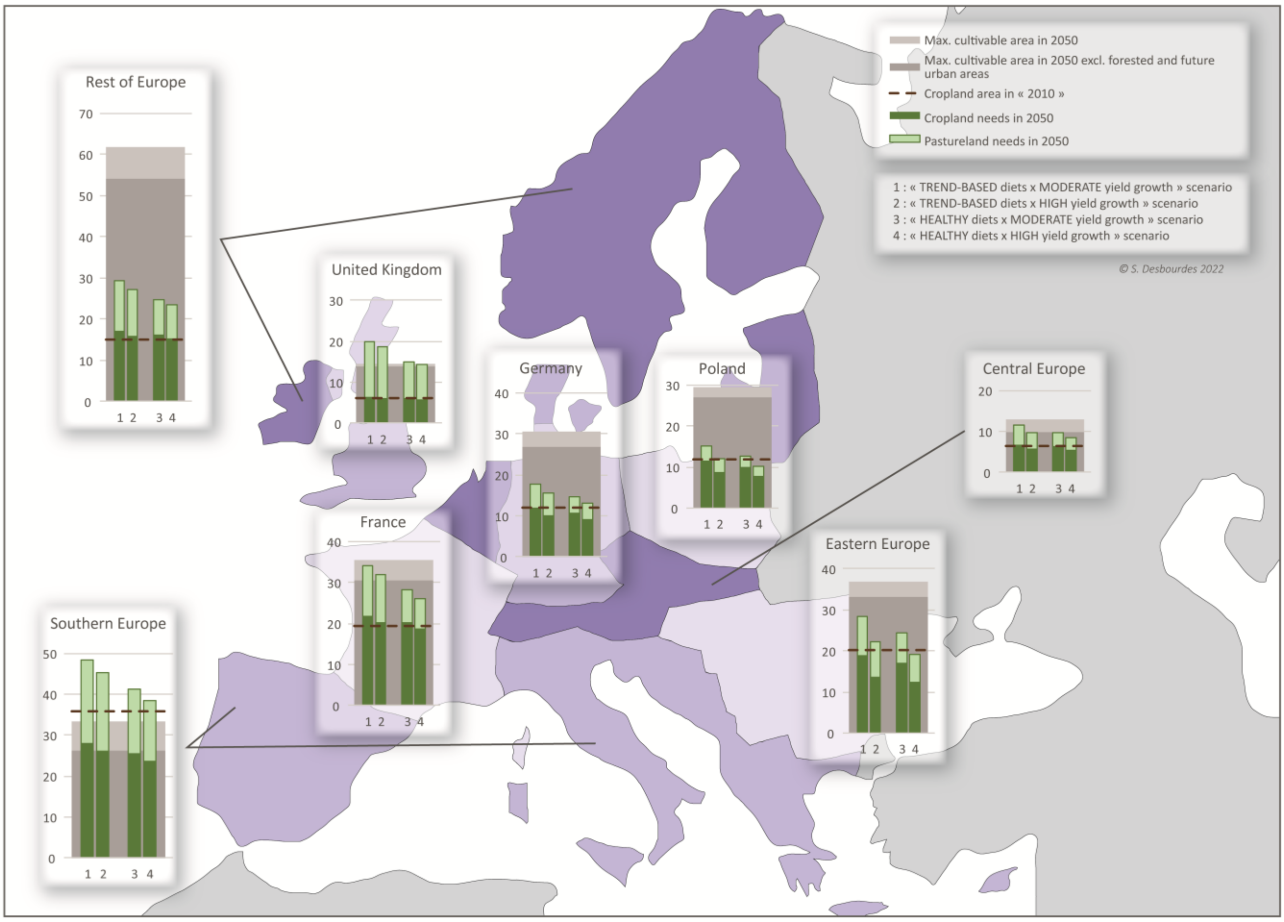


Figure 5. Agricultural area (in million ha) in European regions by 2050 in baseline scenarios



Global trade will grow, participants' positions remaining unchanged

Beyond the growth in agricultural production observed in most world regions in response to the dynamics of the different components of regional demands, **global trade would expand compared to "2010" levels,** reinforcing the positions of regions that were already net exporters in « 2010 » and, mechanically, increasing the reliance on imports of regions that were already net importers in "2010" (Figure 6). This accentuation of net exporters' and net importers' respective positions would be slightly more marked in 2050 if yield growth is "moderate" *vs* "high".

In Europe, all regions will improve their trade positions in 2050 relative to « 2010 »: net exporters will reinforce their positions (France, Eastern Europe); net importers will mitigate theirs (Southern Europe, rest of Europe, United Kingdom); Germany, Poland and Central Europe, will become net exporters in 2050 from net importers in "2010".

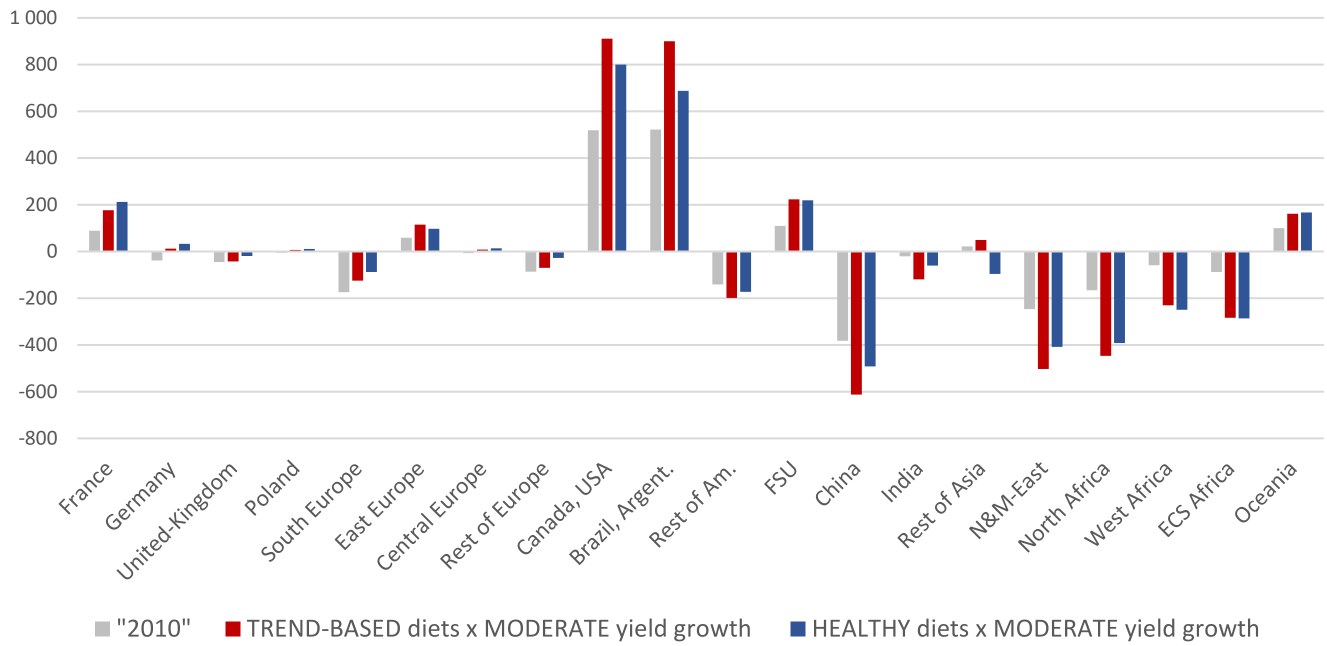
Impacts from the adoption of "healthy" diets at global level

At global level, the adoption of healthier diet patterns would, paradoxically, have little impact on the overall trends described previously for cropland needs. In the high yield growth assumptions, such a change in behaviours and nutritional patterns would however result in **a 51 Mha reduction of cultivated acreage.** Once again, these overall results mask a strong heterogeneity in the evolution of the need for cultivated areas between regions.

In sub-Saharan Africa, where adopting such regimes would require increasing total caloric intake and consumption of animal-based products compared to « trend-based » diets, **the cropland need would further increase** by approximately +50 to +70 Mha compared to the previous scenario, and reinforce food dependency. On the other hand, in other countries such as mostly Canada-USA, China and, to a lesser extent, Brazil-Argentina, the need for **cultivated areas would be reduced** compared to the previous scenario. Adopting "healthy" diets could even allow Canada-USA to join the group of regions likely to have a "land surplus". This is also true for **Europe,** where **all regions would see the emergence of a "land surplus"**.

Under the "healthy diets" hypothesis, as a result of the lesser demand for agricultural products in many regions in the world, there would be a slowdown in production growth and in the reinforcement of historic trade positions observed in the "trend-based diets" assumption.

Figure 6. Net exports (in TKcal) in 2050 with "trend-based" *vs "healthy" diets, combined with "moderate" yield growth*



Reduced cultivable land availability would increase global trade

The definition of cultivable land availabilities used in the baseline scenarios is flexible enough to accommodate ample expansion of cropland in some key regions, such as sub-Saharan Africa, that could experience the highest increases in demand for food by 2050. As a result, there would be no need to increase import dependency rates of these regions compared to "2010". However, the sharp increase in cultivated areas could potentially encroach on natural areas and/or currently forested areas. Such a shift in soil use would increase greenhouse gases emissions and/or affect biodiversity. Complementary simulations excluding currently forested areas from available cultivable area while factoring in the potential expansion of urban areas do not significantly limit the expansion of cropland needs in the most affected regions.

Should any expansion of cultivated acreage beyond "2010" levels be impossible, however, a saturation of the cultivable land constraint at global level would occur by 2050. This could result from international agreements aimed at protecting natural areas and/or from aggravation of land deterioration, a development that was not taken into account in the quantification exercise of available cultivable areas in 2050. Simulations based on such stringent land constraints force regions with the most land needs in the baseline scenarios to rely increasingly on global trade to meet the increased demand for agricultural products, and regions with land surpluses to put them under cultivation and export their "excess" production on global markets.

Assuming a trend-based evolution of diets, the model can only reach equilibrium in the "high yield growth" hypothesis, and with a very significant increase in global agricultural trade by 2050, resulting in a wider gap between net exporting and net importing regions. Under those assumptions, any production increase in sub-Saharan Africa and India would be offset by mobilising all of the global land surpluses identified in baseline scenarios. The reliance of these regions on imports would be accentuated, as would be the case for North Africa and the Near- and Middle East. The other net importing regions in Asia and the rest of America would also need to import more, although to a lesser extent. **Among net exporting regions, Europe would only be a modest contributor to fulfilling global food needs,** compared to Canada-USA, the former USSR (which would quadruple its exports compared to "2010" by mobilising its excess land) and Brazil-Argentina.

What role could Europe play to mitigate impacts of cropland expansion?

As stated previously, if global cultivated acreage in 2050 was not allowed to exceed the "2010" levels, European exports would contribute only modestly to ensuring global food security. Alternative strategies to use its "excess land" would enable Europe to contribute more actively to tackling climate and food security issues. For example, such strategies could aim to **reduce its dependence on imports of certain agricultural products, thus alleviating the expansion of cultivated land in other regions** identified earlier **without affecting global security**.

The 2 to 17 Mha of potential land surplus in Europe[9] identified in baseline scenarios could be used to **develop oil and protein seed crops** to reduce reliance on soybean cakes imports and limit the associated expansion of soybean crops in Brazil-Argentina, which mostly occurs to the detriment of permanent grassland and forests. Soybean accounts for 80 % of European oilseed cake imports in « 2010 » and is used here as a representative example.

The additional soybean cake production on European land surplus – mostly located in Eastern Europe, Poland, Germany, and Central Europe – would amount to 4 to 44 million tons (Mt), depending on the scenarios considered.

Relying on domestic production to reduce European soybean cake imports could thus save 1 to 10 Mha of equivalent cultivated acreage in Brazil-Argentina, compared to 47 Mha of soy-planted areas in "2010" in the region. The best-case scenario, combining « healthy » diets and « high » yield growth, would bring European cakes imports to zero (excluding intra-European trade). Europe would then use only 45 % of its land surplus, or 9 Mha out of the remaining 17, which would then be available for other uses. Beyond this optimal outcome, the development of a combination of protein(-oil) crops would be likelier (soybean, rapeseed, sunflower, protein peas, etc.). Such crop diversification, incorporating pulses, would also further other environmental objectives such as reducing the use of synthetic inputs.

Europe's contribution to limiting land tensions in South America, although substantial, provided crop yields increase steadily, appears modest compared to that of the former USSR and of Canada-USA (assuming "healthy" diets for the latter), whose land surpluses could yield 52 to 132 Mt, and 41 to 123 Mt of soybean cakes, respectively. However, by design, this analysis disregards the conditions necessary for an increase of protein-oil crops to be economically profitable in Europe, Canada-USA and former USSR, given that soybean production costs in Brazil-Argentina are currently very competitive.

[9] Excluding Southern Europe which, it can be assumed, would rather exploit its " land surplus" to reduce its reliance on imports.

Towards less reliance on synthetic inputs in European agricultural systems in 2050?

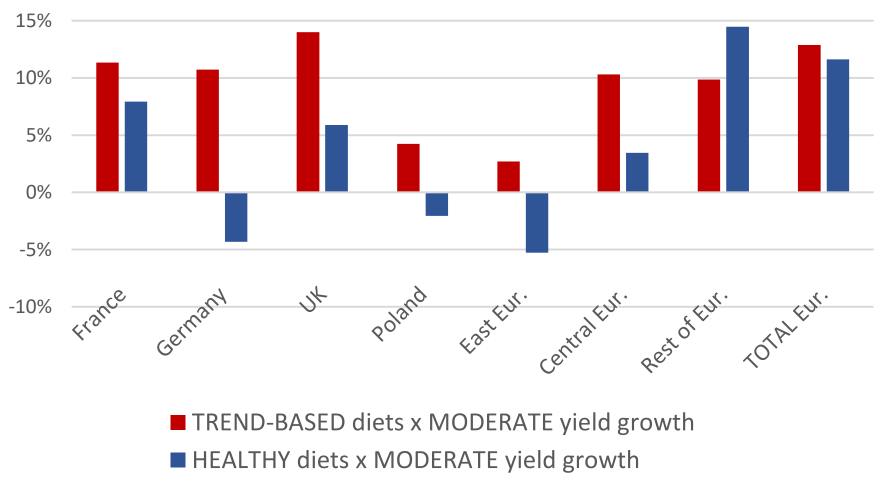
With growing pressures on ecosystems by the cultivation systems currently prevailing in Europe, and faced with societies' evolving expectations towards agriculture, agricultural systems need to become less reliant on synthetic inputs and consume less water, while contributing in the provision of more ecosystemic services. Agroecological systems, although they can facilitate this transition, may not necessarily reach such yields as those considered in the baseline scenarios. Yet, European agriculture needs to reach adequate productivity levels, both to meet domestic demand for agricultural products and to maintain its share in global trade, as global demand is set to soar. Utilising European land surplus for cultivation would be replacing the "yield" lever by the "area" lever, while maintaining production and trade at the 2050 levels estimated in the baseline scenarios. The resulting potential loss in yield represents the wiggle room available to accommodate the transition toward less input-intensive production systems in Europe. This leeway is assessed in relation to the lowest yield levels already incorporated in baseline scenarios (under the "moderate yield growth" assumption)[10].

Cultivating land surplus would create enough space for a 2 % reduction of the 2050 "low" yield levels with "trend-based" diets and a 6 % reduction with "healthy" diets[11]. The increase in average yields compared to current ("2010") levels would then be limited to about 12 % (Figure 7), given that the growth of average yields considered in this study for 2050 in the "moderate yield growth" hypothesis is already very subdued (Figure 7). Once again, these average values mask large disparities between European regions: yield reductions would be larger in regions with more land surplus, such as Eastern Europe, Poland and Germany, where average yields could diminish by as much as 5 %, 2 % and 4 %, respectively compared to "2010" assuming "healthy" diets.

Although Europe appears to have some wiggle room to increase crop yields by 2050, one should not disregard the uncertainty around impacts of the decrease in water resources set to affect in particular France, Southern Europe, Eastern Europe and Central Europe. Factoring in a potential aggravation of water stress during the highest growth period of crops, negative impacts on yields could be worse than in initial projections (which do not include effects of intra-annual variations of rainfall). As a result, the "low" yield levels adjusted further downwards to accommodate both a lesser yield of rain-fed crops and a smaller share of irrigated acreage,[12] would induce need for cropland extension in the four regions, especially in Southern Europe, which would hit its acreage saturation point in the "trend-based" diets assumption. At European level, this could annihilate the land surplus in the trend-based diets assumption and significantly reduce it with "healthy" diets (6 Mha *vs* 14 Mha in the corresponding baseline scenario).

Figure 7. Change in average European yields *vs* "2010" (in %) if "land surplus" are cultivated

Average yields across crops (including cultivated fodder and temporary pastures).



[10] Assuming average yields across crops.

[11] The breakdown of cultivated land between crops (that determines the average yield calculation) differs for different diet assumptions for 2050.

[12] In this scenario, 5 % of European acreage would still be irrigated in 2050, versus 8 % in the baseline scenarios.

Sources of uncertainty and avenues for further research

Several sources of uncertainty could not be taken into account explicitly in the analysis. Each points to a potential research priority. For example, the ability of world agricultural systems to **adapt to the impacts of climate change** by adopting new agricultural practices and breeding improvements, the **evolving pressure from pests**, or the **nutritional quality of harvested produce**.

Yield projections for 2050 incorporate incremental adjustments (for example adjusting sowing dates or using earlier crop varieties) but do not consider **more systemic adaptations of agricultural production systems,** because they could not be qualified robustly for all world regions and their impacts on yields by 2050 could not be quantified. As for **genetic advances**, efforts underway to further explore genetic resources, their diversity, and their relevance to tackle climate change (for example their resistance to drought) suggest that they might help systems to adapt to the impacts of climate change, at least partly. More generally, it would be useful to segregate the respective contributions of the two components of technical change, namely technical progress and use of inputs, to better understand the mechanisms underlying yield levels and, ultimately, assess environmental and health impacts of associated cultivation systems.

Given the number, the diversity of **pests** and their coevolution with climate change and agricultural practices, it appears impossible to predict their impact on yields (crop losses) through synthetic statistical relations, as was done for the climate parameters. A more realistic solution would consist in constructing assumptions for the evolution of major pests affecting key crops and linking them with the evolution of agricultural practices and crop protection measures.

Very recent research suggests a potentially negative impact of climate change, and more specifically of CO_2 concentrations, on **the nutritional properties of harvested plant products,** with lower levels of proteins, of certain trace elements (iron, zinc), and of certain vitamins. It would be of interest to analyse how this impact could be alleviated through measures such as fertilisation adjustment or breeding.

Finally, data robustness remains evidently problematic, despite efforts by the international scientific community. In this respect, let us mention the **weakness of data on cropping intensity** (lack of detailed information per crop and insufficient general data for a given region) and **on areas, yields, and use of fodder both at country levels and** by different animal species (the latter is true for all feed crops).

References cited in this paper:

FAO (2012). Alexandratos N., Bruinsma J. (2012). World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO.

FAO (2018). The future of food and agriculture – Alternative pathways to 2050. Rome, 224 p.

FAO/IIASA (2011-2012). Global Agro-Ecological Zones (GAEZ v3.0). FAO Rome, Italy and IIASA, Luxemburg, Austria. 196p.

Le Mouël C., Forslund A. (2017). How can we feed the world in 2050? A review of the responses from global scenario studies. European Review of Agricultural Economics, 44(4): 541-591.

Le Mouël C. (ed.), Lattre-Gasquet M. de (ed.), Mora O. (ed.). (2018). Land use and food security in 2050: a narrow road. Agrimonde Terra. Versailles (France) : Editions Quae. 398 p. (Matière à Débattre et Décider).

Makowski D., Marajo-Petitzon E., Durand J-L., Ben-Ari T. (*in press*). Quantitative synthesis of temperature, CO2, rainfall, and adaptation effects on global crop yields. European Journal of Agronomy.

ONU (2017). World Population Prospects: The 2017 Revision.

For further information:

Tibi A., Forslund A., Debaeke P., Schmitt B., Guyomard H. (coord.), Marajo-Petitzon E., Ben-Ari T., Bérard A., Bispo A., Durand J.-L., Faverdin P., Le Gouis J., Makowski D., Planton S. (2020). Place des agricultures européennes dans le monde à l'horizon 2050 : entre enjeux climatiques et défis de la sécurité alimentaire. Rapport de synthèse de l'étude. INRAE (France), 159 p + Annexes.

Forslund A., Marajo-Petitzon E., Tibi A., Guyomard H., Schmitt B. (coord.), Agabriel J., Brossard L., Dourmad J.-Y., Dronne Y., Faverdin P., Lessire M., Planton S., Debaeke P. (2020). Place des agricultures européennes dans le monde à l'horizon 2050 : entre enjeux climatiques et défis de la sécurité alimentaire. Rapport technique sur les méthodologies de projection à l'horizon 2050 des variables d'entrée du modèle GlobAgri-AE2050. INRAE (France), 218 p.

Tibi A., Debaeke P. (coord.), Ben-Ari T., Berard A., Bispo A., Charcosset A., Durand J.-L., Le Gouis J., Makowski D., Marrou H., Planton S., Sauquet E., Savary S., Willocquet L., Guyomard H., Schmitt B. (2020). Place des agricultures européennes dans le monde à l'horizon 2050 : entre enjeux climatiques et défis de la sécurité alimentaire. Rapport du volet d'analyse bibliographique de l'étude. INRAE (France), 150 p.

Cover: Vincent Mairy

Directorate for Expertise, Foresight and Advanced Studies
147, rue de l'Université
75007, Paris
Tél. : +33(0) 1 42 75 90 00

Meet us:

https://www.inrae.fr/en/collaborate/expertise-and-support-public-policies

https://www.inrae.fr/en/actualites/agricultures-europeennes-horizon-2050

INRAE science for people, life & earth

Pluriagri