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An agroecological Europe by 2050: What impact on land use, trade and global food security?

Michele Schiavo (IDDRI), Chantal Le Mouël (INRAE), Xavier Poux (IDDRI-ASCA), Pierre-Marie Aubert (IDDRI)

The joint publication in May 2020 of the Farm to Fork (F2F) and Biodiversity strategies, part of the European Green Deal, paved the road for an ambitious and systemic transition of the EU food system. The strategies set ambitious and unquestionable targets that have to be reached by 2030 if we are to keep our food system within planetary boundaries. Since their publication, however, the strategies have been under criticism from most economic actors, according to whom their implementation would lead EU farmers and food processors to be crushed by their competitors and put world food security at risk. Yet, the only impact assessment currently available is the one published in December 2020 by the Economic Research Service (ERS) of the United States Department of Agriculture (Beckman, 2020)—which suffers from several methodological flaws. In particular, it focuses on the consequences of implementing new constraints on production without considering the changes in demand that would result from the strategies' other objectives.

Against this backdrop, this *Study* presents the key results of a research that analysed the implications of an ambitious agroecological[1] transition across Europe, following the TYFA scenario (Poux and Aubert, 2018). While this scenario was published three years ago, what it proposes by 2050 is fully aligned with the objectives that the strategies aim to achieve by 2030, in particular regarding the decrease in pesticides, nitrogen, and antibiotics on the supply side, and the transition towards more plant-based diets on the demand side. Using a world biomass balance model (GlobAgri-AgT, Le Mouël *et al.*, 2018), the impact of the TYFA scenario in the EU on world land use, the EU physical trade balance, the provision of calories and global food security was analyzed in addition to key policy levers to spur the transition.

1 We define agroecology as the combination of the principles of organic agriculture with the redeployment of natural grasslands and the extension of agroecological infrastructures (hedges, trees, ponds and stony habitats)

KEY MESSAGES

Because of the reduction in the consumption of animal protein and the relocation of plant protein production, an agroecological EU outperforms today's system in providing nutrients/calories to the rest of the world, and becomes a net exporter of calories by 12% of what it consumes. Indeed, while today the EU is a major exporter in value terms thanks to high value commodities (ex. spirits, wine, cheese, cigarettes and other high processed commodities) that are not part and parcel of global food security, it is a net importer of calories and proteins by 11% and 26% of what it consumes, respectively.

No sustainable agroecological transition can happen in the EU without strong policies that:

- Support a great dietary transition towards healthier and less calorie-dense diets with less animal and ultra-processed food products;
- Maintain EU price and non-price competitiveness in the domestic and foreign markets through agronomic research, a better coordination between actors and a market segmentation for EU "ecologically intensive" agricultural commodities;
- Change current market conditions to improve EU protein autonomy through the reintegration of legumes in rotations.

STUDY

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LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

1. THE EU NO LONGER FEEDS THE WORLD

Claims that the EU is "feeding the world" with its agricultural exports are no longer tenable, even if they held some truth in the past. Today, the EU is a net importer of calories, it has lost much of its market share when dealing with quantities and remains a major agro-exporter mostly for high-value commodities which little relate to food availability and security.

In the last thirty years, the EU position changed in the world markets. The EU shifted from being a key player in the world agricultural supply to a new situation where this role is shared with traditional players, such as the USA, and new emerging countries showing particularly high potential for agriculture (Brazil, Argentina, Malaysia, Indonesia, Ukraine, etc.). Despite the increase of agricultural production and exports in absolute quantities, EU production and market share stagnated or declined for almost every main exported commodity, meaning that the rest of the world grew at a faster pace. At the same time, after the Uruguay Round (1986-1994), a movement of specialisation took place in Southeast Asia and Latin America. Favoured by greater trade liberalization, the emerging countries in these regions consolidated their position or entered massively in the market of vegetable oils, soya, sugar and poultry meat.

Despite the decline of production and export shares when dealing with quantities, today, the EU is with the USA the main agro-exporting region when considering value. However, of the top-10 exported products, contributing to 44% of total exported value, most are "premium commodities" (ex. spirits, wine, cheese, cigarettes and other high processed commodities) which are bought by wealthy consumers in countries such as Japan, USA, China or Russia. They therefore contribute economically to the EU, but not to global nutritional needs. In addition, in terms of calories, EU is a net importer because of vegetable proteins imports used as feedstuff. Taking its origin in the post-war trade deals between the EU and the USA (Dillon Round), this dependence continues today as a result of unprofitable economic margins for EU growers producing non-genetically modified soybeans and an unsuitable climate in Northern Europe. This unfavourable situation also prevents the EU from closing the nitrogen cycle at a fine territorial level through the (re)integration of legumes in crop rotations.

2. THE AGROECOLOGICAL TRANSITION IN THE EU TO BETTER CONTRIBUTE TO GLOBAL FOOD SECURITY

By way of contrast, our simulation shows that, from a strictly physical point of view, an agroecological EU (Box 1 for a concise description of TYFA scenario) could improve its contribution to the provision of calories and proteins to world market, irrespective of what would happen in the rest of the world—while at the same time restoring biodiversity and natural resources, and greatly reducing GHG emissions from agriculture. This contradicts the recent USDA-ERS assessment regarding the impact of the European Farm to Fork and Biodiversity Strategies on food security (Beckman, 2020) and the vision of many stakeholders such as farmer federations[1] and policymakers.[2]

This result is a direct consequence of two key hypotheses of the scenario that would require significant policy changes to happen (see next section): a reduction of the total amount of calories consumed (in particular calories coming from animal products) and a relocation of vegetal protein production accompanied with a move away from soybean imports. Under the TYFA scenario, the EU can thus feed its own population without expanding its use of agricultural land. While the areas destined to crops such as fruits and vegetables, coarse grains, soybeans and pulses increase substantially, they decline for other crops (wheat, oilseeds).

In terms of trade, while in the EU the share of production oriented to satisfy the domestic market decreases with dietary changes, the exported quantities grow. By 2050, the EU could maintain a similar level of exported commodities as in the business-as-usual scenario. However, this implies a considerable upsurge of absolute exported quantities compared to the initial situation, as the world market size increases in 2050 due to population growth and gradual changing diets in developing countries. Furthermore, because of a lower consumption level and the internalisation of soya production, the EU drastically reduces its imports. Therefore, the EU shifts from being a net importer to being a net exporter of agricultural goods (in calories). However, the EU remains with a marginal role in ensuring the global provision of calories. The share of EU exports is never comparable to the one of Brazil/Argentina or Canada/USA, which remain top exporting regions regardless of the scenario.

1 Coordination rurale (2020). Lettre ouverte aux décideurs français et européens : quelles sont les prospectives de la nouvelle PAC ?

2 https://www.politico.eu/article/epic-battle-over-green-organic-sustainable-farming-divides-eu-departments-green-deal/

Another key result of our study is that the EU agroecological transition does not depend upon the different pathways taken by the rest of the world. The main difference between a scenario combining an agroecological transition in the EU with a business-as-usual scenario for the rest of the world (ALONE scenario) and another one in which the rest of the world also follows an agro-ecological transition and healthier food regimes (TOGETHER scenario) is not the EU land use or the aggregate trade balance, but the composition of the EU exported baskets. Since the rest of the world demand differs between these two simulations, in the first scenario the EU exports relatively more animal products, sugar and wheat, while in the second, the EU exports relatively more coarse grains, pulses, fruits and vegetables.

As far as the rest of the world is concerned, it is also only slightly influenced by the EU agricultural transformations, even if disruptive. For example, in the ALONE scenario, the world agricultural production and land use remain at almost the same level as in the business-as-usual scenario, while exports decrease especially in the oilseed exporting regions because of the reduced EU demand of imported products. Indeed, countries in South and North America and South-Est Asia are the most impacted by the EU changes. Since the EU drastically decreases its imports of soya and other oilseed products, these countries, which are the main exporters of these commodities, reduce their exports relatively to the business-as-usual scenario. However, because of increased world population in developing countries and of the westernization of diets, this level remains similar or even higher than today for products such as soybeans and palm oil showing the rather limited role of the EU in shaping the future of the world agricultural trade patterns.

2. A PLAN FOR THE EU AGROECOLOGICAL TRANSITION

While the agroecological transition is biophysically possible in the EU without expanding the agricultural lands and, at the same time, maintaining or even increasing EU market share, its implementation requires ambitious policy, economic and societal changes. More in detail, policies are needed in order to support a dietary transition towards healthier and less rich food regimes, maintain EU price and non-price competitiveness in the domestic and foreign markets and improve EU protein autonomy.

Changing the current food regimes based on an energy-rich diet with animal products and ultra-processed food commodities (NOVA classification, Monteiro *et al.*, 2017) is a key element for the EU agroecological transition (and from a public health perspective). Only with a vigorous shift in human diets,[3] growers, collectors and manufactures will be ready to accept the challenge and change the existing agricultural production systems. A sign from demand is also needed in order to encourage policymakers to support such a transition with vigorous policy measures which today are often not taken since the risk of losing political consensus is too high. More in detail, promoting the ambitious changes in food regimes envisaged by the TYFA scenario requires a combination of two different kinds of policies: measures to make an agroecological diet appealing to consumers through information and social marketing and government interventions to change the market environment. The nutritional and environmental labelling, the reinforcement of origin indications and the launch of public education campaigns are measures belonging to the first group. Their main asset is the relative simplicity of their implementation, but they risk having a limited effect on influencing the consumer behaviour (Capacci, 2012), especially if they are poorly targeted and not participative. The second group of policies includes subsidies or tax differentiation to food products, regulation of food provision in schools and in workplaces and advertising control in specific media or at certain hours. While these policies could have a greater impact than the ones belonging to the first group, they are also those that arouse the most political opposition as they might be perceived by citizens as an illegitimate limitation of their freedom of choice and could potentially threaten the economic and financial interests of a certain number of actors in the agro-food sector.

A key element for the success of the TYFA scenario is also to maintain EU price and non-price competitiveness. In a current situation already characterized by a decline of EU competitiveness (Wijnands 2016) and a considerable price differential between local and imported feedstuff, the EU could implement an agroecological production system and find itself unable to export its high environmental value products because they are perceived as too expensive by the world consumers. At the same time, the EU could be overwhelmed by cheaper imports coming from regions having lower environmental and GHG emissions standards. This means that the EU should promote agronomic research to increase organic crop yields and reduce their annual variation. The EU should also invest in developing technical references adapted to the pedoclimatic conditions for diversification crops such as course cereals or legumes and for a wider range of varieties inside the same species to enhance intra-crop diversity. Investments are also needed in order to build new storage structures (smaller and more versatile) adapted to the new diversification crops and in sorting equipment to improve the harvest efficiency of crop associations. The EU should also achieve a better coordination between growers, collectors and transformers and segment the market with the help of geographical indications and environmental labelling in order to make the foreign and domestic consumers pay a higher price for EU "ecologically intensive" food products.

Without an effective segmentation in the domestic market, the legislator could impose an artificial one through an increase of tax and tariffs on imported commodities whose methods of production do not comply with the EU environmental standards.

3 In the TYFA report (Poux and Aubert, 2018), the human intake has been estimated at around 2,400 kcal/person/day, while today it is around 2,600 kcal/person/day (EFSA, 2017). In the TYFA scenario, the food waste is also reduced by 10%

This change in trade policies appears particularly important in the sector of protein crops. All model simulations based on the TYFA scenario rely on a golden rule regarding the ban of imported soya in the EU: this aspect becomes compulsory in order to phase out synthetic fertilisers responsible for high greenhouse gas emissions and closing the nitrogen cycle at the finest territorial level. Besides, achieving a better protein autonomy through a domestic production of soybeans and more generally of legumes is in line with the objectives of an increased protein sovereignty declared by various governments at the EU level.[4] However, under constant market conditions, a boost of the protein crops sector is difficult to take place. For good environmental reasons, EU farmers are subject to more rigid environmental conditions than farmers in other regions of the world (ex. genetically modified soybeans) and are not allowed to produce crops which are legal to import. Indeed, a period of temporary protection from international competitiveness seems necessary in order to allow a sort of «import substitution industrialization». During this period, the actors in the EU vegetable protein industry could focus on testing innovations, explore new production possibilities and achieve economies of scale. Given the ecological interest of protein crops and legumes specifically, a subsidy policy through the CAP aids could also be effective. For example, the development of agri-environment-climate measures favouring an increase in the share of legumes in rotation can be a solution. Increasing the current first pillar coupled subsidy scheme in favour of legumes should also be considered. Imposing such a policy to EU commercial partners would be a historical overturn of EU negotiating position since the Dillon Round (1960-1961) and without a change in World Trade Organisation (WTO) regulations, it will certainly be challenged. There is also the risk that foreign countries may trigger strong reactions reducing EU premium exports (liquors, wine, cheese, high value food preparations) in consolidated markets (ex. USA) or emerging ones (ex. Brazil). Since in a regime of "artificial segmentation" imports are limited while the domestic production is submitted to high environmental standards, another consequence of such a policy could be the increase of food expenditures for households because of higher prices for staple commodities. If some of them are ready to accept these changes or have the means to adapt, the more modest households could risk finding themselves in a position of increased food insecurity. For this reason, policies such as food stamps directed to reduce the negative impact of higher prices on these people will probably be necessary.

BOX 1: THE TYFA SCENARIO

The TYFA scenario (Ten Years For Agroecology, Poux and Aubert, 2018) abandons pesticides and synthetic fertilizers, phases-out bioenergy crops and vegetable proteins imports, increases the share of legume crops in rotations, redeploys natural grasslands and extends agroecological infrastructures (hedges, trees, ponds, stony habitats) in Europe (EU-27). It also envisages the generalization of healthier and more balanced diets based on nutritional recommendations. This scenario reduces agricultural sector greenhouse gas emissions, limits feed/food competition, stops imported deforestation, restores biodiversity and protects natural resources (soil life, water quality, more complex trophic chains).

BOX 2: THE GLOBAGRI-AGT PLATFORM

Simulations of the TYFA scenario in the EU under contrasting contexts in the rest of the world are carried out using the GlobAgri platform developed by CIRAD and INRA and the GlobAgri-AgT model specifically customised for the Agrimonde-Terra Foresight (Le Mouël *et al.*, 2018). GlobAgri is based on FAOSTAT Commodity Balances. GlobAgri-AgT includes 38 aggregates of agri-food products and covers 14 world regions. The reference year is the 2007-2009 average, and the simulation horizon is 2050. Biomass balance models provide a resource-utilization balance equation for each region and each agri-food product. Facing changing utilization, the model works to balancing resources. GlobAgri-AgT considers 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, the new equilibrium is reached through trade adjustment.

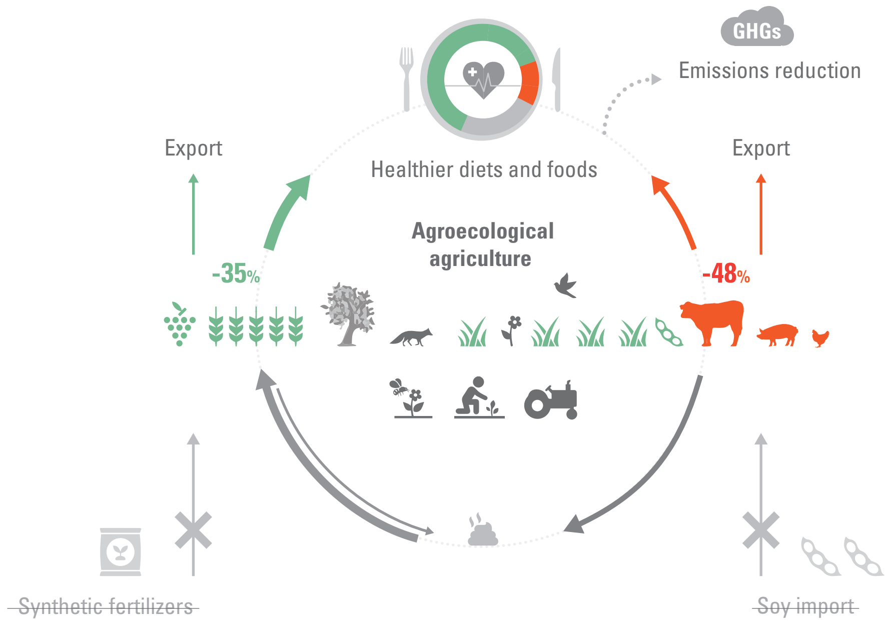
In this study, we coupled TYFA hypothesis for the EU with two contrasting pathways of evolution for the rest of the world borrowed from Agrimonde-Terra foresight (Metropolization_Ultrap and Healthy_AE) (Le Mouël *et al.*, 2018; Mora *et al.*, 2020) to end up with the ALONE and TOGETHER scenarios. Then, we compared the results of ALONE and TOGETHER with the findings of the original Metropolization_Ultrap scenario, which we use as a business-as-usual scenario for 2050. A sensitivity analysis for the hypothesis of changing diets in the EU has also been simulated (ALONE_UltrapEU scenario). It will be discussed in more detail in the full report.

4 https://www.reuters.com/article/us-france-agriculture-idUSKBN28B5I6

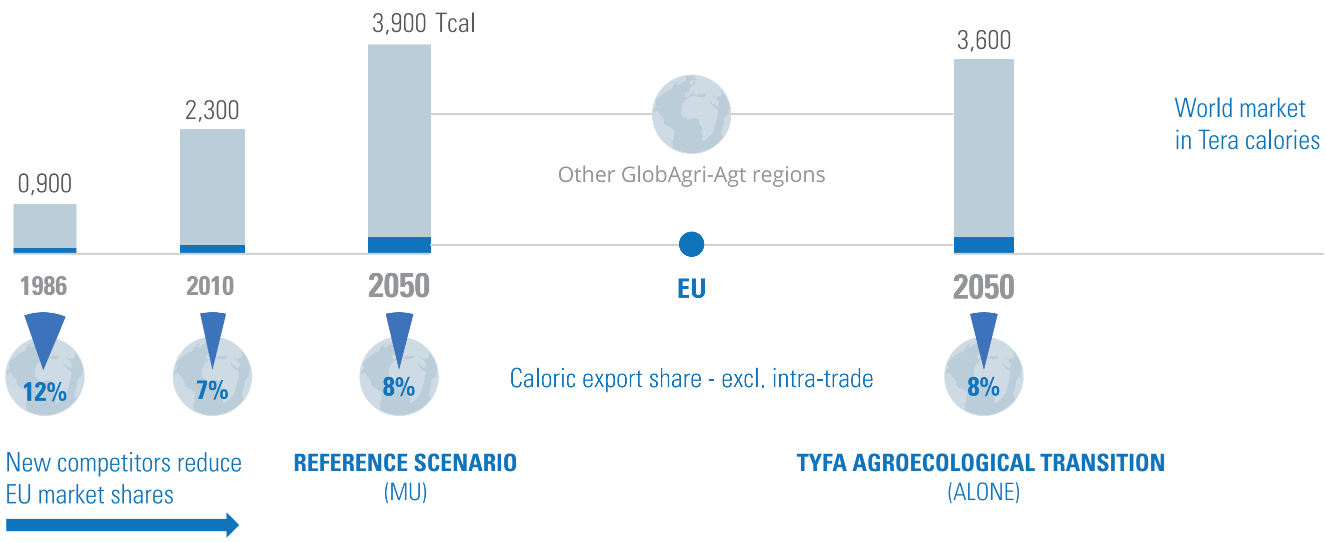
TYFA AGROECOLOGICAL TRANSITION IN THE EU TO BETTER CONTRIBUTE TO GLOBAL FOOD SECURITY

TYFA AGROECOLOGICAL TRANSITION

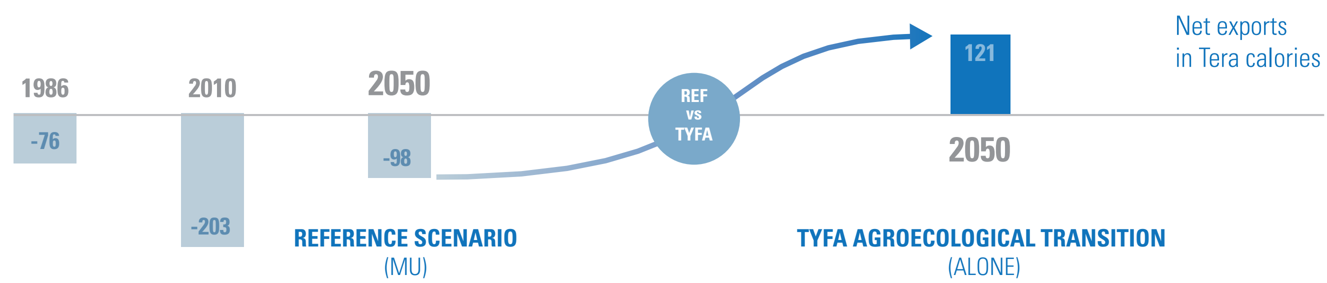
(ALONE scenario)



The EU maintains the same export share



The EU becomes a net exporter of calories



INTRODUCTION

Published in September 2018, the TYFA scenario (Poux and Aubert, 2018) tests the extent to which a large-scale agroecological transition in the EU could be a plausible answer to the pressing environmental and societal challenges the European food system is facing. Based on a biophysical model, it shows that a generalisation of agroecology[1] could feed 530 millions of EU citizens by 2050 under the condition of significant changes in diets.

In a context where food demand is expected to rise sharply by 2050 due to the combined effects of dietary changes and demographic growth[2] (FAO 2018), the TYFA scenario has attracted numerous criticisms regarding its potential impacts on world food security. Today, a multitude of actors such as farmer federations[3] and a large share of policymakers[4] still defends the idea that EU food production levels should be held steady both for the sake of Europeans and also for the sake of people in developing countries (Zahrnt, 2011). The reasoning stems on the (debatable) premise that the EU is today a major contributor to food security and that reducing EU production would necessary lead to a decrease in EU overall physical trade balance.

While those issues were not absent from the set of assumptions that are behind the TYFA scenario, most notably those pertaining to the phasing-out of imported soybeans and the maintaining of surpluses available for export of key commodities such as wheat, dairy products and wine, it is true that the TYFA scenario focused primarily on EU's food system challenges. As such, no specific assumptions were made regarding how the rest of the world could evolve in parallel to the EU agroecological transition.

There is a need to go further and analyse the extent to which the assumptions on consumption, imports and exports in TYFA are consistent with EU land boundary and projected images of the world in 2050. For that purpose, we change perspective by looking at the EU from a global point of view, in order to assess the impacts of the TYFA scenario on:

- The world land use;
- The EU physical trade balance;
- The provision of calories with respect to evolutions in the global demand, and how this might affect food security.[5]

Using a similar approach as Le Mouël *et al.* (2018) and Tibi *et al.* (2020), in this study, we use the GlobAgri-AgT model to simulate the TYFA scenario in EU and alternative pathways of evolution to 2050 for the rest of the world. The GlobAgri-AgT model and the contrasting pathways to 2050 for the rest of the world are borrowed from the Agrimonde-Terra foresight (Le Mouël *et al.*, 2018; Mora *et al.*, 2020).

In a first section, we explore how the EU position in the world market and in the world agricultural production evolved in the last decades. This sets the scene for a better understanding of what the impacts of an agroecological transition in the EU would be on world food availability and global food security. Then, we present the TYFA scenario and the two contrasting Agrimonde-Terra scenarios that are used in this study, and how they are combined to develop four contrasted scenarios—the results of which are presented in a third section. Finally, in the fourth section we provide the key findings issued from the simulation results.

1 We define agroecology as the combination of the principles of organic agriculture with the redeployment of natural grasslands and the extension of agroecological infrastructures (hedges, trees, ponds and stony habitats).

2 Food and agriculture Organization (2018). The Future of Food and Agriculture: Alternative Pathways to 2050. Licence: CC BY-NC-SA 3.0 IGO.

3 Copa-Cogeca (2008). Visions for the Future of Agricultural Policy in Europe: Declaration on the Occasion of the 2008 Congress of European Farmers.

4 Barnier, M. (2008). How Europe should tackle the global food crisis: Europe's World, Autumn 2008.

5 We need to keep in mind that the provision of calories is only one of the four pillars of food security, the three others being: access, utilization and stability.

1. THE EU IN THE WORLD AGRICULTURAL PRODUCTION (1961-2013)

In the last 60 years, the world population and the food regimes changed substantially in almost all regions of the planet along with drastic changes in agricultural production patterns. This led to a reconfiguration of agricultural markets all around the world. In this section, we analyse how the EU position changed over this period and more precisely how the EU shifted from being a key player in the world agricultural supply to a new situation where this role is shared with traditional agricultural "superpowers" (USA, Canada) and new emerging regions (Brazil, Argentina, South-Est Asia, China, Russia, Ukraine).

In the following sections, all the figures present a world subdivision based on the GlobAgri-AgT regions (**Figure 1**). GlobAgri-AgT is the INRA-CIRAD model used to simulate the 2050 scenarios of this study. A general description of GlobAgri-AgT and of its components is given in the Annex 2 of this report.

1.1. A world food demand in rapid expansion

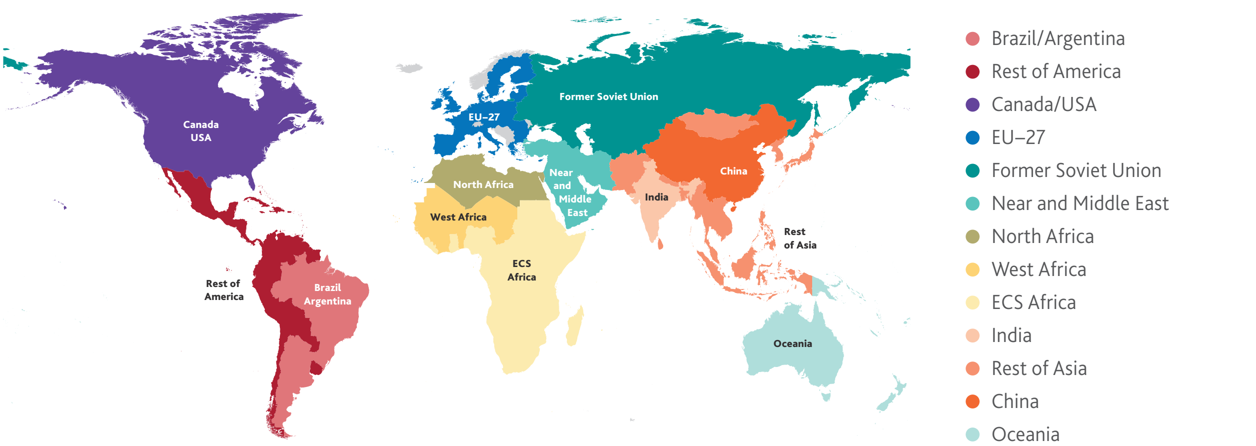
Between 1961 and 2013, the world population more than doubled, rising from 3 to almost 7 billion people. These numbers hide a great heterogeneity between regions. While EU countries increased by 31% their population, the growth rates in Asia, Sub Saharan Africa and South America were significantly higher. High fertility rates combined with a decline in mortality (spread of antibiotics, use of insecticides such as DDT having the effect to bring down malaria, widespread application of sanitation and hygiene measures) pushed these three regions to increase their population respectively by 155%, 308% and 165%. Consequently, EU passed from representing 12% of world population in 1961 to 7% in 2013.

Dietary patterns also evolved during this period. FAO food balance sheets show a worldwide increase in daily calorie availability reaching 2,884 kcal/person/day in 2013, while 50 years before this level was 2,196 kcal/person/day. This increase affected every region in the world, but not uniformly. Pushed by economic growth, developing countries incremented relatively more their caloric intake than developed ones. For example, people in Asia and Africa increased by 54% and 32% their average available calories reaching respectively 2,779 and 2,624 kcal/person/day, while in the EU the increase was only by 14% with the EU population attaining 3,409 kcal/person/day. Focusing on the composition of their food basket, developing countries experienced a westernization of their diets. They increased the share of animal products, sugar and vegetable oils in their dietary plans.

The combination of population growth and dietary changes produced a higher food demand for all agricultural products. **Figure 2** shows how the total use[6] of cereals, milk, meat (especially poultry), sugar and vegetable oils changed during the 1961-2013 period. For almost every product, we can see that the growth in

6 Sum of Food, Feed, Waste, Other uses, Seed, Processing categories in FAOSTAT Commodity Balances.

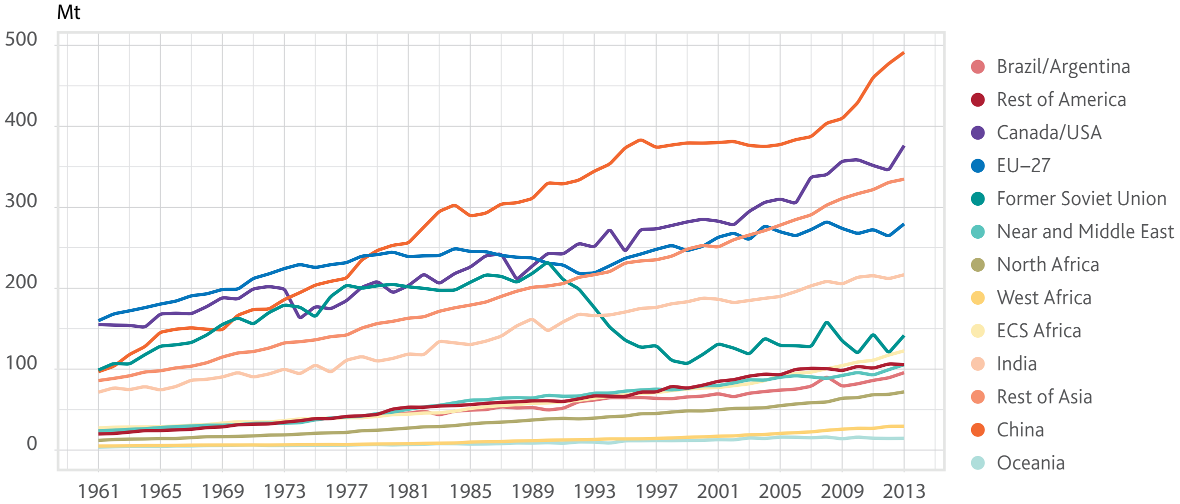
FIGURE 1. The GlobAgri-AgT regions



The Figure presents one additional region called "Rest of Europe" (in light grey) which includes the countries belonging to the physical European region, but not taking part in the EU-27

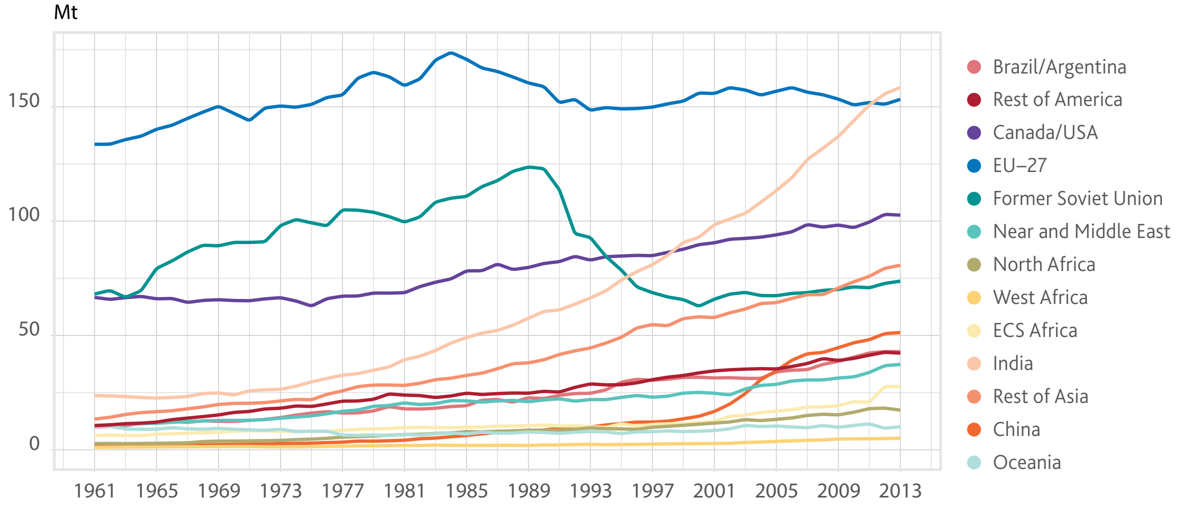
Source: Le Mouël et al., 2018

FIGURE 2a. Cereals, total use by GlobAgri-AgT regions (1961-2013)



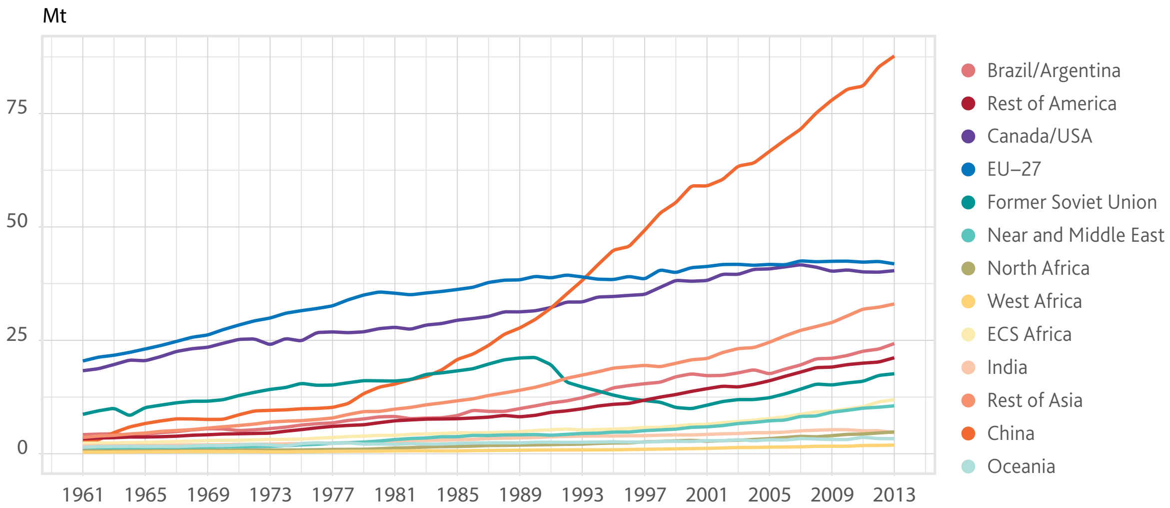
Source: FAOSTAT, IDDRI treatment

FIGURE 2b. Dairy products, total use by GlobAgri-AgT regions (1961-2013)



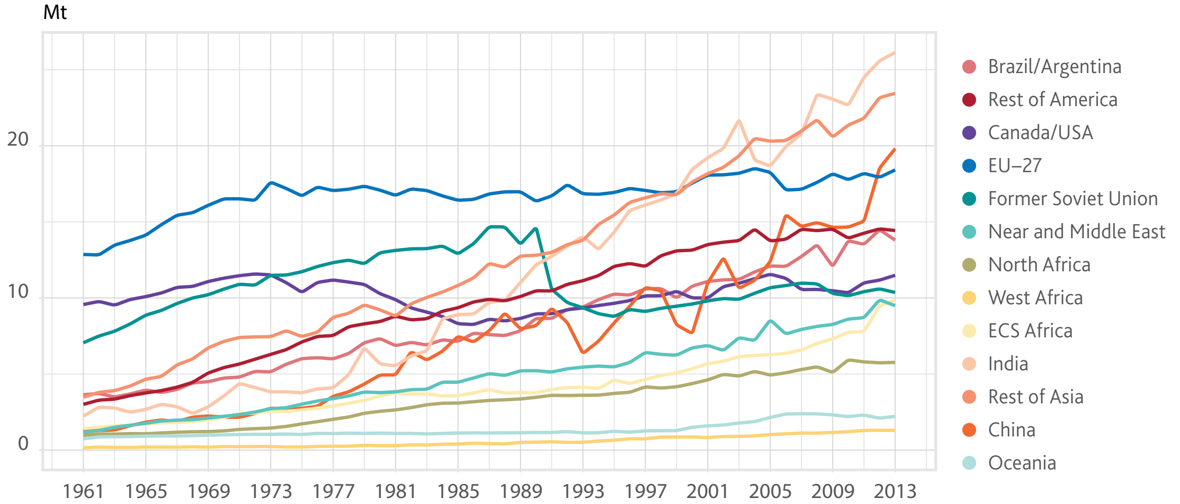
Source: FAOSTAT, IDDRI treatment

FIGURE 2c. Meat, total use by GlobAgri-AgT regions (1961-2013)



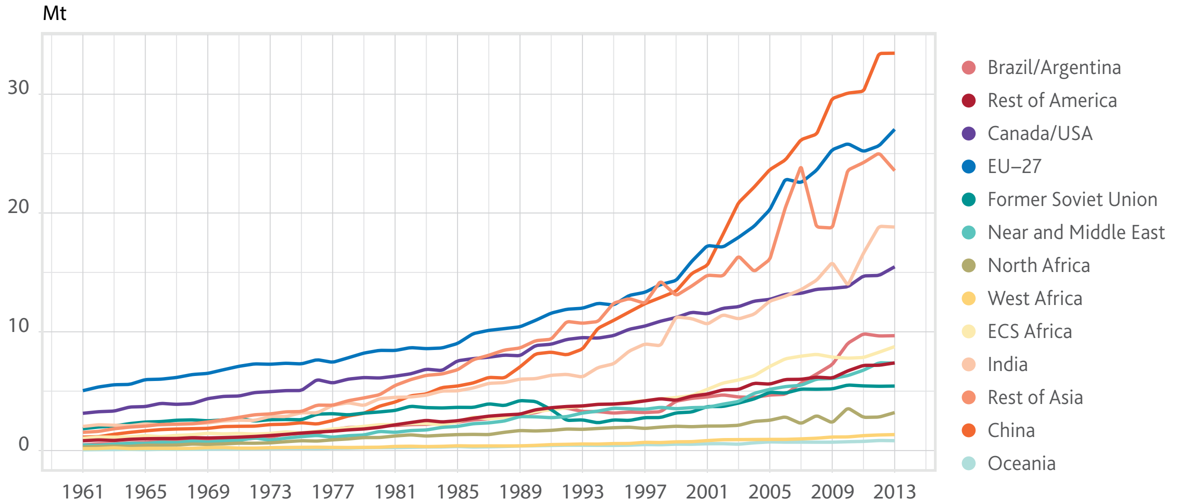
Source: FAOSTAT, IDDRI treatment

FIGURE 2d. Sugar, total use by GlobAgri-AgT regions (1961-2013)



Source: FAOSTAT, IDDRI treatment

FIGURE 2e. Vegetable oils, total use by GlobAgri-AgT regions (1961-2013)



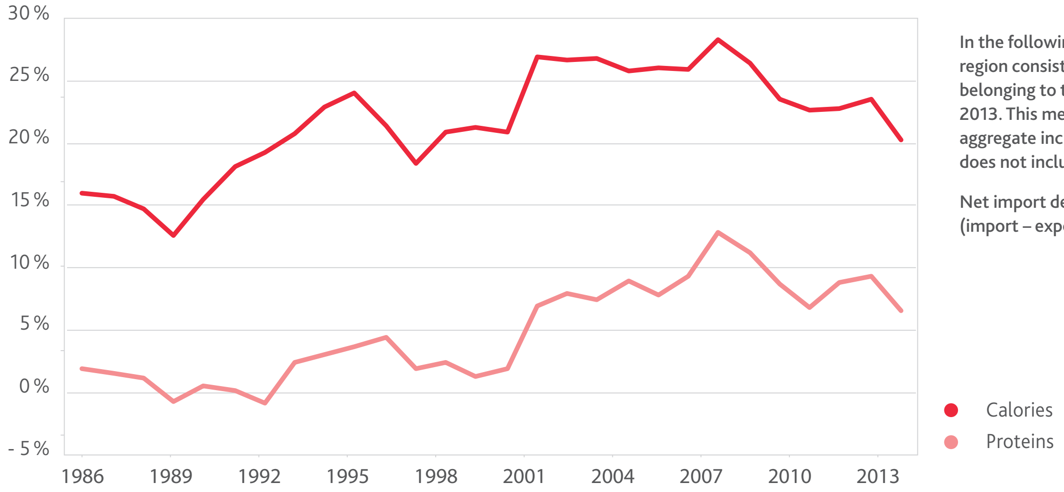
Source: FAOSTAT, IDDRI treatment

used quantities is higher for emerging regions in Asia (China, India and Rest of Asia). The evolution of Chinese demand is particularly strong. In only 50 years, this country more than quadrupled its total use of cereals, skyrocketed its demand of soybeans (starting from the late 90's) and became by far the first consumer of meat (pork and poultry in particular). Developed regions such as the EU or Canada/USA grew their total use of these food commodities at a slower pace, except for vegetable oils. Because of low prices in the international market (liberal trade policies, public subsidies, food aid), the use of vegetable oils grew in every region and has increased with a higher speed since the 90's. Employed to produce ultra-processed food products (NOVA classification, Monteiro *et al.*, 2017), oilcakes and biofuels, vegetable oils structure western diets and are one of the symbols of the nutrition transition taking place over the last decades.

1.2. Despite an increasing domestic production, the EU is a net importer of calories

In 1947, the USA launched the Marshall Plan in order to help the post-war reconstruction in Europe. Since Western European countries were important US allies in the block aimed to contain the Soviet expansion in the Continent, they benefited from financial aid and technical assistance. In the farming sector, the Marshall plan paved the way for the future agricultural interconnection between the USA and Europe. European countries received US surplus of commodities at a specific subsidized rate and agricultural inputs such as fertilizers in order to boost their agricultural production. A decade later, prompted by strong economic growth, Western European countries created the

FIGURE 3. EU-27 Net import dependence in calories and proteins (1986-2013)



In the following graphs, the EU region consists of all countries belonging to the EU-27 2007-2013. This means that this aggregate includes the UK and does not include Croatia

Net import dependence = (import – export)/ domestic use)

Source: FAOSTAT, IDDRI treatment

Common Agricultural Policy. They established an agricultural support scheme based on domestic protection, price support and the subsequent recurrent surplus of agricultural commodities.

Pushed by a higher world demand (see previous paragraph), CAP subsidies and increased farming productivity, the agricultural production grew substantially in Europe. This increase affected primarily the cereal and monogastric meat sectors. Between 1961 and 2013, wheat, pork and poultry meat grew their production respectively by +204%, +132% and +568%. On the other hand, because of national quotas limiting over-production introduced by the Common Agricultural Policy in 1984, milk and beef industries interrupted the growth started in the post-war decades and began to stagnate. As a result, both sectors grew at a slower pace (+25% and +18%) during the same period.

Despite this increase in agricultural production, EU is today a net importer of calories. This means that the exported calories from the EU to the world market are lower than the imported ones. EU high value exports of dairy products and animal meat are made possible only through massive imports of vegetable proteins (soybeans and soybean cakes in particular) from the American continent.

The dependence on imported feedstuff is not a recent happening (**Figure 3**) but takes its origins from the post-war trade deals between the EU and the USA. The US accepted the protection of European wheat and dairy markets and in return, the EU exempted maize and soy products from import restrictions implemented as part of the Common Agricultural Policy (Friedman, 1993). As a result, oilseeds and oilseeds meals entered in the EU at world market prices (Dillon Round 1960-1961), pushing producers to shift from domestic and colonial raw materials such as flax and cotton meal to maize and imported soy from the US (Bickerton, 1990). **Figure 4** reports the evolution of imported and produced quantities of soybeans and soybean cakes from 1986 to 2013 in the EU. While domestic soybean production stagnated at a very low level because of unprofitable economic margins for non-GM soybeans and an unsuitable climate in Northern Europe, soybean and soybean cakes imports increased massively (+49% and +87%).

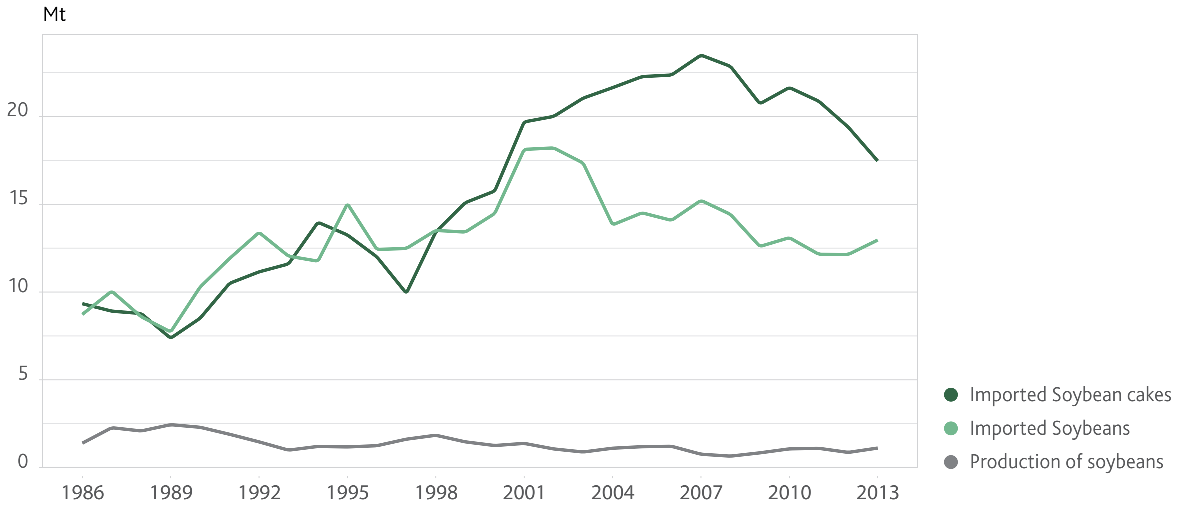
1.3. Declining EU shares in the world agricultural production and exports

In the last decades, despite the growth of domestic agricultural production in absolute quantities, the EU did not increase its share in world production (**Figure 5**), meaning that during this period the rest of the world production developed at a faster pace. Starting from the '80s, the EU shares in world production drastically decreased for milk, sugar and meat. In the first case, this decline follows the exponential growth of India's and Rest of Asia's milk production. In the second case, Brazil/Argentina and India are the main contributors to the growth of the world sugar production. In the third case, the development of meat mass production in emerging countries such as Brazil/Argentina and China is the principal reason explaining the decrease of EU share in world production.

In contrast, EU world production shares for cereals and oilcrops remained relatively stable over the same period. In the first case, the European comparative advantage for wheat production and the EU grain support policy largely explain the EU keeping its world production share. In the second case, despite the significant rise in production in the Rest of Asia (palm), Canada/USA and Brazil/Argentina (soybean), the EU maintained its share of the world oilcrops production. Indeed, EU protein plans and the industrial set-aside scheme established with the 1992 CAP reform allowed the development of biofuel crop production and the partial import-substitution of vegetable proteins for animal feed with local oilseed cakes (Thomas, 2013).

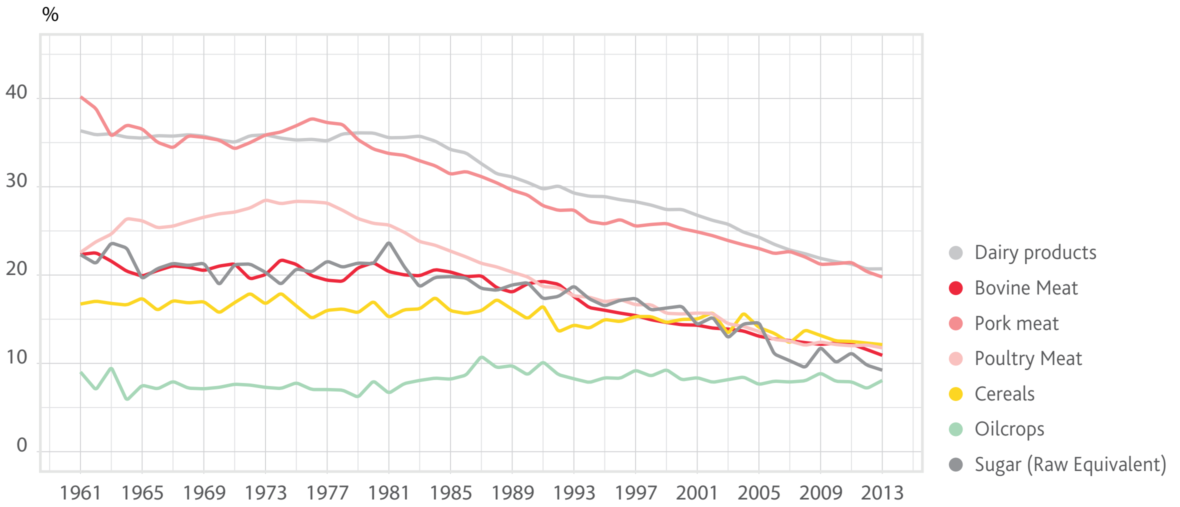
EU agricultural exports to third countries (i.e., excl. intra-trade) followed the same trends. While they increased significantly in

FIGURE 4. Imported soybeans and soybean cakes vs EU production of soybeans (1986-2013)



Source: FAOSTAT, IDDRI treatment

FIGURE 5. EU-27 share in world production for selected products (1961-2013)



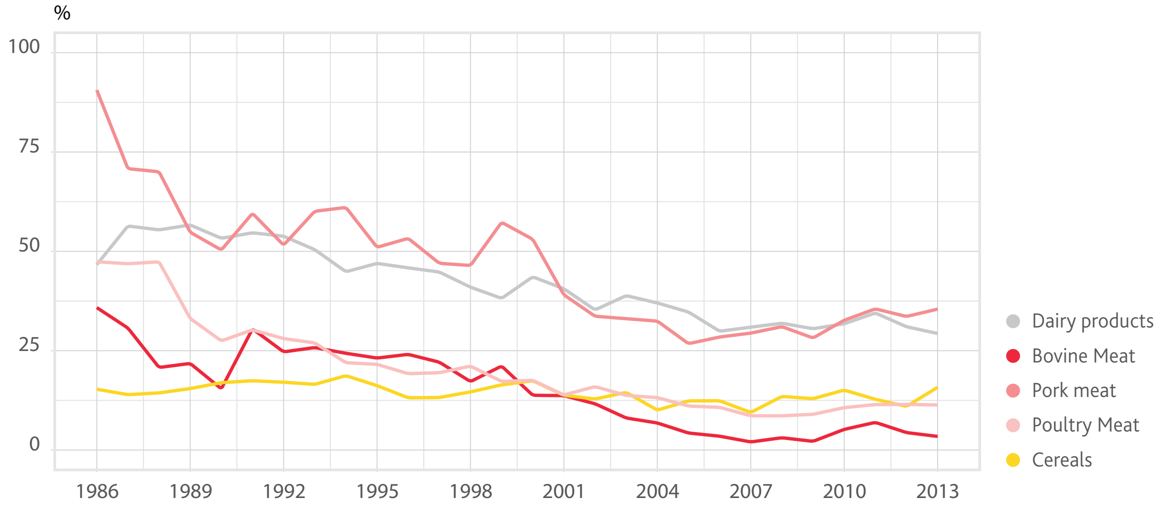
Source: FAOSTAT, IDDRI treatment

absolute quantities, the EU shares of world exports declined for almost all main exported products since the '80s (**Figure 6**). In the monogastric meat sector, the EU suffered from the competition with Canada/USA and the rapid development of Brazil/Argentina exports. For example, the EU export share for poultry meat passed from 48% in 1986 to 11% in 2013, while at the same time, the corresponding Brazil/Argentina export share increased from 25% to 40%. In the dairy sector, Oceania grew substantially its exported quantities and became the main world-exporting region. Together with Brazil/Argentina, Oceania also contributed to provide a large share of world bovine meat exports. At the same time, both the EU milk and cattle meat export shares declined.

On the contrary, the EU managed to maintain its world export share for cereals. Once again, its comparative advantage on wheat production and its support policy helped the EU expand the domestic production and maintain its export position on the world cereals market. Two additional factors also contribute to explain this achievement. Firstly, in the last decades, the world wheat demand increased due to both population growth and a switch from rice to wheat consumption in some very populated regions such as South-East Asia, Sub-Saharan Africa and North Africa. Secondly yet importantly, since growers shifted areas from wheat to more profitable crops, such as maize and soybeans, the first world-exporting region (Canada/USA) slowed down the growth of its wheat exports (+10%) (Liefert, 2018). This allowed other temperate regions such as the Former Soviet Union, Oceania and the EU to consolidate their respective positions on the world cereals market.

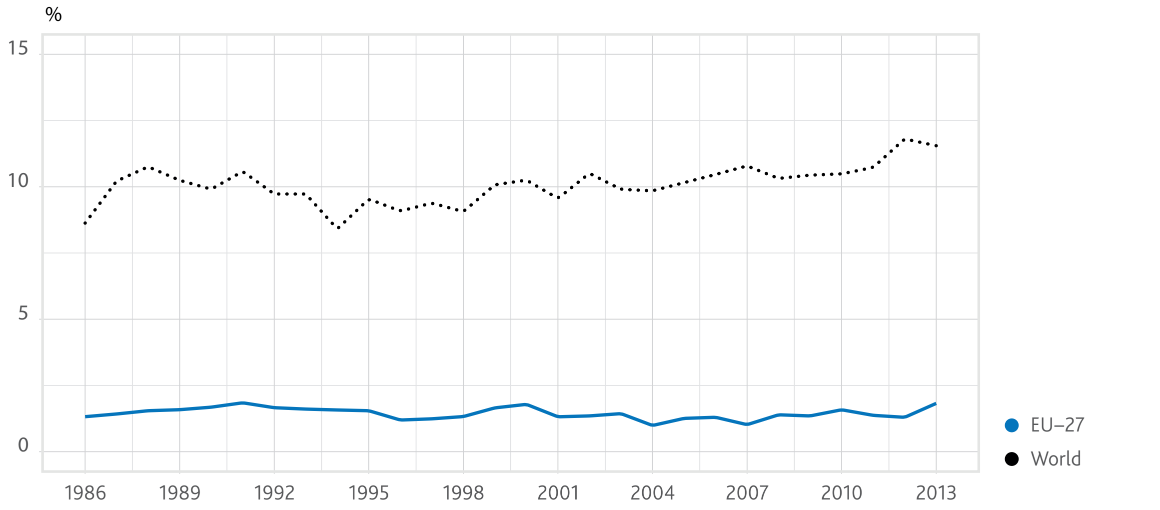
Looking at **Figure 7**, we can see the ratio between exports and world total use of cereals. It can be noticed that over the

FIGURE 6. EU-27 share in world exports for selected products (1986-2013)



Source: FAOSTAT, IDDRI treatment

FIGURE 7. Cereals, ratio between exports and world total use (1986-2013)



Source: FAOSTAT, IDDRI treatment

period world cereal exports accounted for 9 to 12% of world cereal needs. The corresponding ratio for the EU reached 1.8% at the end of the period. In other words, despite increasing exports, the EU contributes only slightly to cover the world total needs of cereals.

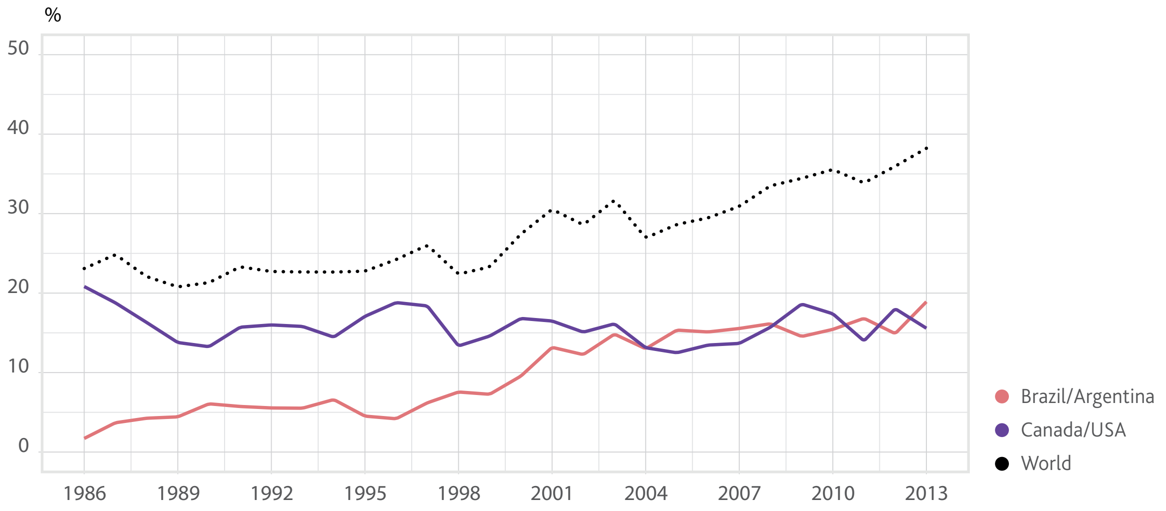
From a more general point of view, the last decades marked a change in countries export positions on agricultural world markets, with emerging big players competing traditional ones. Among the latter, the EU particularly suffered from this rising competition and, as we have seen in the previous paragraphs, it experienced a deterioration, at best a stagnation, of its world export shares.

Over the whole period, emerging players experienced higher yield growth than traditional ones, because they started from lower productivity levels.

During the same period, an increasing international specialisation took place in the world agricultural production, with production of main agricultural commodities expanding dramatically in emerging regions exhibiting particularly high potential for agriculture. The emergence of this specialization movement coincides with the end of the Uruguay Round (1986-1994) which, for the first time, integrated agriculture as a whole sector into the GATT negotiations. In this round, the USA and the traditional net exporting countries managed to reduce EU market protection (export subsidies, import tariffs and domestic price support) and, more generally, liberalized world markets for agricultural products (Bouët, 2001).

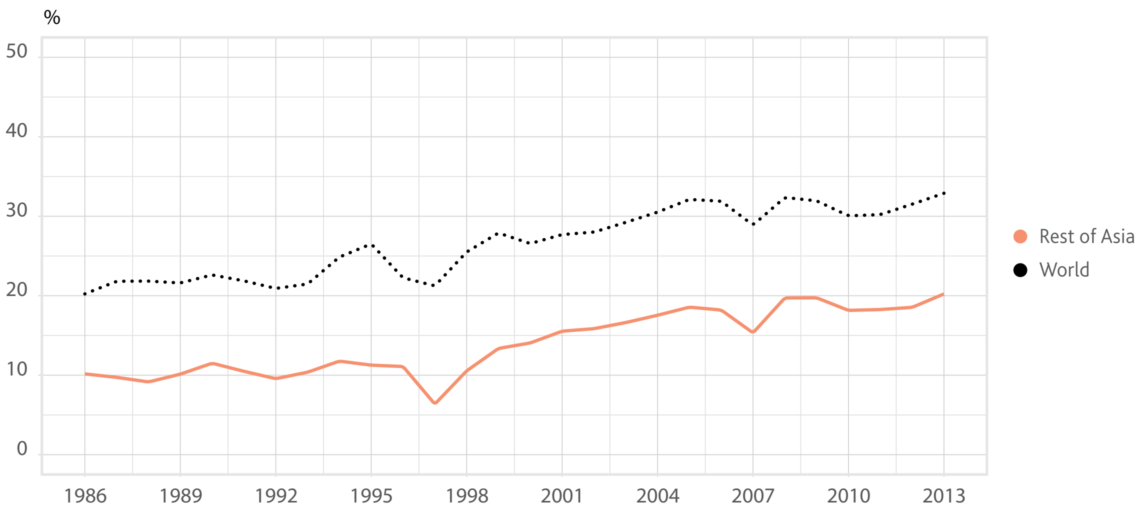
Rest of Asia and Brazil/Argentina benefited significantly from this deal. Rest of Asia consolidated its hegemonic position in selling vegetable oils, and Brazil/Argentina entered massively on

FIGURE 8. Soybeans, ratio between exports and world total use (1986-2013)



Source: FAOSTAT, IDDRI treatment

FIGURE 9. Vegetable oils, ratio between exports and world total use (1986-2013)



Source: FAOSTAT, IDDRI treatment

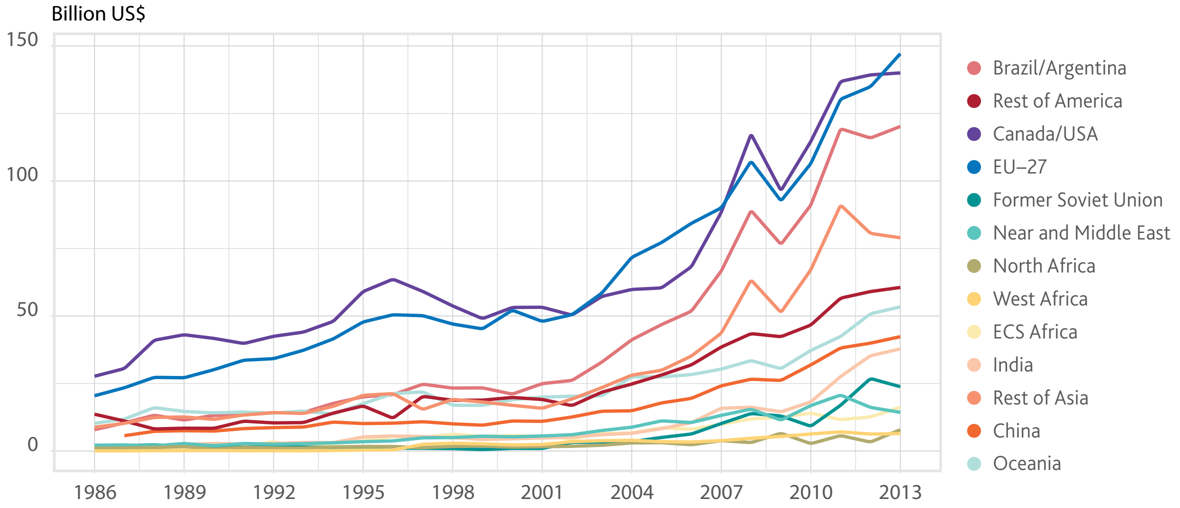
the world markets of soybeans, sugar and poultry meat. Despite the threat to deforestation and biodiversity preservation, Brazil/Argentina boosted its agricultural production favoured by large potential available agricultural areas and the introduction of genetically modified crop varieties and reduced the yield gaps with developed countries for exported commodities. Soon, this region became a large agro-exporter and acquired a similar export position as a traditional player such as Canada/USA.

The impact of international specialisation over the 1986-2013 period is particularly tangible for two highly exported commodities such as soybeans and vegetable oils, which "world exports/world total use" ratios increased significantly (**Figure 8** and **Figure 9**). For soybeans, the ratio increased from 23% to 38%, while for vegetable oils it rose from 20% to 33%. In the case of soybeans, the contribution of exports from Brazil/Argentina to the world total use increased from 2% in 1986 to 19% in 2013 reaching a similar level as Canada/USA. For vegetable oils, exports from the Rest of Asia accounted for 10% of world total use in 1986 and reached 20% in 2013. These are dramatic changes especially if we keep in mind how the world total use of these commodities increased during the last decades (**Figure 2**), meaning that Brazil/Argentina and Rest of Asia grew even more their exported quantities.

1.4. EU remains a major agro-exporting region in value, with top exported products slightly contributing to food security

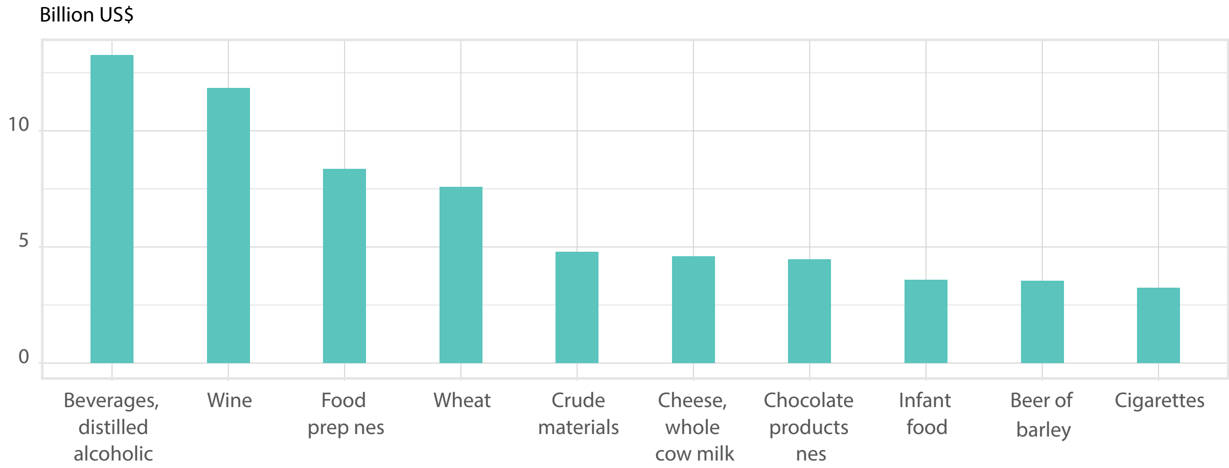
Despite the decline of the shares of the EU in world agricultural production and exports when dealing with quantities, the

FIGURE 10. All agricultural products, value of exports by the GlobAgri-AgT regions (1986-2013)



Source: FAOSTAT, IDDRI treatment

FIGURE 11. Export value of top 10 agricultural exports in EU (2013)



Source: FAOSTAT, IDDRI treatment

EU strongly increased its agricultural exports to third countries over the last decades when considering values. As a result, the EU became the first world agro-exporting region in value, jointly with Canada/USA (**Figure 10**). Even though Brazil/Argentina and Rest of Asia grew substantially their export quantities after the Uruguay Round, they could not fill the gap with the traditional players in terms of export values.

This situation could suggest that EU still plays a major role regarding global food availability and hence security. However, looking further into the structure of EU export value in 2013, over the top 10 exported products, contributing to 44% of the total exported value, most do not relate to food security (**Figure 11**). Excluding wheat (5%) and eventually cheese (3%), these commodities are alcohols (liquors, wine, beer) or highly processed products (food preparations, infant food) non-necessary (chocolate) or non-food (crude materials[7], cigarettes) products.

The EU is no longer a major contributor to the world food availability and security. Today it remains a net importer of calories and a major exporter in value terms but with most of its top-exported products not relating to food availability and security. In other words, it is most likely that the transition of EU agriculture towards agroecology (implied by the TYFA scenario) will not have large-scale impacts on world food availability.

7 FAOSTAT category including vegetal and animal products used in various industries (ex. chemical, pharmaceutical, clothing industries), all of them not related to food production.

2. TYFA AND AGRIMONDE-TERRA SCENARIOS

2.1. TYFA for the EU

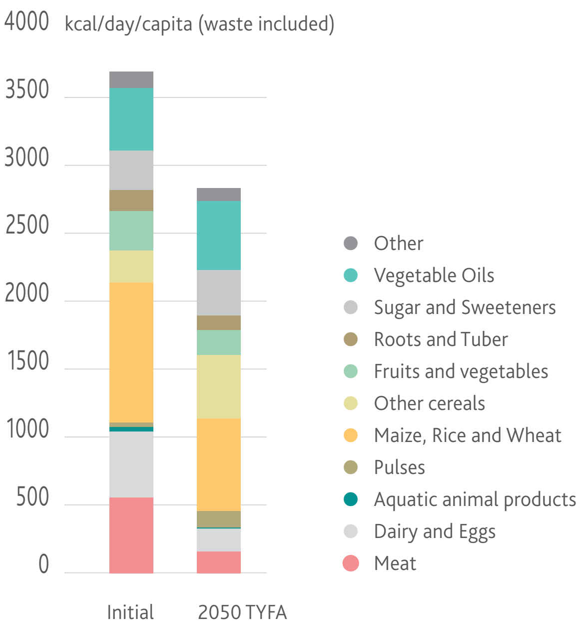
Modelling an agroecological EU: the TYFA analytical framework

The development of the TYFA scenario was based on an original modelling exercise of the EU food system having the European Union of 27[8] as unit of analysis. This region is configured as an aggregate without any direct consideration regarding its functioning or its internal heterogeneity. This aspect has two implications. First, only flows between the EU and the rest of the world are considered. Second, all the reasoning is based on average values for the EU, whether for production (yields and livestock systems) or for consumption (diets). This "black box" constitutes the "European farm". This approach appeared essential from a policy perspective: this is indeed the level at which most public policies involved in the agroecological transition are negotiated (Common Agricultural Policy, trade agreements, environmental policies).

The biophysical model is organised around five compartments: crop production, livestock production, demand (food and non-food agricultural products), nitrogen flows and interactions between the first four compartments.

For each of those five compartments, specific assumptions were made to parametrize the model and test the coherence and the plausibility of the scenario from a quantitative point of view. These hypotheses are described in the following section.

FIGURE 12. EU food diet in 2050 under the TYFA scenario (waste from storage, distribution, transport and at the consumer level included)



Source: authors

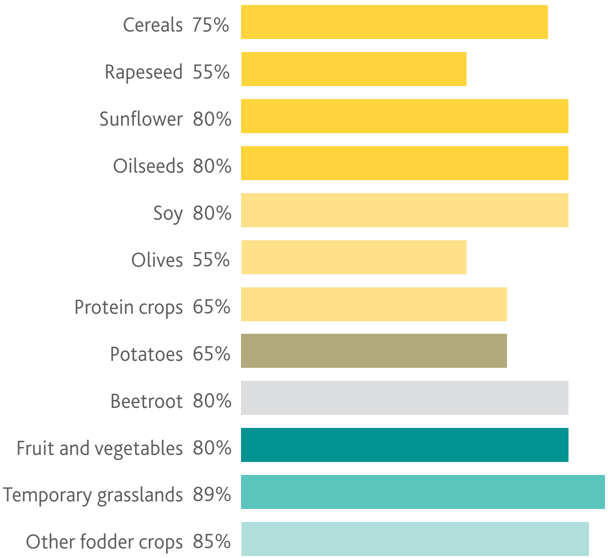
TYFA hypotheses for an agroecological EU

Figure 12, **Figure 13** and **Table 1** briefly recall the set of assumptions of the TYFA scenario. They are fully detailed and discussed in the TYFA report (Poux and Aubert, 2018). TYFA assumptions concern the five compartments of the model:

- Nitrogen cycle and management: closing fertility cycles at the finest territorial level possible, which depends on:
  - The phase-out of soybean imports;
  - The reintroduction of legumes into crop rotations;
  - The reintroduction of legumes in permanent grassland and the transfer of nitrogen to crops through optimal manure management, thus leading to
  - the re-territorialisation of livestock systems in cropland areas;
- Crop production and land use: extensifying crop production in a re-diversified agricultural landscape, a two-level approach:
  - An extensification of crop production at the plot level that relies on the phasing-out of both pesticides and synthetic fertilizers;
  - The extension of semi natural vegetation (agroecological infrastructures) and the redeployment of natural/permanent grasslands across the EU territory;
- Livestock production: extensifying livestock production (both ruminants and granivores) and limiting the feed/food competition;
- Human diets: adoption of healthier and more balanced diets according to nutritional recommendations. Food waste is improved by 10%;
- Priority to human food, then animal feed, then non-food uses. In the TYFA scenario, this results in the total phase-out of bioenergy crops, neither under the form of biofuel nor that of biogas.

8 The EU region adopted in TYFA scenario and in GlobAgri-AgT modelling includes the UK and does not include Croatia (EU-27 2007-2013)

FIGURE 13. Yield gaps between TYFA 2050 and 2010 yields



Source: Ponisio et al. (2015), values for Europe.

Waste in GlobAgri and TYFA is accounted following different procedures. In order to get comparable entry variables, a specific procedure has been adopted (see Annex 2). As a result, we can compare food regimes between the two models, all things being equal, only if we consider the human intake jointly with the waste originated from storage, distribution, transport and at the consumer level. For a more complete overview of TYFA diet, additional information is available in the TYFA report where the human intake has been estimated at around 2,400 kcal/person/day (Poux and Aubert, 2018).

2.2. Two contrasting Agrimonde-Terra scenarios for the rest of the world

While the EU is operating its transition to agroecology, we consider two contrasting pathways for the rest of the world. Both pathways are borrowed from the Agrimonde-Terra foresight exercise[9]. The first one (Metropolization_Ultrap) is based on ongoing trends, meaning that while the EU is moving towards agroecology, all other world regions are keeping food systems based on past observed nutritional transition and conventional intensification of agricultural production. In the second one (Healthy_AE), similar to the EU, all world regions experience a transition towards healthier diets and agroecological agriculture. **Table 2** presents the qualitative hypotheses of change of drivers to 2050 involved in the Metropolization_Ultrap and the Healthy_AE scenarios. Each component of both scenarios is presented in more details in Annex 1.

TABLE 1. Technical bibliographic references used to configure livestock systems in TYFA

Livestock sector	References used for livestock system	General references used (typologies)
Dairy cattle	(Barataud et al., 2015)2015 (Coquil et al., 2014) (Réseaux d'élevage *et al.*, 2005)	(CEAS & EFNCP, 2000) (Solagro et al., 2016) (Devun & Guinot, 2012) (Pflimlin *et al.*, 2006) (Pflimlin, 2013)
Beef cattle	(Chambres d'agriculture *et al.*, 2014)	
Sheep	(Tchakérian & Bataille, 2014)	(Poux *et al.*, 2006)2006
Pigs	(Jurjanz & Roinsard, 2014) (Calvar)	Not mobilised for granivores
Poultry	(Bordeaux, 2015)	
Laying hens	(Bouvarel *et al.*, 2013)	

Source: Poux and Aubert, 2018.

TABLE 2. Hypotheses of change to 2050 of drivers in both Metropolization_Ultrap and Healthy_AE

	Metropolization_ Ultrap	Healthy_AE
Global context	Conventional development lead by market forces	Sustainable and cooperative world
Climate change	Runaway climate change	Stabilization of global warming
Food Diet	Transition to diet based on ultra-processed products (Ultrap diet)	Healthy diet based on food diversity (Healthy diet)
Livestock system	Conventional intensive livestock	Agroecological livestock
Cropping system	Conventional intensification	Agroecology

Source: Le Mouël *et al.* (2018).

9 Held by Inra and Cirad, the Agrimonde-Terra foresight proposes a set of five contrasted scenarios of land use and food security in 2050. The Agrimonde-Terra's "land use and food security" system encompasses three external drivers: global (political, economic and social) context, climate change and food diets; and four direct drivers: rural-urban relationships, agricultural structures, cropping, and livestock systems. Alternative hypotheses about the future of each driver up to 2050 were built. Scenarios are coherent combinations of hypotheses of change per driver. In a second step, the impacts of each scenario on land use, production and trade of agricultural products were quantitatively assessed using the GlobAgri-AgT biomass balance model, at the world scale and for the 14 considered world regions. For that purpose, the alternative hypotheses of change to 2050 of each driver (more specifically of each driver that the model is able to account for: global context, climate change, food diets, cropping systems and livestock systems) were translated into quantitative inputs for GlobAgri-AgT. Agrimonde-Terra scenarios are described in full details in Mora (2018). Agrimonde-Terra method, results and main insights are reported in Le Mouël *et al.* (2018).

3. SIMULATED SCENARIOS AND THEIR IMPACTS

Four scenarios were considered in this study. The first one is the reference scenario considered as "probable" or "likely" and directly borrowed from Agrimonde Terra: Metropolization_Ultrap (named MU). The second is the main scenario of this report. It enables us to test the consequences of an agroecological EU on trade, land use and food security: TYFA in the EU alone (ALONE). The third and fourth scenarios are called respectively ALONE_UltrapEU and TYFA in the EU going with the global flow (TOGETHER). They are carried out as a sensitivity analysis to ALONE. ALONE_UltrapEU tests the implications of ALONE if only the production side changes in the EU, i.e. assuming that the EU consumer is not ready to switch to a healthier diet and continues purchasing the energy-rich diet based on ultra-processed products of the MU scenario. In contrast, in TOGETHER the EU maintains the complete TYFA configuration (on production and consumption sides), but the rest of the world, differently from the previous scenarios, evolves towards a similar pathway as the EU. The world regions adopt the hypotheses of Healthy_AE, which lead to the spread of agroecological production systems and healthy diets. **Table 3** illustrates the four simulations carried out in this study.

3.1. Metropolization_Ultrap (MU)

In this scenario, the EU as well as the rest of the world remain on ongoing trends. In particular, for all world regions, agricultural production systems develop according to conventional intensification processes and consumers continue experiencing the ongoing nutritional transition towards more caloric diets, with higher shares of vegetable oils, sugar and sweeteners and animal products, especially poultry meat. Metropolization_Ultrap hypotheses apply to all world regions. (**Table 3**)

TABLE 3. The simulated scenarios accordingly to hypotheses on production and demand for the EU and the rest of the world Metropolization_Ultrap (MU)

EU			Rest of the world		
	Metropolization_Ultrap	TYFA		Metropolization_Ultrap	Healthy_AE
Production			Production		
Consumption			Consumption		

TYFA in the EU alone (ALONE)

EU			Rest of the world		
	Metropolization_Ultrap	TYFA		Metropolization_Ultrap	Healthy_AE
Production			Production		
Consumption			Consumption		

The ALONE scenario without the TYFA assumption of changing diets in the EU (ALONE_UltrapEU)

EU			Rest of the world		
	Metropolization_Ultrap	TYFA		Metropolization_Ultrap	Healthy_AE
Production			Production		
Consumption			Consumption		

TYFA in the EU going with the global flow (TOGETHER)

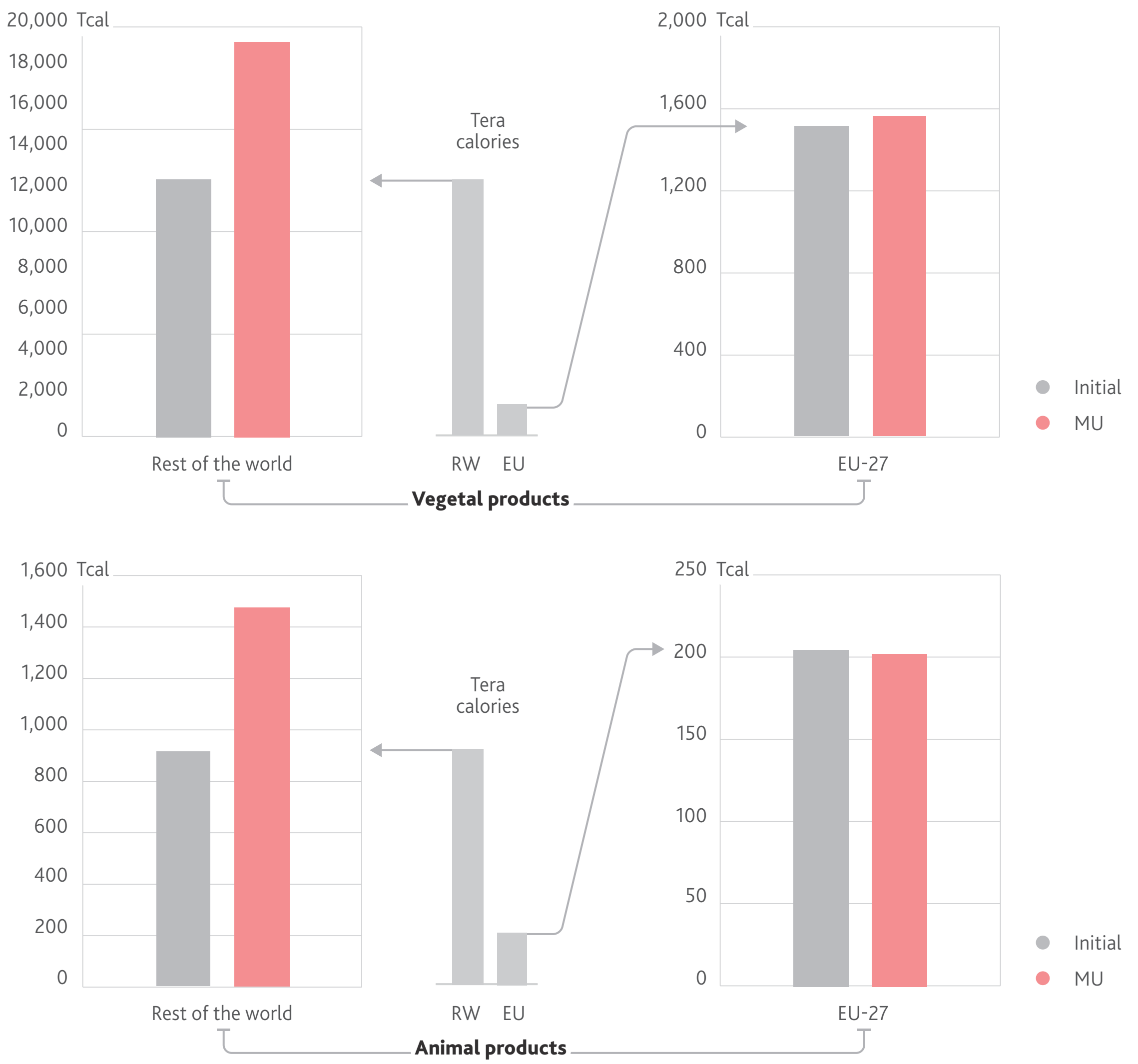
EU			Rest of the world		
	Metropolization_Ultrap	TYFA		Metropolization_Ultrap	Healthy_AE
Production			Production		
Consumption			Consumption		

A dramatic increase in world agricultural production in 2050 as a response to demographic growth and westernization of diets, but a limited and decreasing contribution of the EU

Because of a stagnant population and an advanced nutritional transition, food demand in the EU increases very slightly from 2010 to 2050. More specifically, vegetal food consumption increases while animal food consumption stagnates. Thus, EU agricultural production responds to a nearly stagnant domestic food demand and to a fast-growing food demand in the rest of the world (**Figure 14**), the latter enlarging the world agricultural markets together with the agricultural exports of the main exporting regions. For the EU, this results in a slight increase in vegetal production (+3%) and a small reduction in animal production (-1%) from 2010 to 2050.

The trend is completely different in the rest of the world. Pushed by demographic growth and the westernization of diets in developing countries, food consumption increases drastically. As a response, the production of agricultural commodities also rises significantly: +53% for vegetal production and +61% for animal production. The extent of the increase is particularly marked in developing regions. For instance, ECS Africa and West Africa boost their agricultural production and reach a level almost four times higher than in 2010. As a result, the EU contribution to the world agricultural production decreases. While in 2010, EU vegetal and animal production accounted for, respectively, 11% and 18% of corresponding world production, these shares drop to 7% and 12%, respectively in 2050 with the MU scenario.

FIGURE 14. Production of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU scenario



Source: Globagri-Agt

Trade specialisation and conventional intensification of agricultural production systems help stabilising world agricultural land, but with harmful effects on the environment

Because of a declining population and more intensive agricultural production systems, EU land requirements lower for both cropland (-3%) and pastureland (-14%). Almost every crop is concerned by this reduction except sugar plant products whose consumption levels rise sharply in this scenario (**Figure 15**).

Despite the growth in global consumption, the conventional intensification development pathway promoted by MU allows a slight decrease in the rest of the world agricultural land (-1%), which is unevenly distributed between cropland (+17%) and pastureland (-9%). Due to the westernization of traditional diets and increased demography, India, Near and Middle East, North Africa and West Africa are constrained by their maximum cultivable area and forced (according to GlobAgri-AgT solving rules) to deteriorate their trade balances. Because of rapid population growth and changing diets, grassland in ECS Africa and cropland in West Africa, India and Rest of Asia escalate to levels which could lead to severe deforestation or grasslands conversion to crop production. It is important to underline that these land requirements could even be greater without the efficiency gains in both vegetal and animal production assumed by this scenario in the rest of the world.

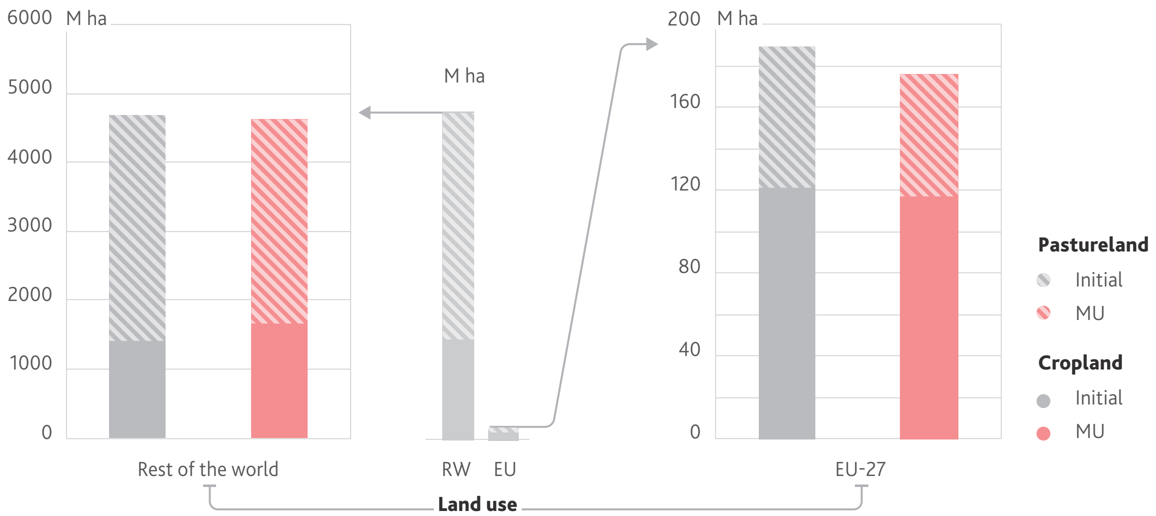
Despite the low global land requirements, MU presents severe environmental concerns, which throw into question the future performance and, thus, the sustainability of such a global food system. In addition to the natural resources' deterioration, such as soil fertility, water quality, and biodiversity, the MU scenario also has significant impact on global warming.

EU trade balance improves reinforcing the EU exporting position

MU increases EU exported quantities for vegetal (+81%) and animal (+75%) products. Almost every commodity is concerned with dairy, poultry, rapeseed and cereals exports experiencing a significant growth over the 2010-2050 period. At the same time, EU maintains almost similar levels as those observed in 2010 for imported vegetal (+8%) and animal (-13%) products (**Figure 16**). As a result, the EU improves its caloric trade balance, which however remains negative. Indeed, the EU net import dependence decreases from 11% in 2010 to 5% in 2050 (**Figure 17**), the EU remaining highly dependent on vegetable protein imports (and on mineral fertiliser imports, which are not explicitly accounted for in GlobAgri-AgT). Soybean and soybean cakes imports slightly decrease (-1% and -7%), but continue to be necessary to maintain EU livestock production system.

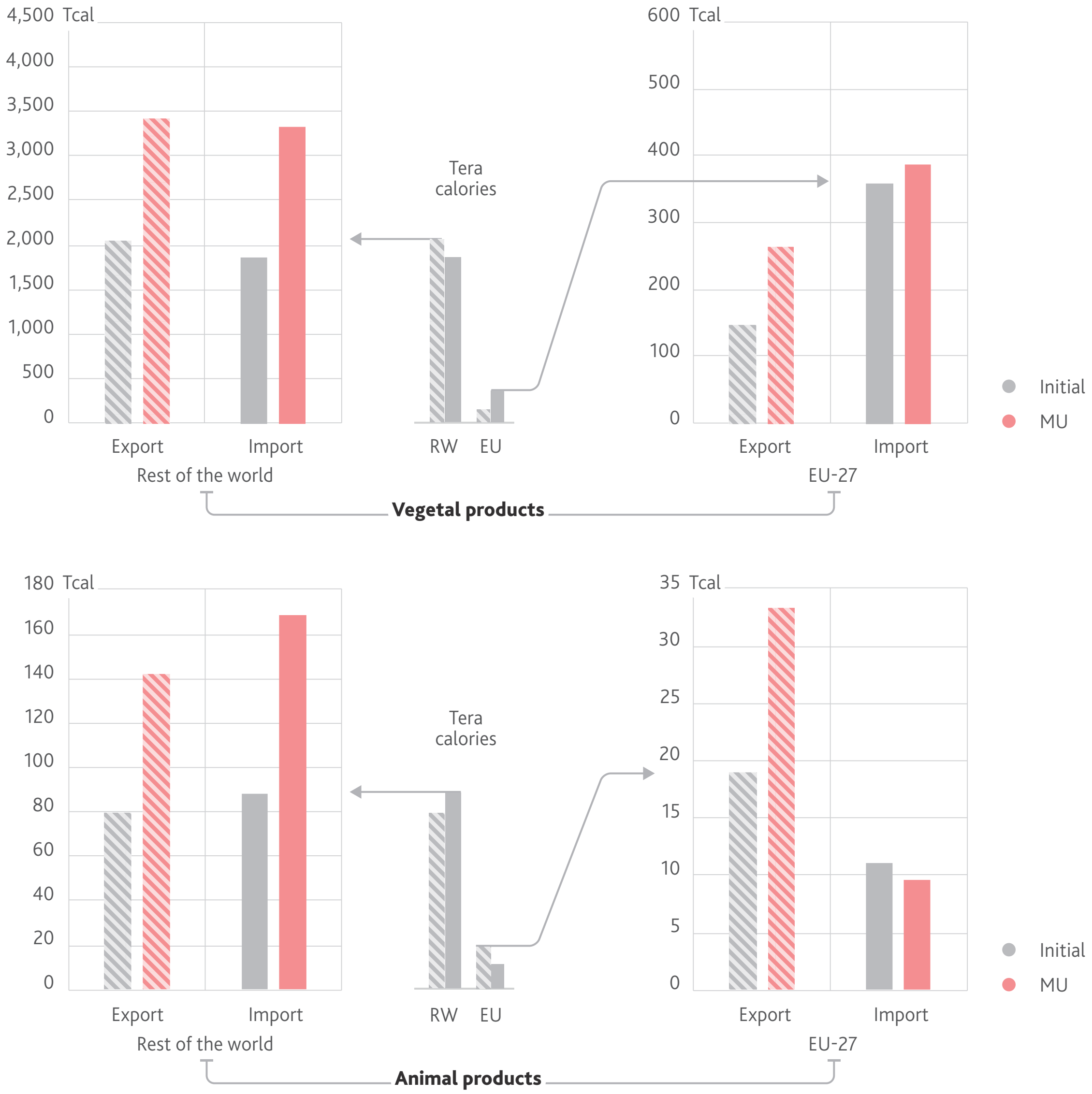
The world trade expands heavily and the exchanges of agricultural commodities almost double compared to 2010. We assist to a greater specialisation of agricultural production based on comparative advantages. World agricultural production concentrates in few of the most competitive regions (Brazil/Argentina, Canada/USA, Former Soviet Union and Oceania) which increase their exports of oilseeds, sugar plants, feed ingredients (maize and cakes) and meat. By contrast, regions having low available land and a growing population (North Africa and Near Middle East) reach very high levels of food dependence (respectively, 73% and 44%).

FIGURE 15. Land use in the EU and in the rest of the world in the Initial situation and in 2050 under the MU scenario



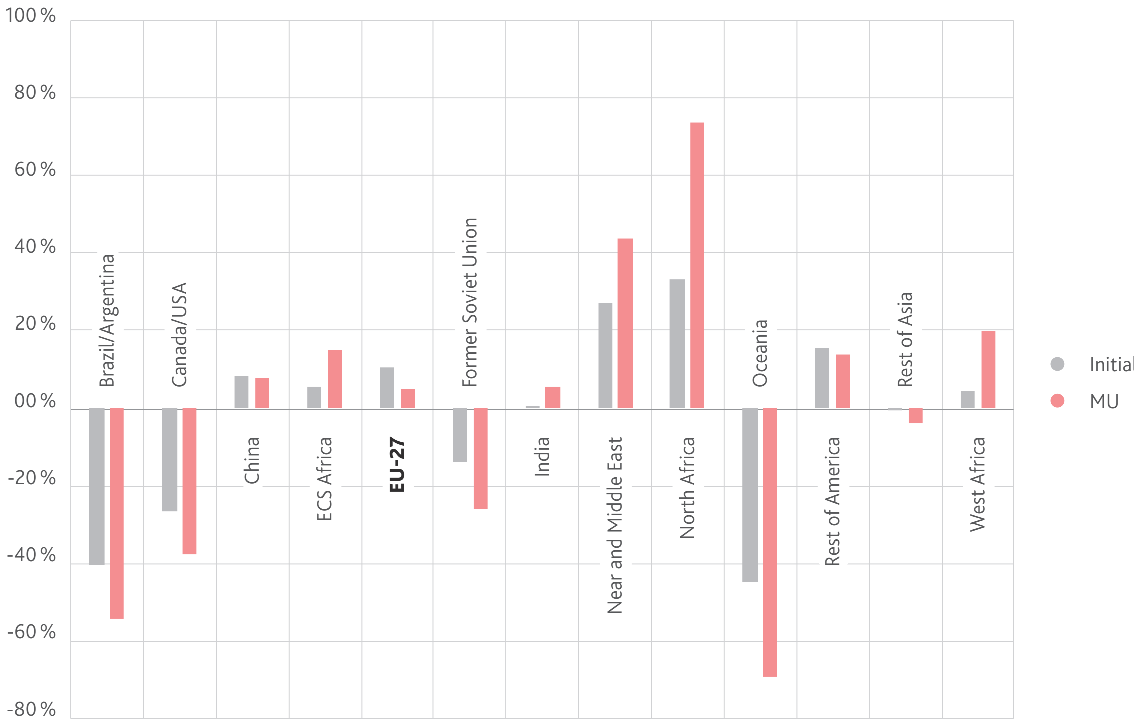
Source: Globagri-Agt

FIGURE 16. Export and import of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU scenario



Source: Globagri-Agt

FIGURE 17. Net import dependence in the GlobAgri-AgT regions in the Initial situation and in 2050 under the MU scenario



Source: Globagri-Agt

3.2. TYFA in the EU alone (ALONE)

In this scenario, the EU and the rest of the world adopt two completely different pathways. The EU follows completely TYFA prescriptions including soya import ban and constant cropland area at the observed 2010 level. EU consumers lower their caloric intake and start increasing the share of fruits and vegetables, coarse cereals and vegetable proteins in their food diet. At the same time, EU farmers adopt TYFA production system based on agroecology. In contrast, the rest of the world remains with the hypotheses of the Metropolization_Ultrap scenario.

Lower performances of EU agriculture face reduced food needs of EU consumers

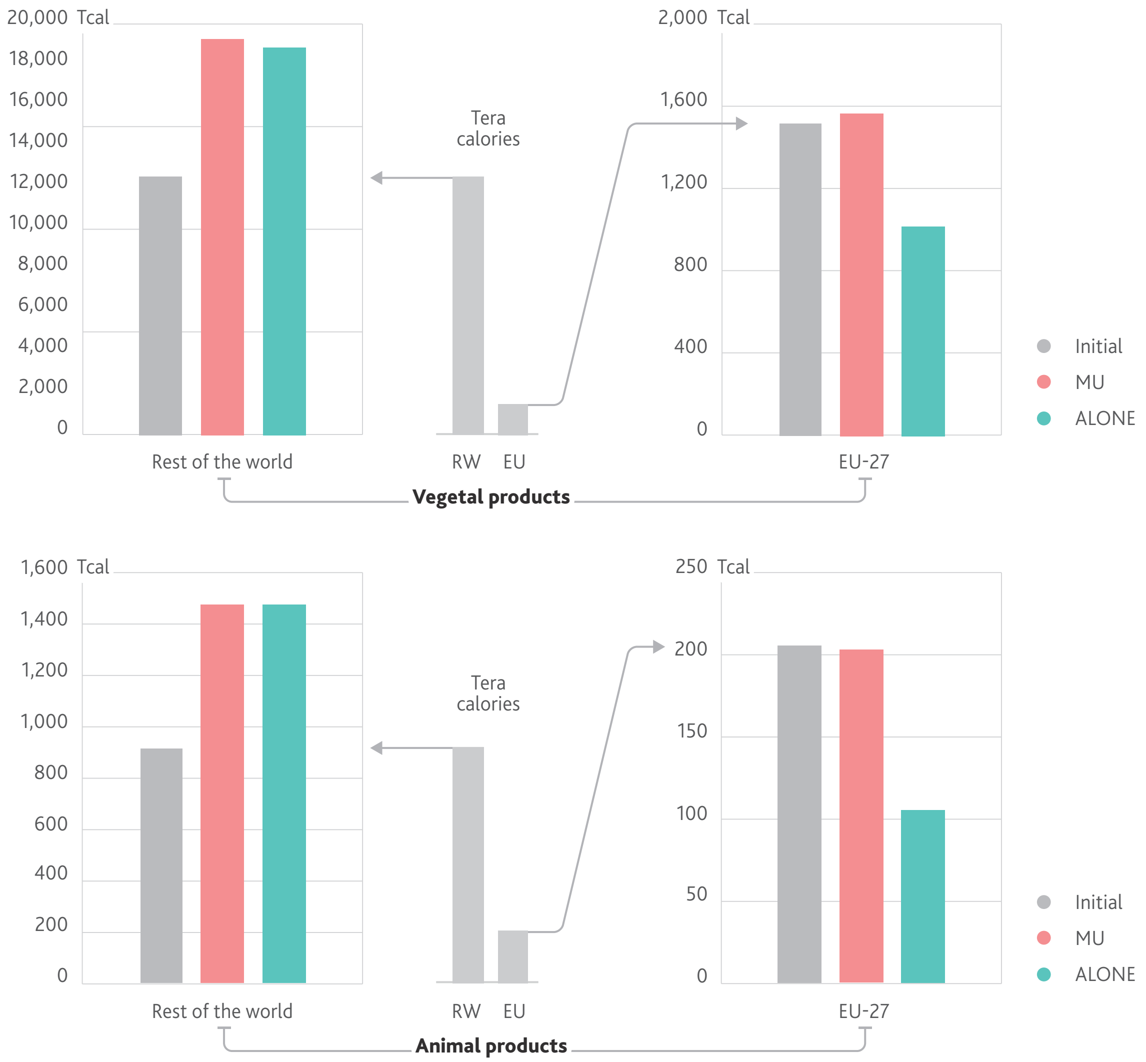
Following TYFA hypotheses, in the ALONE scenario, EU agricultural productivity declines compared to 2010 and to MU. However, at the same time, EU consumers change their diet towards lower daily caloric intake and reduced shares of animal, oil and ultra-processed products. As a result, compared to MU, the volume of EU agricultural production drops for vegetal (-35%) and animal (-48%) products. The EU share in world production also declines reaching 5% and 7% level respectively for vegetal and animal products (**Figure 18**). Despite the drop in domestic production, EU is able to satisfy the EU population food needs without expanding its agricultural land area and even getting its agricultural trade balance improved (see next paragraph).

Compared to MU, the rest of the world is slightly impacted by EU changing pathway. In response to the declined EU needs of imported products, the rest of the world production of vegetal (-2%) and animal (-1%) products suffers a small decline.

Agricultural land area stagnates in the EU and at the global scale

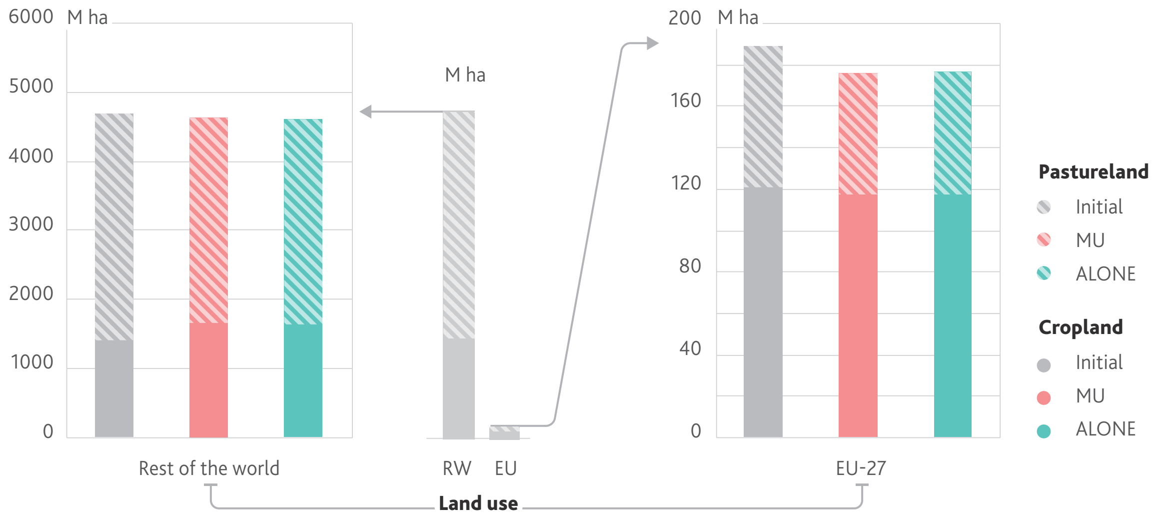
In ALONE, the impacts of the TYFA assumption of changing diets in the EU completely offset the effects of the TYFA assumption of reduced EU agricultural productivity in terms of domestic agricultural land area. Compared to MU, both the EU cropland and pastureland areas stagnate (**Figure 19**). As far as cropland is concerned, several crops reduce their surface (wheat, other oilcrops, grass like-forage, rape and mustard seed, sugar plant and products) while others increase their areas (fruits and vegetables, coarse grains, maize, other forages, pulses and soybeans). In particular, pulses and soybean area expansion is exceptionally high (**Table 4**). The increased land area of pulses results from the changing preferences of EU consumers towards vegetable proteins on the one hand and from the changing feed rations of agroecological livestock systems on the other. The rising soybean area is the consequence of the TYFA requirement of stopping the use of synthetic fertilisers and achieving a complete autonomy in vegetal protein in the EU. Compared to the original TYFA scenario, ALONE is more stringent in terms of agricultural land area (+7%). This is mainly due to the growing food needs in the rest of the world, which was not accounted for in the original

FIGURE 18. Production of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU and ALONE scenarios



Source: Globagri-Agt

FIGURE 19. Land use in the EU and in the rest of the world in the Initial situation and in 2050 under the MU and ALONE scenarios



Source: Globagri-Agt

TYFA scenario, and which increases EU exports and the related agricultural land use relative to the original scenario.

On a global scale, ALONE shows that the adoption of the TYFA assumptions in the EU (agroecological production systems and a healthier diet) does not lead to an expansion of the world agricultural land area. Compared to MU, the rest of the world cropland slightly decreases (-2%), while pastureland remains constant (+0%).

TABLE 4. Change in the EU cultivated area of the main crops (%) in 2050 in the ALONE scenario relative to MU

Agricultural product	%
Wheat	-21%
Maize	+32%
Other cereals	+4%
Rapeseed	-47%
Sunflower seed	+18%
Other Oilcrops	-89%
Soybeans	+1,856%
Pulses	+596%
Sugar plants and products	-30%
Fruits and vegetables	+21%
Grass-like forage	-26%
Other forages	+14%

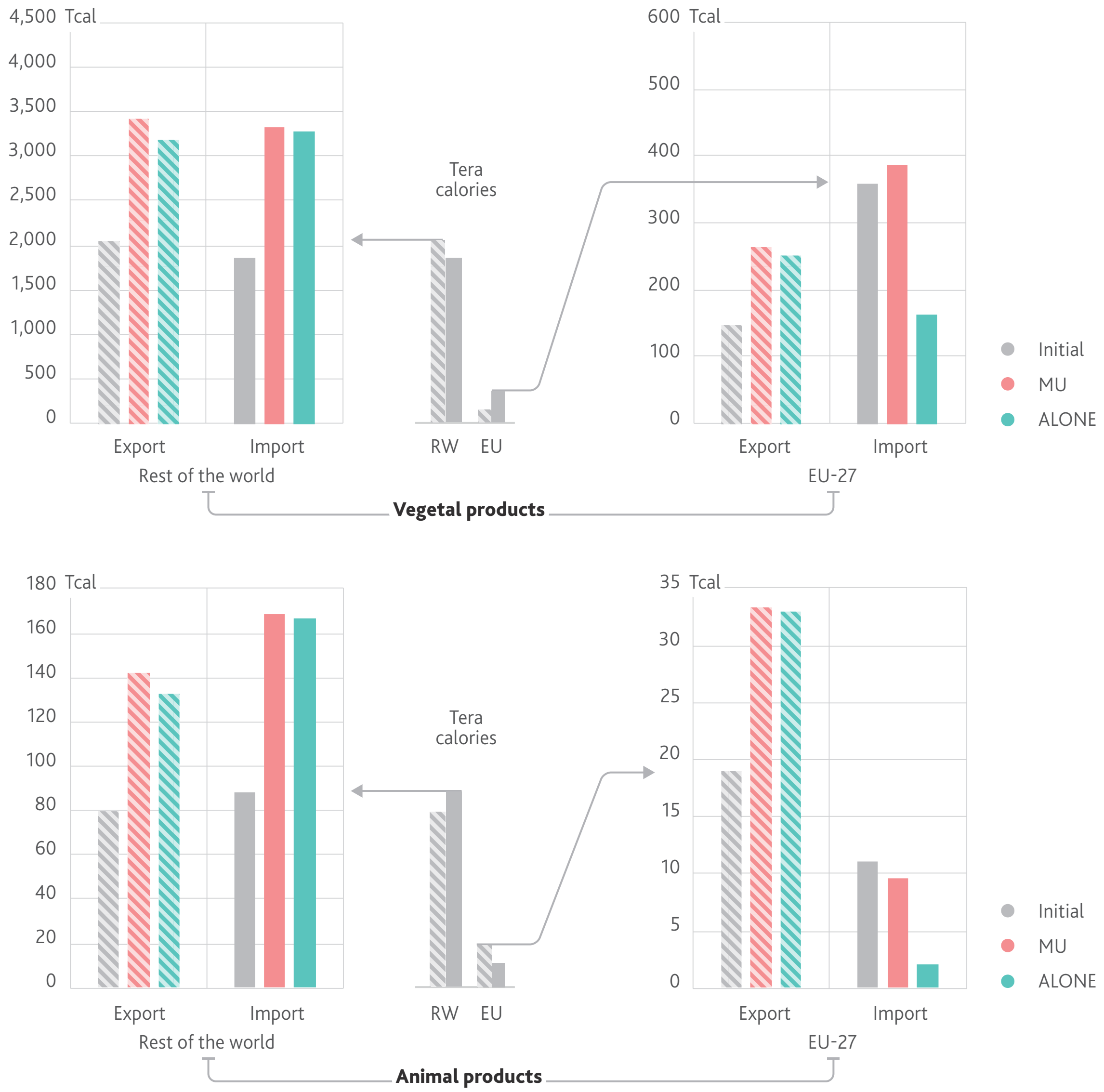
Source: Globagri-Agt.

EU shifts from net importer to net exporter

The ALONE scenario does not significantly change EU exports relative to MU. But it induces a sharp decrease in EU imports (-58% for vegetal and -78% for animal products) following lower domestic food consumption levels and zero soybean imports assumptions. As a result, EU switches from being a net importer to being a net exporter of agricultural products, with a net import dependence reaching -12% in ALONE as compared to 5% in MU (**Figure 20**). Therefore, in a global context marked by population growth and a "westernization" of world diets, an agroecological EU is quantitatively able to reach a positive caloric trade balance and offers its contribution, albeit small, to the global food provision (**Figure 21**).

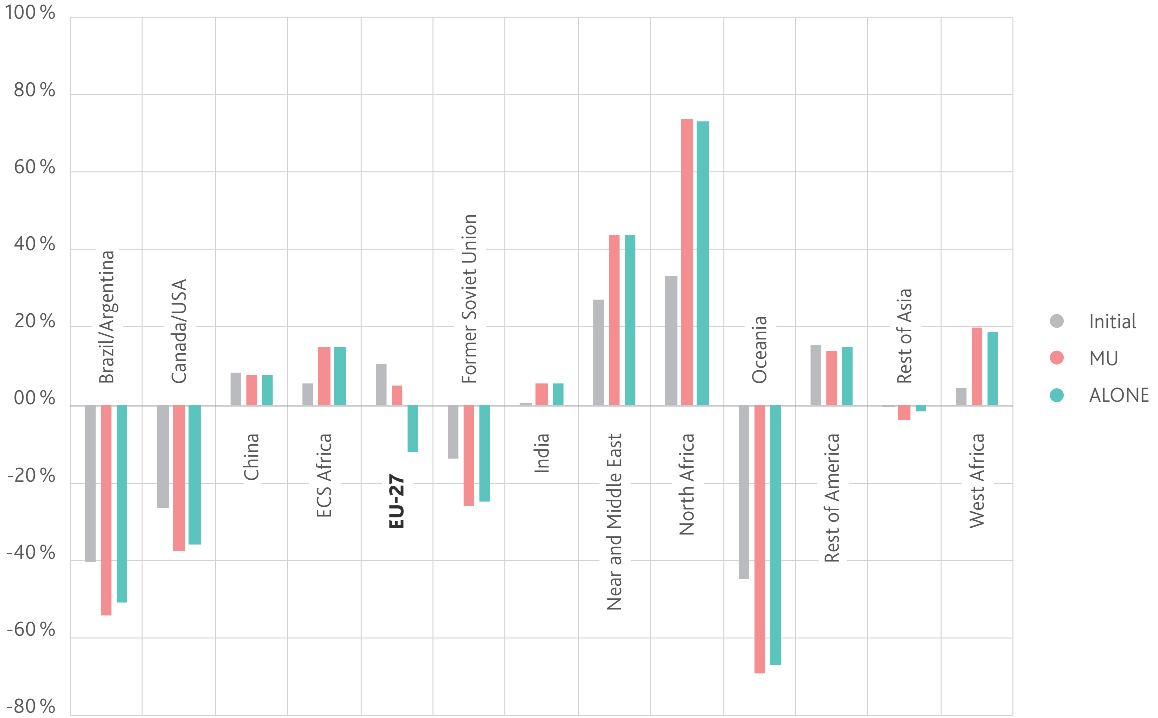
Because of the declined EU imports, in ALONE the rest of the world reduces its exports in both vegetal and animal products (-7% compared to MU). At the same time, the rest of the world imports remain constant. Since they are the main world exporters of soya and other oilseed products, Brazil/Argentina, Canada/USA and the Rest of Asia are the regions which reduce the most their net exports. Therefore, such regions are the most sensitive, at least in terms of trade, to the evolution of the EU food system. The extent of the reduction is however limited with the net import dependence of the three regions moving from -54%, -38% and -4%, respectively, in MU, to -51%, -36% and -2%, respectively, in the ALONE scenario. These small changes illustrate the rather limited role of the EU regarding the future of the world agricultural trade patterns.

FIGURE 20. Export and import of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU and ALONE scenarios



Source: Globagri-Agt

FIGURE 21. Net import dependence in the GlobAgri-AgT regions in the Initial situation and in 2050 under the MU and ALONE scenarios



Source: Globagri-Agt

3.3. Sensitivity analysis #1: the ALONE scenario without the TYFA assumption of changing diets in the EU (ALONE_ UltrapEU)

As a sensitivity analysis to the ALONE simulation, we decided to set up an alternative scenario called ALONE_UltrapEU. In this scenario, we assume that EU agricultural production systems evolve towards agroecology while EU consumers are not ready to switch to a healthier diet and continue purchasing the energy-rich diet based on ultra-processed products[10].

Therefore, in the EU a mix of TYFA and Metropolization_Ultrap hypotheses applies:

— Ultra-processed food diets;
— TYFA cropping system;
— TYFA livestock system.

Just as in ALONE scenario, the EU bans the imports of soya and respects the observed 2010 level of its cropland.

In the rest of the world, the previously mentioned hypotheses of the Metropolization_Ultrap scenario apply.

EU reduces its production of vegetal products

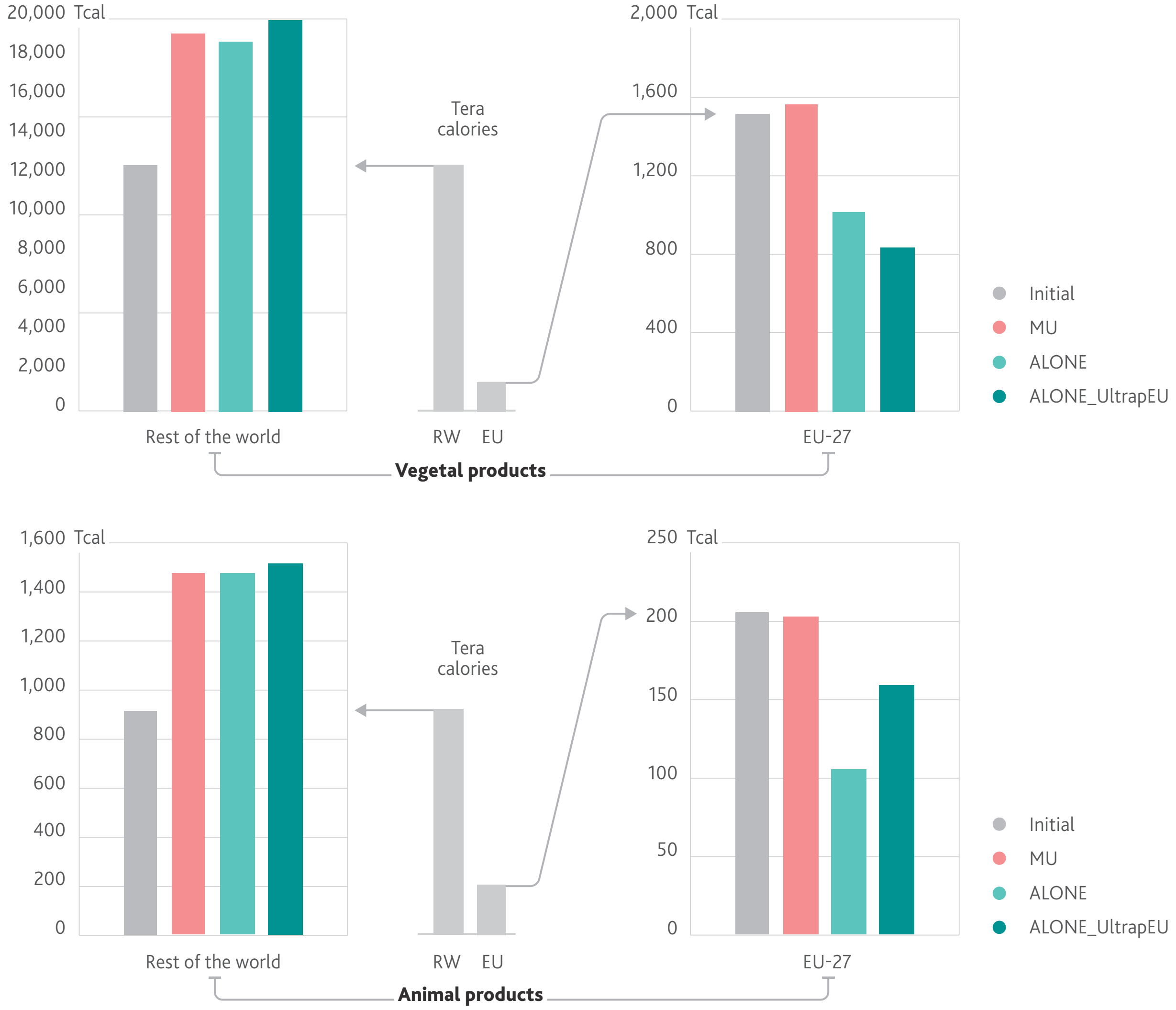
In the ALONE_UltrapEU scenario, assumptions for the EU are the same as in ALONE on the supply side and the same as in MU on the demand side. As a result, contrary to the situation described in the ALONE scenario, in the ALONE-UltrapEU scenario, the EU domestic production in 2050 is no longer sufficient to cover the EU domestic consumption. As the EU is assumed to not being allowed to expand its cropland, it is forced to reduce its exports and increase its imports, in other words to increase its net import dependence.

Constrained by the 2010 level of its cropland, the EU reduces its agricultural production with respect to MU. However, compared to ALONE, this decline affects relatively more the vegetal (-18%) than the animal products (+50%) (**Figure 22**). This difference is explained by the food regime, which is rich in meat and dairy products in ALONE_UltrapEU and the land constraint which is adopted in our simulations. Only the cropland is constrained by the 2010 observed cultivated area in the EU and by a maximum cultivable area in other would regions. In contrast, the grassland area adjusts freely. Then, the EU specializes relatively more in livestock farming fed extensively with a large share of pasture grass.

In ALONE_UltrapEU, the EU reaches the highest level of soybean production. In order to maintain at the same time its ultra-processed diets rich in animal products and an autonomy from vegetable protein imports, the EU develops a large-scale soybean domestic production. This crop production

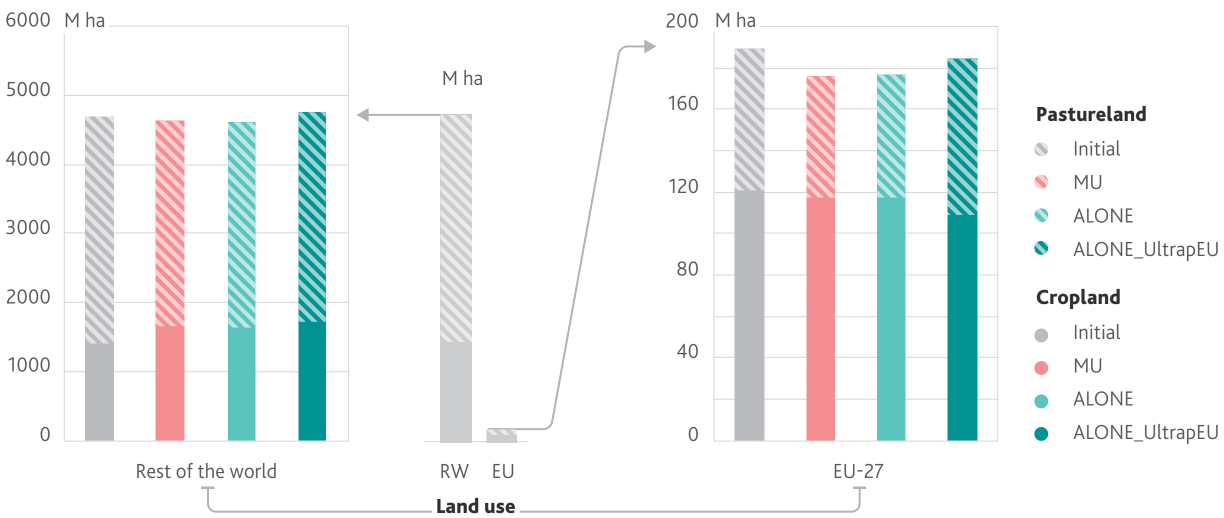
10 Biomass use for energy production is also kept constant in EU 27 between MU and ALONE_UltrapEU scenarios

FIGURE 22. Production of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE and ALONE_UltrapEU scenarios



Source: Globagri-Agt

FIGURE 23. Land use in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE and ALONE_UltrapEU scenarios



Source: Globagri-Agt

reaches 16.5 million tonnes letting the EU become the fourth soybean-producing region at a similar level as India (19 million), but still far behind Brazil/Argentina (114 million) and Canada/USA (97 million).

In ALONE_UltrapEU, the cropland needed to maintain the EU export share in the world market is too high with respect to the 2010 observed level. Hence, the EU leaves to other regions its export shares in the world markets. Consequently, compared to ALONE, the rest of the world production of vegetal (+5%) and animal (+3%) commodities increases.

EU expands domestic forage production and reaches its maximum cultivable area

As mentioned in the previous paragraph, the EU reaches its land boundary and cannot exceed its initial cropland area. Since the EU preserves a relatively higher share of animal production with respect to ALONE and the grassland is let free to adjust to all the shocks introduced into the model, the pastureland increases (+28%) (**Figure 23**). In order to feed the preserved amount of livestock and since forages are not exchanged in world markets, the EU is forced to increase the domestic production of these crops (grass-like forage +44%, other forages +45%). At the same time, the land use for almost all other crops declines, except for soybean production (+38%).

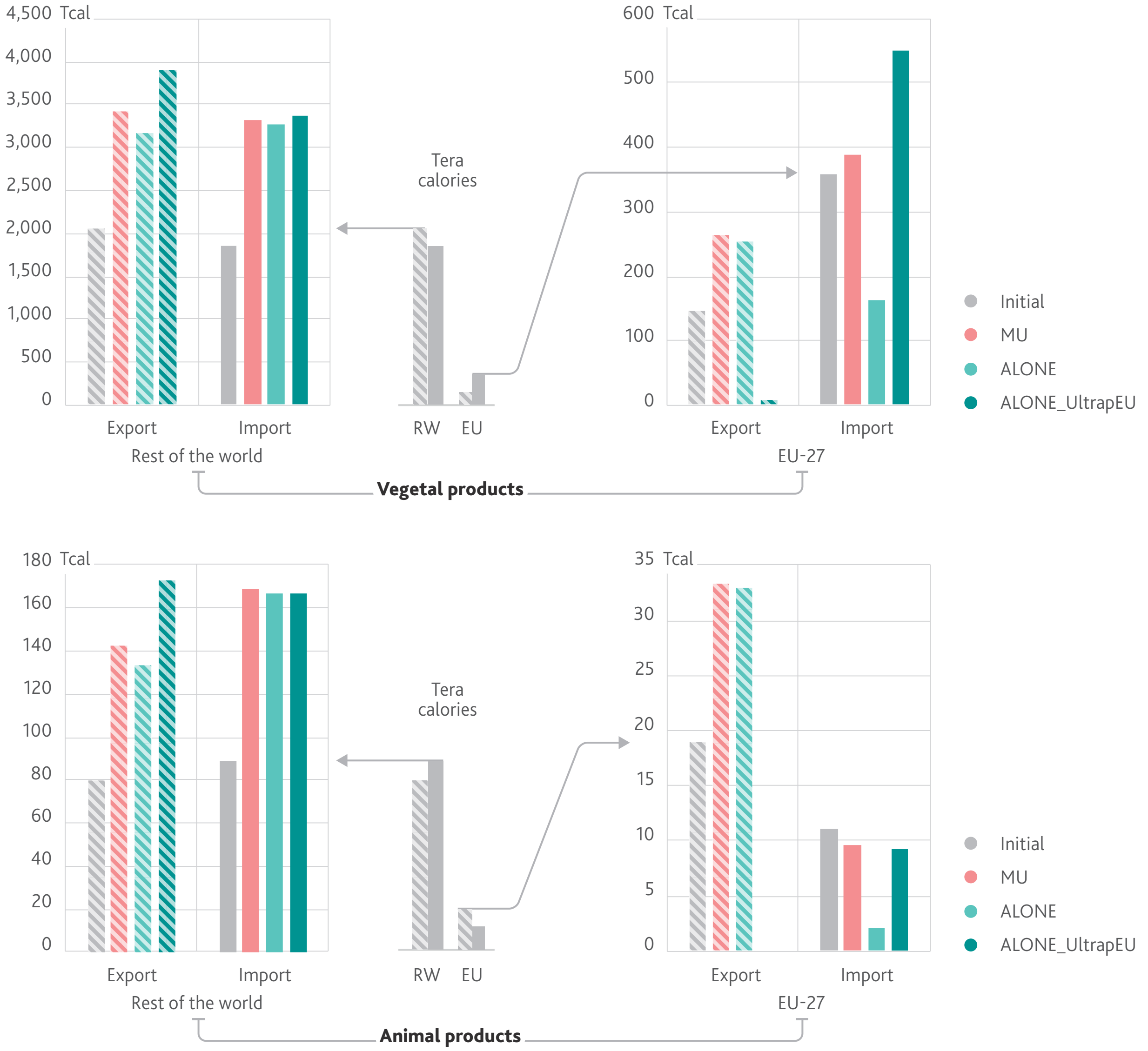
The EU's increased dependence on the world markets leads to amplified land requirements for the other exporting regions, which have to cover the initial export shares of the EU and provide for its increasing imports. Consequently, compared to ALONE, the rest of the world agricultural areas raises both in cropland (+5%) and in pastureland (+2%).

EU import dependence skyrockets

Constrained by the initial level of its cropland, the model forces the EU to drop its exports and then, since this is not sufficient, increase the level of its imports. Therefore, the EU moves from being a net exporter of goods such as dairy products, cereals and pork meat to being a net importer of these commodities. EU import ratio coefficients rise for several products and the total amount of imported calories significantly increases (+241% compared to ALONE) (**Figure 24**). The EU escalates its food requirements towards the world market reaching a very serious net import dependence (36%) with a similar value as the one observed in 2010 for historical importing regions such as North Africa and Near and Middle East (**Figure 25**). A segmentation in domestic market risks appearing in such a scenario: high value food commodities produced domestically with agroecological certifications destined to rich consumers, and low value imported food commodities destined to processing or to poor consumers.

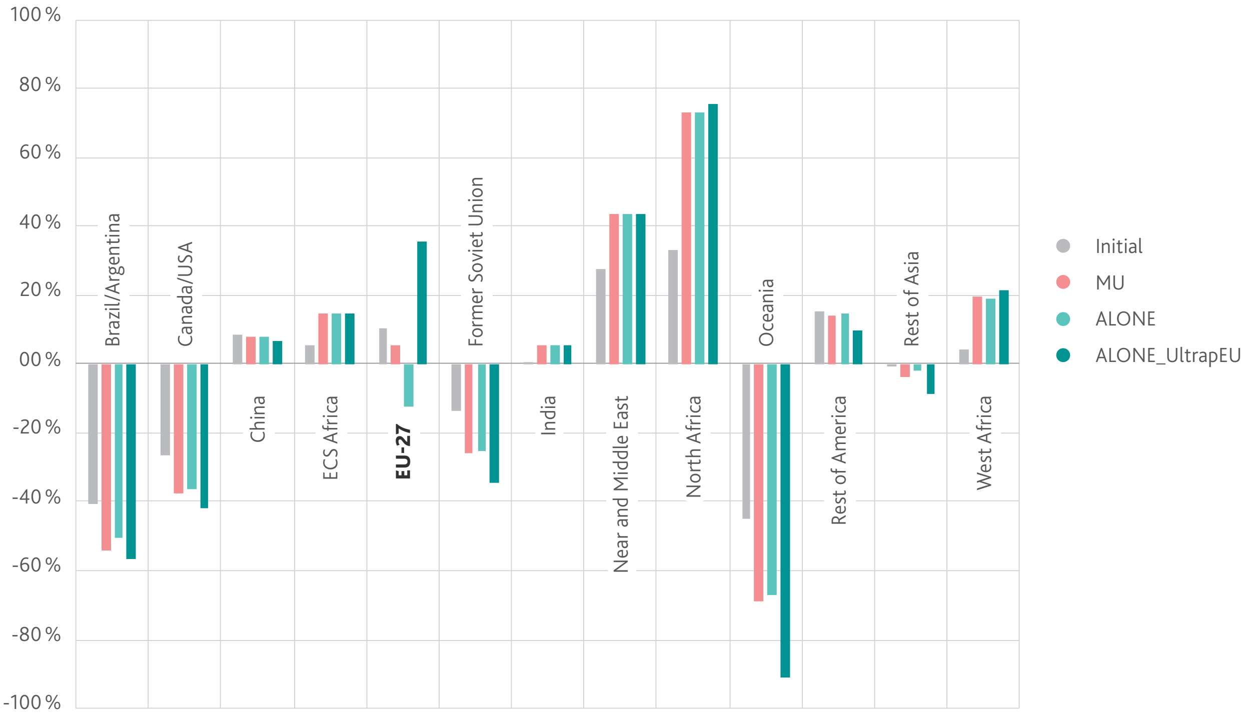
For the rest of the world, the main difference compared to ALONE is that exports expand for vegetal (+23%) and animal (+30%) products, while imports remain constant. This increase compensates the declined EU exports and provides goods for the growing EU import demand of fruits and vegetables, cereals, oils and sugar. Since they have a comparative advantage on these products, Rest of Asia (+445%), Former Soviet Union (+46%), Oceania (+41%) and Canada/USA (+20%) are the regions which increase most significantly their net exports.

FIGURE 24. Export and import of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE and ALONE_UltrapEU scenarios



Source: Globagri-Agt

FIGURE 25. Net import dependence in the GlobAgri-AgT regions in the Initial situation and in 2050 under the MU, ALONE and ALONE_UltrapEU scenarios



Source: Globagri-Agt

3.4. Sensitivity analysis #2: TYFA in the EU going with the global flow (TOGETHER)

As a sensitivity analysis to the hypothesis regarding the evolution taking place in the rest of the world, we simulated the TOGETEHR scenario. In TOGETHER, the EU and the rest of the world follow similar pathways. The EU inherits the TYFA configuration of the ALONE scenario. At the same time, the rest of the world adopts an agroecological production system and a healthy diet based on food diversity. The world population consumes far more fruits and vegetables, coarse grains and pulses, while the shares in diets of meat, vegetable oils and sugar and sweeteners are reduced.

Therefore, the EU keeps the TYFA configuration and the rest of the world adopts the hypotheses of the Agrimonde-Terra Healthy_AE scenario.

Slight decrease of EU agricultural production in 2050 relative to the ALONE scenario

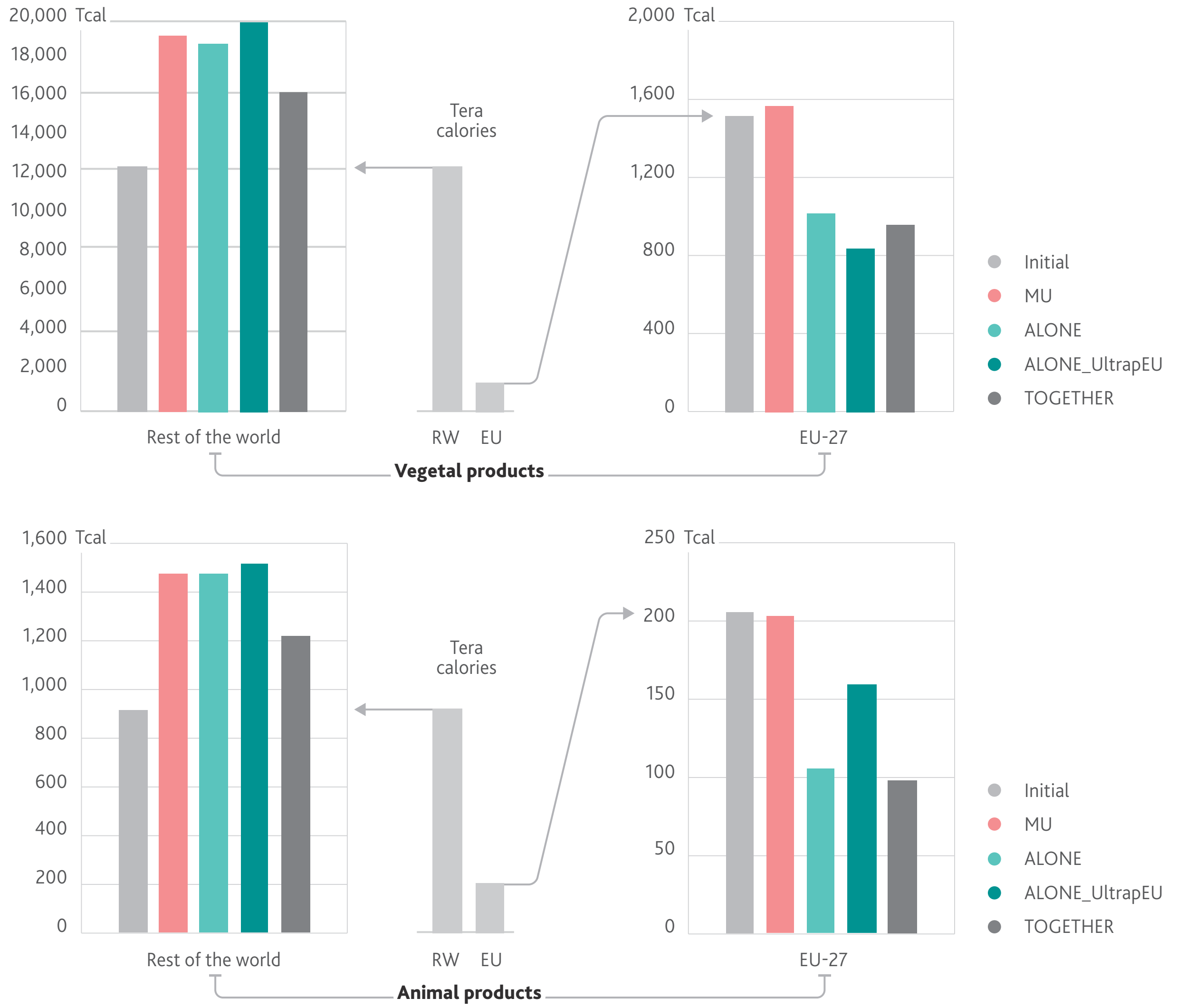
In TOGETHER, the EU keeps the same pathway as in ALONE. The main change takes place in the rest of the world, which adopts a similar pathway as the EU: agroecological production systems and a healthy diet. Food consumption in the EU is not affected when shifting from ALONE to TOGETHER. Thus, EU agricultural production slightly decreases following the contraction of the world markets and the induced reduction of EU exports. EU vegetal and animal productions are 6% and 8%, respectively, lower in TOGETHER than in ALONE (**Figure 26**).

The reduced caloric intake and the healthy diets adopted in developed and emerging countries favour a decline in food consumption and consequently in agricultural production in the rest of the world (and for the world as a whole as well). Compared to ALONE, vegetal (-13%) and animal (-17%) production declines in the rest of the world and especially in oilseed exporting regions such as Brazil/Argentina, Canada/USA and the Rest of Asia. In contrast, in developing regions, for food security purpose, the healthy diet of TOGETHER does not imply a reduced but an increased caloric intake. In addition, the diet shares of animal products are assumed to increase as well relative to the initial situation. It results that the developing regions (India, ECS Africa, West Africa) maintain a similar level of agricultural production compared to ALONE and substantially higher than in 2010.

Agricultural land area slightly increases at the global scale

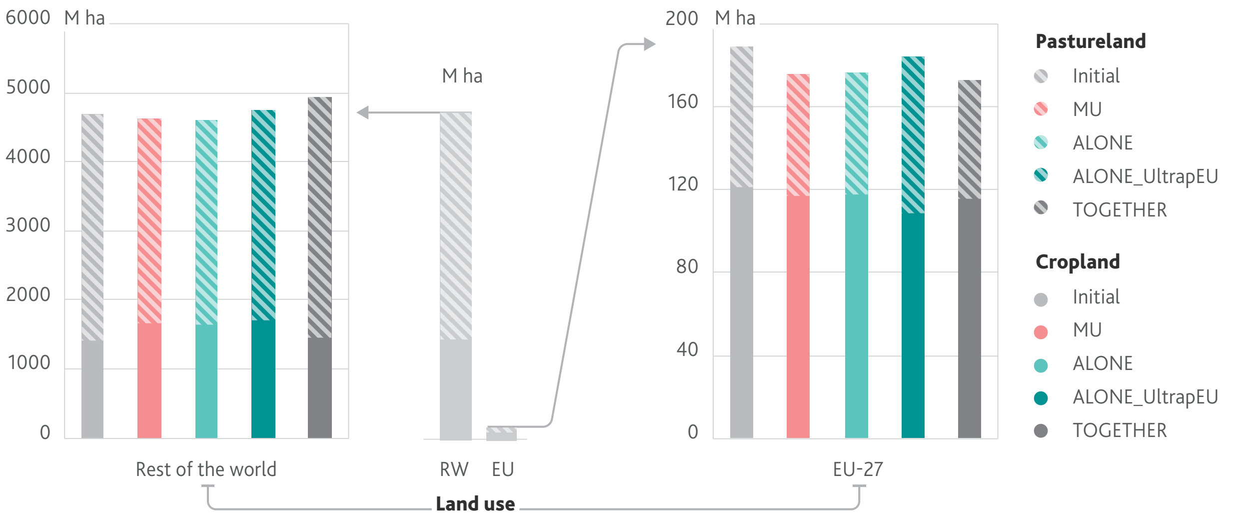
The EU aggregate land requirements are similar in ALONE and TOGETHER for both cropland (-2%) and pastureland (-3%). Because of a lower global food demand than in ALONE, the cultivated area slightly decreases for all crops except for fruits and vegetables, coarse cereals and pulses whose area rises in order to satisfy these renew export sectors (**Figure 27**).

FIGURE 26. Production of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE, ALONE_UltrapEU and TOGETHER scenarios



Source: Globagri-Agt

FIGURE 27. Land use in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE, ALONE_UltrapEU and TOGETHER scenarios



Source: Globagri-Agt

The implementation of agroecological farming practices in all regions of the world reduces yields growth and the output efficiency of livestock productions. For this reason, if compared to ALONE, the rest of the world agricultural area rises (+7%) driven by an increased grassland (+17%), while the cropland declines (-11%). The grassland expands in developing regions where promoting healthier diets implies an increased consumption of animal products. Meanwhile, the cropland decreases in the oilseed exporting regions since the total use of these commodities declines. As a result, TOGETHER is the only scenario where the rest of the world soybeans cultivated areas lower with respect to the initial level and especially in Brazil/Argentina (-39%). More generally, in the rest of the world, all crops reduce their cultivated areas except fruits and vegetables, coarse cereals and pulses which constitute the basis of the healthier diet of this scenario.

In TOGETHER, the transition of agriculture and food systems towards agroecology and healthier diets takes place all over the world. Thus, in this scenario under- and over-nutrition decrease at the world level while agricultural production systems become less detrimental to the environment, at least locally. Indeed, at the global scale, the shift to agroecological production systems makes the world agricultural areas to slightly expand with a potential threat to forest conservation. Deforestation is clearly against the pathway of this scenario, which relies on the stabilization of global warming and requires the implementation of all possible options to mitigate climate change. This means that further improvement in agricultural production systems and especially in livestock systems efficiency in developing regions are essential in order to preserve world forest areas.

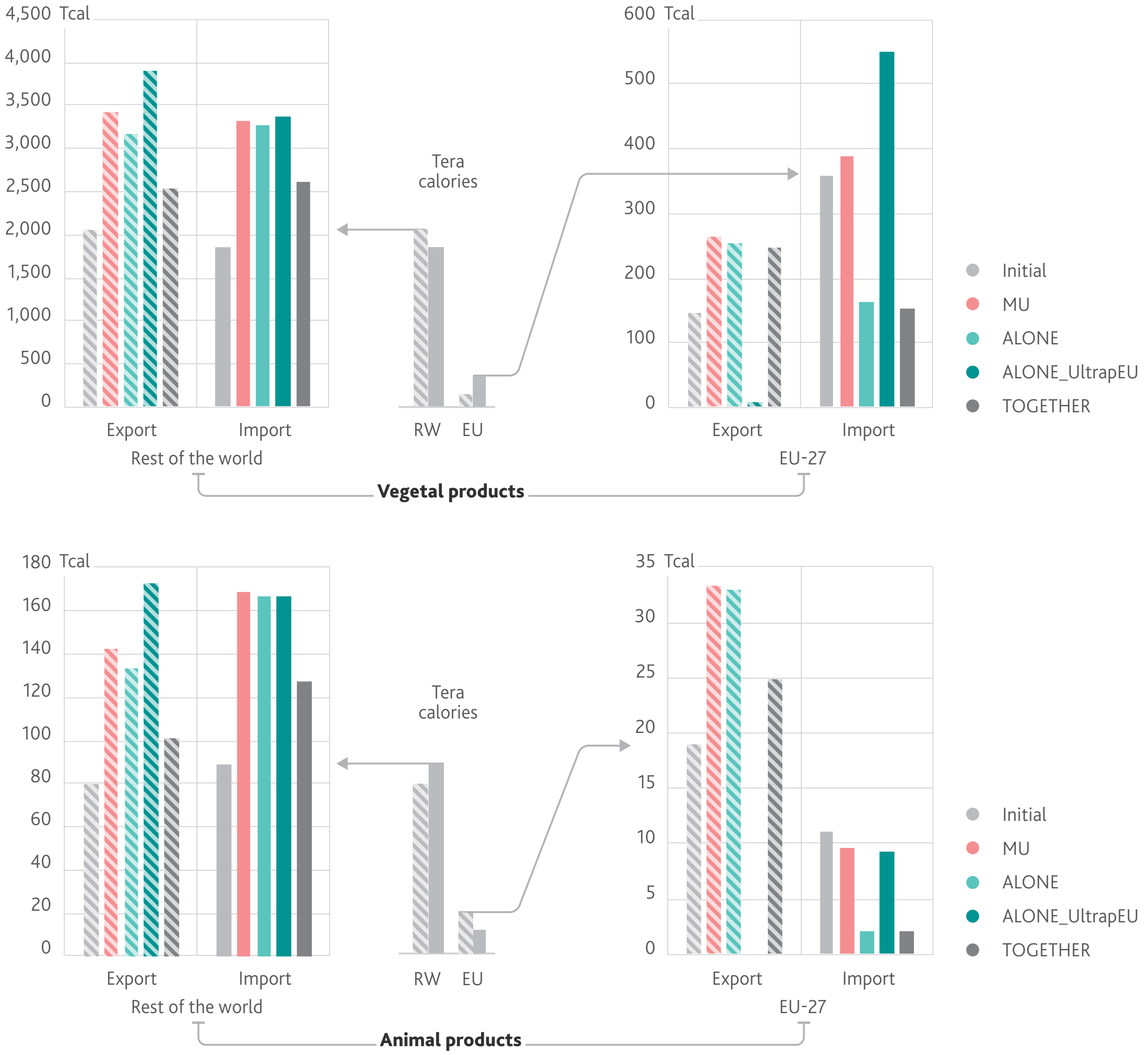
EU exports adapt to the healthy configuration of the global market

The shift of world food consumption and agricultural production systems to healthy diets and agroecology slightly affects the EU aggregate caloric trade balance, which remains positive just as in the ALONE scenario (net import dependence of -12%) (**Figure 29**). More in detail, EU exports of vegetal products remain almost constant (-2%), while exports of animal products decrease (-24%) because of a reduced world demand for these commodities (**Figure 28**). Nevertheless, the structure of EU exports changes to fit the shift of food consumption from ultra-processed to more diverse and healthier products in the rest of the world. In TOGETHER, the EU exports more fruits and vegetables, coarse cereals and pulses, while in ALONE, major EU exports include sugar, wheat, dairy products, poultry and pork meat. The EU position in the world export market is slightly reinforced in the TOGETHER scenario. Indeed, the EU export share for animal and vegetal products moves up from 8% in ALONE to 9% in TOGETHER with a lower area of agricultural land.

Since, by assumption and unless one or more regions reach their maximum cultivable areas, the model maintains the trade structure issued from the initial calibration, if the global demand declines, this leads to reduced imported and exported quantities. Consequently, in TOGETHER, the rest of the world cuts by around a fourth its imports and exports for vegetal and animal calories compared to ALONE. The net exporting regions adapt to the new structure of world trade. They give up their agricultural specialized and intensive systems rose after the nutritional transition experienced in the last decades and replace them with more diversified systems with reduced impact on soil degradation, water pollution and biodiversity loss.

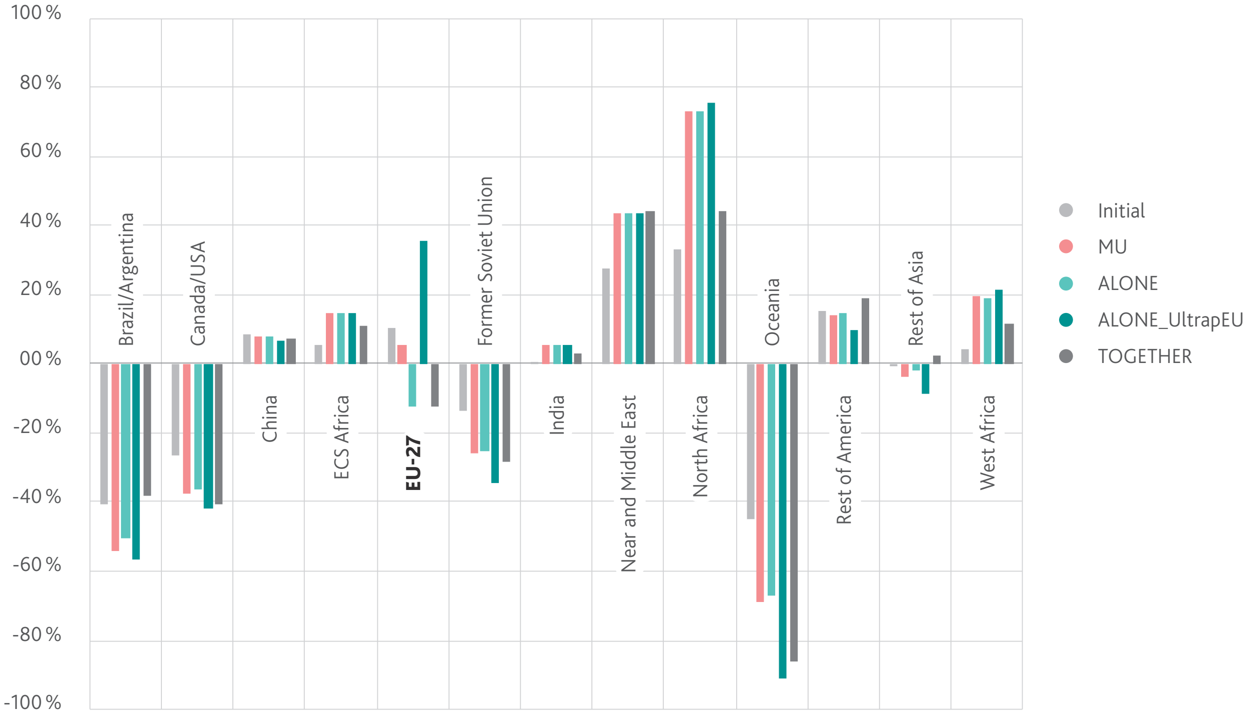
Similarly to what happens in the EU, the rest of the world decreases its exported quantities for all products except coarse grains, pulses and fruits and vegetables. In TOGETHER, the Former Soviet Union and Oceania experience a significant improvement in their trade balance, partly because of the rising share of cereals in the food diets of both developed and emerging countries. As these regions have comparative

FIGURE 28. Export and import of calories in the EU and in the rest of the world in the Initial situation and in 2050 under the MU, ALONE, ALONE_UltrapEU and TOGETHER scenarios



Source: Globagri-Agt

FIGURE 29. **Net import dependence in the GlobAgri-AgT regions in the Initial situation and in 2050 under the MU, ALONE, ALONE_UltrapEU and TOGETHER scenarios**



Source: Globagri-Agt

advantages in cereals production, their net export position is highly reinforced. In contrast, Brazil/Argentina deteriorates its export position with respect to ALONE because of the reduced world demand of oilseed cakes and vegetables oils. India, Near and Middle East and North Africa remain constrained by their maximum cultivable area and are forced to deteriorate their trade balances. In these last two regions, the level of net import dependence is reduced in TOGETHER relative to other scenarios, but remains significantly high showing that an increase in agricultural productivity combined with healthy diets and waste reduction would remain necessary.

4. KEY FINDINGS

4.1. An agroecological Europe can maintain or even increase its export share on the world market, but remains a rather marginal player in terms of global food provision

In both complete TYFA scenarios (ALONE and TOGETHER), the EU can achieve a double objective: it can maintain a relatively unchanged domestic agricultural land area and, at the same time, keep its place on the world markets. This result remains true whatever the evolution pathway ongoing in the rest of the world whose land areas are not affected by EU transition to the TYFA system. In the EU, the share of production oriented to satisfy the domestic market decreases, while the exported quantities grow. Indeed, in ALONE and TOGETHER, the EU shifts from being a net importer to being a net exporter of agricultural goods (in calories). This may be beneficial for EU agricultural producers. They could create a market segmentation based on the high agroecological value of their exported products promoting environmental certifications such as organic labels and increasing their export share in the world markets.

Thus, the main difference between these two scenarios for the EU is not the land use or the aggregate trade balance, but the composition of the exported baskets. For example, in TOGETHER, the EU expands relatively more coarse grains, pulses and fruits and vegetables exports, while in ALONE the EU exports relatively more animal products, sugar and wheat.

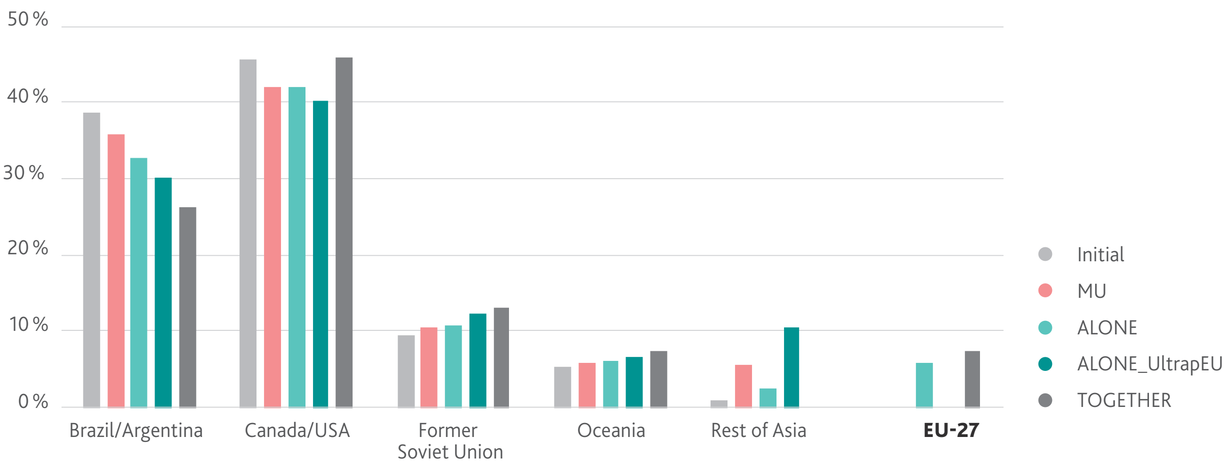
Despite being a major agro-exporter in value with commodities purchased by wealthy consumers all over the world, the EU has no longer a key role in ensuring global food security, even in the scenarios where it becomes a net exporter of calories (ALONE and TOGETHER). The share of EU net exports compared to the share of net exports of the main exporting regions (Canada/USA, Brazil/Argentina, Former Soviet Union, Oceania and Rest of Asia depending on the scenarios) remains low in both simulations with values between +6-8%. This share is never comparable to the one of Brazil/Argentina or Canada/USA, which remain top exporting regions regardless the scenario (**Figure 30**).

4.2. Adopting agroecological production systems without sustainable diets drastically increases EU import dependence

In order to embrace an agroecological production system in the EU, a radical change in food diets seems to be mandatory. Otherwise, a trade-off between land expansion and import dependence risks being present for European policymakers. As suggested by the ALONE_UltrapEU sensitivity analysis, a EU following the TYFA guidelines only on the production side reaches import dependence levels similar to the ones experienced today by historical importing regions such as North Africa and Near and Middle East. This could lead European net importing countries to a position of high food insecurity, especially in a global context marked by trade specialization, price volatility and a runaway climate change.

The alternative to greater food import dependence could be the expansion of agricultural areas in the EU. However, this also seems an impossible solution for the potential harmful effects on deforestation and grasslands conservation. To embrace such a drastic solution, ex-post calculations show that the agricultural area in the EU should increase by around 40% compared to the

FIGURE 30. Share (in calories) of net exports for the main exporting regions in the Initial situation and in 2050 under the MU, ALONE, ALONE_UltrapEU and TOGETHER scenarios



Source: Globagri-Agt

initial level. Therefore, conserving unsustainable diets based on sugar, vegetable oils and animal products seems incompatible with the spread of agroecological production systems in the EU and with the objectives of climate change mitigation and biodiversity conservation.

More in general at a global scale, in order to prevent deforestation and reduce the environmental impact of agriculture, the combination of two factors seems necessary. First, developed countries should switch from ultra-caloric, animal-based diets to a healthier food consumption, lower feed cakes imports and limit the use of mineral fertilisation and pesticides. Second, developing countries should close their yield gaps and improve agricultural productivity in order to curb the effects of their rising demography on cropland and grassland extension.

4.3. A sustainable agroecological transition relies on ambitious policy, economic and societal changes

The key findings presented above show that a sustainable agroecological transition in the EU is biophysically possible without increasing the agricultural land and at the same time maintaining the EU export share on the world markets. However, to start this transition, some disruptive socio-political, economic and commercial pathways seem mandatory.

Since diets are an entry variable in GlobAgri-AgT, in ALONE and TOGETHER scenarios, we make the assumption that EU consumers are ready to switch to healthier food regimes. Though, it seems difficult to propel such as a radical change without policies aimed to sustain this nutritional transition. Announced by the Farm to Fork Strategy but without concrete measures so far, these policies can be divided in two main groups. The first group involves policies which help the consumer to make more informed choices. Among these measures we have the nutritional and environmental labelling, the reinforcement of origin indications and the launch of public education campaigns (ex. nutrition education since young age in the school system). These policies are likely to have a limited effect on changing the consumer behaviour (Capacci, 2012), but if the marketing is well financed and targeted through participative activities (ex. cooking workshops at school or in specific neighbourhoods), they can produce an effect (George, 2016). The second group of policies envisages a specific State intervention to change the market environment. For instance, policies in the second group encompass subsidies to healthy food products (in the form of food stamps for example) or taxes to the unsustainable ones (ex. VAT rate differentiation for animal and ultra-processed products), the regulation of food provision for meals served in school and in the workplace and the advertising control in specific media or at certain hours. While the potential impact of these policies could be greater than the ones belonging to the first group, their implementation is made difficult by a stronger social resistance. Governments fear the consequences of such a direct public intervention, which can be perceived by citizens (and voters) as an unnecessary limitation of their freedom of choice and can threaten the economic interests of a certain number of actors in the agro-food sector.

From an economic point of view, the preservation of EU market shares for agricultural commodities relies on maintaining the EU price and non-price competitiveness. We need to keep in mind that having no prices to solve market equilibria, the GlobAgri-AgT model functions assuming rigid trade structure in each considered world region. Endogenous changes in import ratios and export shares are possible only when a region reaches its maximum cultivable land area (see Annex 2). Otherwise, nothing happens. This means that in the ALONE and TOGETHER scenarios, the EU maintains its export shares simply because its land requirements are satisfied within the maximum cultivable area. In a real-life scenario, the consequences could be slightly different. In a current situation already marked by a decline of EU competitiveness (Wijnands, 2016) and a considerable price differential between local and imported protein-rich feedstuff, the EU could find itself in 2050 with an agroecological production system, but unable to export its high environmental value products on the foreign markets because they are perceived as too expensive by the world consumers. At the same time, the EU could be overwhelmed by cheaper imports produced in regions having lower environmental standards. This means that the EU should try as much as possible to segment the market in order to persuade the foreign and domestic consumer to pay a premium for the "different quality" of EU agricultural production. Without a proper segmentation in the domestic market, the legislator could create an artificial one through an increase of tax and tariffs on imported products. However, this decision risks being counterproductive. As a response, foreign countries could trigger strong reactions reducing EU premium exports (liquors, wine, cheese, high value food preparations) in consolidated markets (ex. USA) or emerging ones (ex. Brazil).

This risk is particularly true for protein crops. In terms of trade policies, the agroecological transition modelled in our scenarios is based on a golden rule regarding the ban of imported soybeans. A domestic production of soybeans and more generally of legumes in the EU becomes compulsory in order to close the nitrogen cycle and phasing out synthetic fertilisers.[11] Imposing such a policy to EU commercial partners in South and North America implies a drastic overturn of EU historical negotiating position since the Dillon Round (see section 1). However, under constant market conditions, a take-off of the EU protein crops sector is difficult to realise. Thus, a period of temporary protection of EU production seems necessary to protect growers and agri-business from unfair foreign markets competition (ex. possibility to import commodities that EU growers are not allowed to produce) and allow them to develop a kind of «import substitution industrialization». During this period, it would be possible to achieve economies of scale, to test innovations and to explore new production possibilities in an economic context «protected» from international competitiveness.

11 See Annex 3 for a more detailed analysis of EU nitrogen balance for the ALONE scenario

The EU should also boost its own productivity in this field by supporting domestic vegetal protein feed productions though agronomic research aimed to increase yields and crop growing in all parts of the continent and through a more efficient market integration between growers, collectors and processors. Given the ecological interest of protein crops and legumes specifically, increasing the current first pillar coupled CAP subsidies in favour of legumes should also be considered provided that the agricultural production follows the agroecological principles. The development of agri-environment-climate measures favouring an increase in the share of leguminous plants in rotation can also be considered.

TABLE 5. Land use change in the EU and at the world level over 2010-2050 in the different scenarios (million ha and % with respect to base period levels)

	Agricultural land	Cropland	Pastureland
MU			
EU	-13 (-7%)	-4 (-3%)	-10 (-14%)
World	-67 (-1%)	+239 (+16%)	-305 (-9%)
ALONE			
EU	-13 (-7%)	-3 (-3%)	-9 (-14%)
World	-84 (-2%)	+213 (14%)	-297 (-9%)
ALONE_UltrapEU			
EU(*)	-5 (-3%)	-12 (-10%)	+7 (+11%)
World	+72 (+1%)	+285 (+19%)	-213 (-6%)
TOGETHER			
EU	-16 (-9%)	-15 (-4%)	-11 (-16%)
World	+245 (+5%)	+37 (+2%)	+209 (+6%)

(*) EU is constrained to the initial level of its cropland

Source: Globagri-Agt.

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5. CONCLUSION

Released in May 2020, under the European Union (EU) Green Deal (European Commission, 2020), the Farm to Fork (F2F) and Biodiversity Strategies involve the EU's vision to stimulate a transition toward sustainable food systems. In a broad approach, the EU commission proposes policy targets to 2030 and policy measures for promoting sustainability in four areas: sustainable food production, sustainable food consumption, sustainable food processing and distribution, and reduced food loss and waste. The Farm to Fork and Biodiversity Strategies constitute a significant shift in the EU agricultural and food sector and is currently a topic of debate.

Very recently, the Economic Research Service (ERS) of the United States Department of Agriculture (USDA) provided an assessment of the impacts of the F2F and Biodiversity Strategies on world food security (Beckman, 2020). Their simulated scenarios cover the sustainable production part only of the EU F2F and Biodiversity Strategies and do not consider the environmental and health costs of current agricultural practices. [12] Simulation results show that restricting input use (fertilizers, pesticides, antimicrobials and agricultural land), as targeted in the EU Strategies on the agricultural supply side, without changing nothing downstream in the food chain, especially consumers' demand, would lead to negative impacts on world food security. Food prices would increase worldwide, negatively affecting consumer budgets, and contributing to rise the number of food-insecure people in the world's most vulnerable regions. The extent of such impacts would increase the widest if the adoption of EU Strategies will be replicated by other countries in different world regions.

It is worth noting that this argument of a reduced EU's contribution to the world food security, which could result from a transition toward a more sustainable EU food system, is regularly advocated by the most reluctant groups to such a transition. The latter already wave the USDA-ERS report as a proof of the global disaster that the EU Strategies would induce (e.g., l'Opinion, 2020; Farm Europe, 2020; Coordination rurale, 2020).

As mentioned in the introduction, the TYFA scenario attracted exactly the same criticisms as soon as it was released, and this was the starting point of the current study: what could be the worldwide impact of the TYFA scenario? Indeed, our objective was twofold: assessing the impact of the TYFA scenario at the global scale on the one hand, exploring how the TYFA scenario's impacts inside the EU are sensitive to the pathway of change in food systems in the rest of the world, on the other hand.

In line with the USDA-ERS findings, our simulation results confirm that implementing a truncated TYFA scenario in the EU, involving transition toward agroecology of the agricultural production systems only, while the other parts of the food chain remain on business-as-usual trends (ALONE_UltrapEU scenario), would likely be detrimental in terms of global food availability. Our GlobAgri-AgT tool is a biomass balance model and thus does not involve a price equilibrium mechanism. However, our results show that under this scenario, the EU would exceed its maximum cultivable area constraint and have to decrease its exports and increase its imports dramatically. Such adjustments have the potential to drive world food prices up and affect global food security.

On the contrary, when considering the whole TYFA scenario, whatever the evolution of food systems in the rest of the world, our results clearly contradict those of the USDA-ERS report. We show that a broad transition toward agroecology involving the whole EU food chain, from the agricultural production systems to the food diets, including food loss and waste, would not challenge the EU export potential and would contribute to decrease EU imports needs (mainly following the phasing out of oilseeds/protein crop imports). As a result, the EU would turn from a net importer to a net exporter of calories. In other words, a transition toward agroecology of the whole EU food system might not contribute to challenge the world food availability.[13] Furthermore, this finding is not sensitive to the evolution pathway of the food systems in the rest of the world: ongoing trends (ALONE) or transition towards healthier diets and agroecological agriculture (TOGHETHER). Overall, our results suggest that if the EU population accepts drastic changes in the food regimes (healthier and more balanced diets with a lower caloric amount and a reduced share of animal and ultra-processed food products), the EU could adopt the TYFA prescriptions. This means that at the same time, the EU can maintain unchanged its actual amount of agricultural areas, keep its export potential in quantity, decrease its dependence to imports and transform its agricultural production system with positive effects on biodiversity, greenhouse gas emissions, the protection of natural resources and also human health.

The TYFA scenario goes further than the F2F and Biodiversity Strategies in terms of input reduction in agricultural production systems. It is also more specific regarding the required changes in food regimes and waste and loss decrease. This means that even if the EU Strategies are in line with the spirit of the TYFA scenario, the latter would require a more ambitious EU policy intervention. Firstly, the overall support of the CAP should be

12 https://www.inrae.fr/en/news/usda-assessment-european-strategies-associated-green-deal-gives-pessimistic-view-due-simplistic-approach

13 It is worth noting that starting from a different perspective (analysing how the share of the EU in world agricultural trade could change up to 2050, under contrasting assumptions on food diets and agricultural productivity change at the global level), Tibi *et al.* (2020) indirectly show consistent results: in 2050, the EU could increase its domestic protein crops production and/or reach lower crop yields without undermining its contribution to world food availability.

re-designed as to favour the transition to agroecological production systems. Secondly, strong intervention and appropriate policy instruments are necessary to influence food regimes and make them compatible with the transition toward agroecology of the whole EU food system. Thirdly, the EU will have to promote trade policy measures and quality and market segmentation incentives in order to preserve the price and non-price competitiveness of EU agriculture and food. Indeed, no transition will be possible if EU farmers suffer from the competition of cheaper imports and if consumers (EU and non-EU) do not differentiate food products according to the way they are produced and are not willing to pay for the specific quality attributes of these products.

Our study is not a broad assessment of the impacts of a transition toward agroecology of the EU food system. Due to the modelling tool we use, we were only able to assess the impacts on food quantity balances in the EU and abroad of such a transition. Of course, this is insufficient since it does not provide a clear information on the costs and benefits of this transition as well as on the potential induced trade-off. For that purpose, we would need to assess the impacts of the TYFA scenario on food prices inside and outside the EU and the related economic indicators such as income and welfare changes. Similarly, we would need to evaluate the environmental impacts of the TYFA scenario, especially biodiversity preservation and greenhouse gas emissions. These are directions for further research.

ANNEX 1: DETAILED AGRIMONDE TERRA SCENARIOS

Global context

Regarding the global context, quantitative assumptions concern population change and change in trade conditions. Change in GDP (gross domestic product) per capita is implicitly taken into account through its impact on food diet change (see hereafter). The general rules for building these quantitative assumptions are the following:

— Changes in total world and regional population are the same in both global context pathways. The median projection up to 2050 provided by the United Nations (2015 revision) is used.
— Import coefficients[14] and export shares[15] of world regions are not changed exogenously whatever the global context pathway. They may change endogenously when a region reaches its maximum cultivable area (see Annex 2).

Climate change and mitigation

Climate change patterns to 2050 are described through two pathways, inspired from the Representation Concentration Pathways (RCP) of the fifth assessment report of the IPCC (Intergovernmental Panel on Climate Change): 'Runaway climate change' (close to RCP 8.5) for Metropolization_Ultrap and 'Stabilisation of global warming' (close to RCP 2.6) for Healthy_AE.

The general rules for building the corresponding quantitative assumptions are as follows:

— We assume that in the 2007-2009 (named '2010' for simplicity) initial situation, the maximum cultivable area (i.e., the maximum area which can be devoted to arable and permanent crops) in each region equals the area under suitability indices 1 to 4 according to the Global Agroecological Zones (GAEZ) approach. [16]
— We assume that up to 2050, this maximum cultivable area is affected by climate change. To quantify the climate change effects we use Zabel *et al.* (2014)'s results and adopt the following assumptions: i) change according to Zabel *et al.*'s results (RCP 8.5) in the 'Runaway climate change' pathway; ii) no change in the 'Stabilization of global warming' pathway.
— We assume that climate change is likely to affect the evolution of crop yields induced by changes in cropping systems up to 2050. For quantifying the climate change effects on crop yield evolution, we use Müller and Robertson (2014)'s results and adopt the following hypotheses: i) change according to Müller and Robertson's results (RCP 8.5) in the 'Runaway climate change' pathway; ii) no change in the 'Stabilization of global warming' pathway.
— Due to data uncertainties and absence of consensus in the literature, we did not establish quantitative hypotheses on the impact of climate change and mitigation pathways on grass and forage yield change, nor on livestock productivity change.
— Quantitative mitigation hypotheses (Table 6) have been established based on IPCC work (IPCC, 2014). In both the 'Runaway climate change' and the 'Stabilization of global warming' pathways, we assume that up to 2050, food, feed and energy crops are competing on the maximum cultivable area in each region: regional maximum areas available for food and feed crops equal regional maximum cultivable areas *minus* areas devoted to energy crops.

TABLE 6. World production of energy from biomass (EJ) in 2050

	Energy crops (2G)	Forest	Residues	Other (algae)
Runaway climate change	30	0	30	0
Stabilization of global warming	30	30	30	12

Food diets

Two food diet pathways are considered: 'Transition to diet based on ultra-processed products' (Ultrap diet) and 'Healthy diet based on food diversity' (Healthy diet). The general rules that we established for building our quantitative hypotheses for both food diet pathways relate to both the change in the daily calories availability per capita and the share of the various groups of food in the diet. They are reported in **Table 7**.

14 Ratio between imports and total use of a commodity.

15 Ratio between the exports of a commodity of one region and the sum of total world exports of this commodity.

16 In the GAEZ approach, land is classified according to its quality or suitability for agricultural production. There are eight classes ranging from 'very suitable' to 'not suitable'. GAEZ suitability indices 1 to 4 correspond to 'very suitable' to 'moderately suitable' land. For more details, see Le Mouël *et al.* (2018).

TABLE 7. General rules for the changes in food diets over 2010-2050 under both diet pathways

	Ultrap diet	Healthy diet
Diet energy (Daily calories available per capita)	- Regions over 3,300 kcal/cap/day in 2010: unchanged up to 2050 - Regions between 3,000 and 3,300 kcal/cap/day in 2010: increase to 3300 in 2050 - Regions under 3,000 kcal/cap/day in 2010: increase to 3,000 kcal/cap/day in 2050	- Regions over 3,000 kcal/cap/day in 2010: decrease to 3,000 - Regions under 2,750 kcal/cap/day in 2010: increase to 2,750 - Regions between 2,750 and 3,000 kcal/cap/day in 2010: unchanged
Diet pattern	- Change according to 1998/2008 trends in Brazil. In all regions except Canada/USA: no change relative to 2010 - 2 diet share minimum thresholds: 13.5% for vegetable oils; 10% for animal products - Within the meat group: strong substitution from ruminant meat to poultry meat	- Diet share of animal products and pulses: 20% - Diet share of cereals: 50%, coarse grains accounting for 1/4 to 1/3 - Diet share of fruits and vegetables: 15% - Diet share maximum thresholds: 10% for vegetable oils, 2.5% for sugar and sweeteners - Within the meat group: substitution from ruminant meat to poultry meat

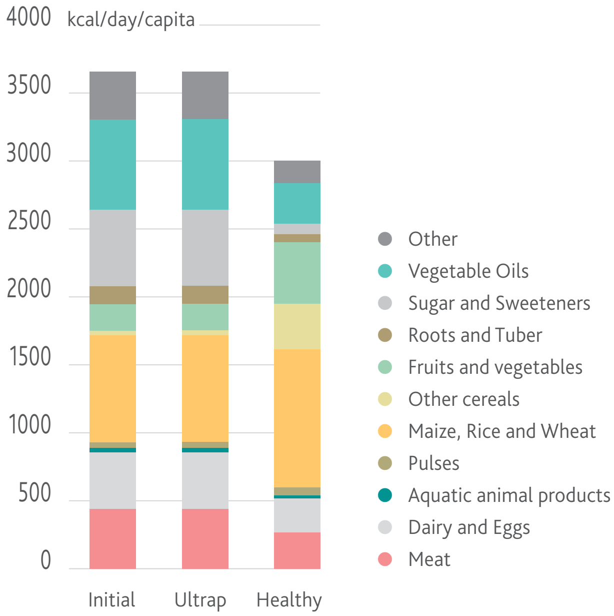
Under the 'Ultrap' pathway, the average world diet becomes richer in daily calories per capita from 2010 to 2050, with more vegetable oils and sugar and sweeteners. On the contrary, the 'Healthy' pathway makes the average world diet in 2050 nearly unchanged in terms of daily calories per capita, but with more fruits and vegetables, coarse grains and pulses, and significantly less meat and sugar and sweeteners, relative to 2010. As shown in **Figure 31**, our assumptions induce very different changes in food diets from 2010 to 2050 across regions. For developed regions, such as Canada/USA, only the 'Healthy' pathway leads to significant change in food diets from 2010 to 2050. While both pathways imply moderate changes in food diets for emerging countries such as China. In contrast, our assumptions induce significant changes in food diets, whatever the pathway, in developing countries such as ECS (East, Central and South) Africa.

It is worth noting that for ECS Africa, according to our assumptions:

— Both pathways involve an increase in the daily calories availability per capita. As a sharp increase in population is also expected in ECS Africa, this means that food consumption will increase significantly under both pathways in this region (the same is observed for India).

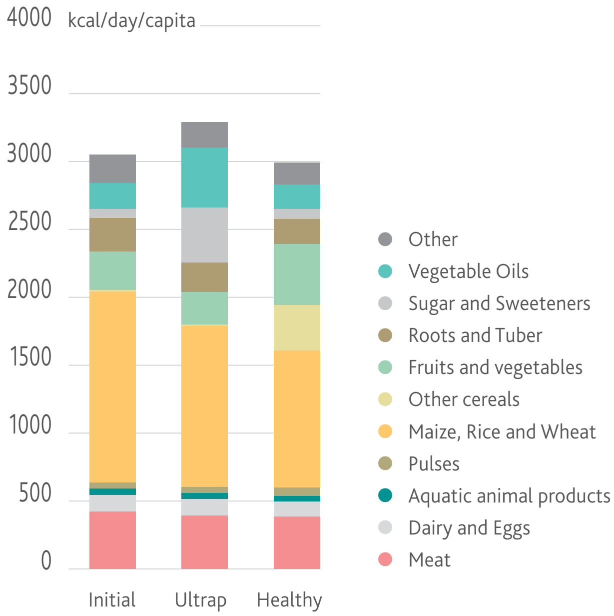
— Both pathways result in a rise in the share of animal products in diets. Once again, joint with the expected population increase, this rising share of animal products in diets will lead to a huge increase in food consumption of meat, dairy and eggs under both food diet pathways in ECS Africa (even under the healthy diet assumption) (the same is observed in India and West Africa).

FIGURE 31a. Food diets in 2010 and in 2050 under the Ultrap and Healthy pathways in Canada / USA



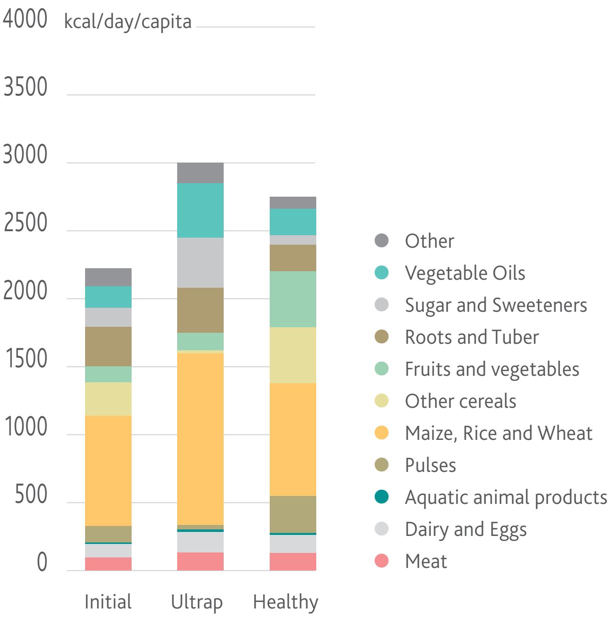
Source: Le Mouël et al., 2018

FIGURE 31b. Food diets in 2010 and in 2050 under the Ultrap and Healthy pathways in China



Source: Le Mouël et al., 2018

FIGURE 31c. Food diets in 2010 and in 2050 under the Ultrap and Healthy pathways in ECS Africa



Source: Le Mouël et al., 2018

Cropping systems

Two pathways for the evolution of cropping systems are considered: 'Conventional intensification' and 'Agroecology'.

We adopted three general rules in order to translate the cropping systems pathways into quantitative hypotheses for regional per-hectare yield changes (**Table 8**):

— We calculated current yield gaps for Agrimonde-Terra's crops and regions using potential and observed per-hectare yields provided by the GAEZ database portal.[17] Then, we assumed a level of yield gap reduction between 2010 and 2050, which is differentiated according to cropping pathways, and which we applied uniformly to groups of crops (cereals, protein seeds and other crops) and grass and forages.

— We hypothesized that there is induced technical change together with induced change in the distribution of crops across land fertility classes, which results in greater rate of yield increase for crops which are the most demanded at the world level. If we consider a group of crops, such as cereals, the above-described yield gap reduction applies to the average cereal yield. Then, we assume that within the cereal group, cereal crops which are the most demanded will benefit from above-average yield gap reductions (H in **table 8**), while cereal crops which are less demanded will experience below-average yield gap reductions (L in **table 8**). The retained indicator for "most demanded/less demanded" crops is the change in the respective crop shares in the average world diet under the two food diet pathways.

— Grass and forage crops benefit from the same yield gap reduction than other crop groups.

TABLE 8. General rules for the changes in crop yields over 2010-2050 under both cropping systems pathways

	Average yield gap reduction	Higher (H)/Lower (L) yield gap reduction for specific crops
'Conventional intensification' with the Ultrap diet	-50%	Grains: H maize/L coarse grains Oilseeds and pulses: L pulses Other products: H sugar crops
'Agroecology' With the Healthy diet	-30%	Grains: H coarse grains/L others Oilseeds and pulses: H pulses/L others Other products: H fruit and vegetables/ L Others Grass and forage: 0

As far as cropping intensity ratios are concerned, our general rules imply that cropping intensity ratios in 2050 remain equivalent under 'Conventional intensification' and 'Agroecology'.

Following the above-described hypotheses, in average crop yield growth from 2010 to 2050 is greater in the 'Conventional intensification' than in the 'Agroecology' pathway. These hypotheses, which are key factors regarding the land-use change effects of the scenarios, are controversial and were extensively discussed with the Scenario Advisory Committee of Agrimonde-Terra (see Le Mouël *et al.*, 2018).

It is noteworthy that when simulating the whole scenarios, the 2050 yields are those including both the impacts of changes in cropping systems and the impacts of climate change. Five main points may be underlined:

— Following our general rules, per-hectare yields increase between 2010 and 2050 in both 'Conventional intensification' and 'Agroecology' pathways, for all crops in all regions, except those exhibiting initial zero yield gaps (such as rice in Rest of Asia for instance). For the latter, per-hectare yields are constant in 2050 compared to 2010. In all other situations, whatever the cropping system pathways, the higher the initial yield gap, the higher the yield increase over 2010-2050.

— Following our general rules, for the main current cereals (maize, rice and wheat) and oilseeds (soybean) and for sugar crops, in all regions, yield increases over 2010-2050 are greater with the 'Conventional intensification' than with the 'Agroecology' pathway.

— The situation is different for other crops such as other cereals, pulses, fruits and vegetables and roots and tubers, which consumption increases more with the 'Healthy' diets. For these crops, in all regions, due to our induced technical change hypothesis, yield increases between 2010 and 2050 are higher with the 'Agroecology' pathways than with the 'Conventional intensification pathway'".

17 We used the data for year 2000, the potential yields obtained with so-called "high inputs" cropping systems (potential yields are also available for "intermediate inputs" and "low inputs" cropping systems) and, for both actual and potential yields, a weighted average of rainfed and irrigated yields (the weights being the relative shares of rainfed and irrigated land areas).

— In average, whatever the pathway of the cropping systems, all regions experience a growth of crop yields (in contrast with yield decrease in TYFA). This increase is greater in developing regions than in developed ones.

Livestock systems

Based on trends in animal feed, efficiency of animal systems, crop-livestock synergies, and herd mobility, two hypotheses for the future of livestock systems were produced: 'Conventional intensive livestock' and 'Agroecological livestock'.

In GlobAgri-AgT, regional livestock systems are quantitatively described and modeled based on data from Herrero *et al.* (2013). In each region, we consider five livestock sectors (dairy, beef, small ruminants, pork and poultry), producing six animal products (milk and dairy, beef meat, small ruminant meat, pork meat, poultry meat and eggs). Each ruminant livestock sector is made up of four production systems (Herrero *et al.*'s so-called mixed, pastoral, urban and other systems). Each monogastric sector involves two production systems (Herrero *et al.*'s so-called urban and other systems).

We faced difficulties when quantifying the hypotheses for the future of livestock systems and had to adopt restrictive assumptions. Our difficulties resulted from, at least, two main reasons. First, only two entry variables of the GlobAgri-AgT model were available to quantify the hypotheses for the future while the latter involved livestock pathways, which are differentiated on a set of various dimensions. Secondly, as far as ruminant sectors are concerned, there was not a clear ranking of the different production systems, from the least to the most intensive, emerging from the initial data we used. Hence, it was not easy to choose which production system(s) would expand more than the others in each retained hypothesis for the future (see below).

The two concerned entry variables of the GlobAgri-AgT model are:

— regional feed-to-output ratios (measuring the quantity of dry matter feed per unit of output produced) of each system in each sector;

— regional shares of the different production systems in the total output production of the considered sectors.

We assume that, in each region, the overall productivity of a livestock sector (as measured by its global feed-to-output ratio) may change between 2010 and 2050. This could happen through both the change in the feed-to-output ratios of the various systems in the sector (measuring the mixed effects of changes in the productivity per animal, in animal diseases and mortality and in the efficiency of feed rations) and the change in the relative shares in production of these various systems.

The general rules adopted for quantifying the livestock systems pathway of change are the following. They apply at the regional level:

— each future pathway is associated with one or two specific production systems per sector: the chosen systems are those where changes are occurring, other systems remain constant over 2010-2050. For each livestock systems pathway, production systems concerned by changes are chosen as those best fitting the dynamics involved in the pathway (**Table 9**).

— For production systems experiencing changes between 2010 and 2050, feed-to-output ratios are assumed to change according to projections to 2030 provided by Bouwman *et al.* (2005). This rule applies to all regions except West Africa and ECS Africa. In both regions, we assume that feed-to-output ratios change two times faster than expected in Bouwman *et al.*'s projections for the beef sector.[18]

TABLE 9. General rules for the changes in livestock systems over 2010-2050 under both pathways

	Conventional intensive livestock	Agroecological livestock
Change in feed-to-output ratios[19]		
Ruminant		
Mixed	Decrease (Bouwman *et al.*)	Decrease (Bouwman *et al.)*
Pastoral	Decrease (Bouwman *et al.*)	Decrease, (Bouwman *et al.*)
Urban	No change	No change
Other	No change	No change
Monogastric		
Urban	Decrease (Bouwman *et al.)*	No change
Other	No change	No change
Change in production shares		
Ruminant		
Mixed	Increase	Increase
Pastoral	Decrease	No change
Urban	Decrease	Decrease
Other	Decrease	Decrease
Monogastric		
Urban	Increase	Decrease
Other	Decrease	Increase

Following our general rules, applied reductions on feed-to-output ratios:

— do not differ between 'Conventional intensive livestock' and 'Agroecological livestock' for ruminant sectors. Indeed, in contrast to our quantitative hypotheses regarding cropping systems pathways, we were not able to find evidence of any performance gaps (in terms of feed-to-output ratios) between conventional and agroecological systems. Hence,

18 As shown in Le Mouël *et al.* (2018), initial feed-to-output ratios of the mixed system in the beef sector in West Africa and ECS Africa are very high compared to those exhibited by the other regions. There are consistent explanations for such a situation related to the specific role of livestock in both regions: livestock provide nutrient-rich food 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, etc. Despite huge uncertainties, we assumed however, notably on the basis of literature and experiences, that there exist rooms of manoeuvre for improving livestock feed-to-output ratios in West and ECS Africa, and that Bouwman *et al.*'s projections are rather pessimistic to this regard.

19 For feed-to-output ratios: decrease means that 1 ton of animal product requires less quantity of dry-matter feed, implying higher productivity of the production system.

the only difference in global performance changes in ruminant sectors lies in the diverging evolution of production shares of the various ruminant systems under both pathways: the production shares of mixed systems increase to the detriment of all systems in the 'Conventional intensive livestock' pathways, including the pastoral one, while in the 'Agroecological livestock' pathway, the production shares of the mixed systems increase to the detriment of urban and other systems only, the shares of pastoral systems remaining constant;

— are greater in 'Conventional intensive livestock' than in 'Agroecological livestock' for monogastric sectors. Based on expert knowledge, we considered that shifting to agroecological systems would not allow to gain any efficiency in monogastric sectors as far as feed-to-output ratios are concerned;

— are significantly greater in developing regions than in developed regions. For the latter, Bouwman *et al.*'s projections to 2030 suggest that nearly no further improvement in efficiency (as measured by feed-to-output ratios) could be realized in the dairy, pork and poultry sectors.

Finally, following our general rules and due to initial data, our quantitative hypotheses generally lead to:

— improvement of the global efficiency of ruminant sectors for both the 'Conventional intensive livestock' and the 'Agroecological' pathways;

— ambiguous results regarding the global efficiency of monogastric sectors, mainly due to the initial better performances of "Other" systems in terms of feed-to-output ratios, which contribute to deteriorate the global efficiency of the sectors when the production shares of these "Other" systems are adjusted down.

ANNEX 2: THE GLOBAGRI-AGT DATABASE AND MODEL

The GlobAgri-AgT model

The GlobAgri platform was set up by CIRAD and INRA to generate consistent databases and biomass balance models using data from FAOSTAT and different institutions. 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 and other) for each region and each agri-food product. In each equation, imports are a linear function of total domestic use 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 use of agri-food products, provided that hypotheses on a set of variables (such as plant and animal yields, maximum available cultivable land, trade conditions etc.) are made.

The GlobAgri platform has been used to generate a database and a biomass balance model specifically customized for the Agrimonde-Terra foresight (Le Mouël *et al.*, 2018). The resulting tool is named GlobAgri-Agrimonde-Terra (GlobAgri-AgT). It encompasses 38 agri-food products and 14 world regions (**Table 10** and **Table 11**). The reference year is the 2007-2009 average (often named "2010") and the simulation horizon is 2050. Data used are mainly the FAO's Commodity Balances (FAOSTAT Statistics Database, 2016). Additional data used are from Herrero *et al*. (2013) for feed rations (including grass and forage), Monfreda *et al*. (2008) for production and area of forage plants, and GAEZ (2012) for maximum cultivable areas.

The GlobAgri-AgT biomass balance model is made up of a resource-utilization balance equation for each agri-food product in each region:

$$Prod_{ijt} + Imp_{ijt} - Exp_{ijt} = Food_{ijt} + Feed_{ijt} + Oth_{ijt} + Wast_{eijt} + VStock_{ijt}$$

Where i is the product ($i \in I$), j the region, t the reference year, $Prod$ the domestic production, Imp imports, Exp exports, $Food$ the domestic food consumption, $Feed$ the domestic feed use, Oth the other domestic uses, $Waste$ the waste and $VStock$ the stock change.[20]

For all plant (vegetal) products ($v \in I$), domestic production equals harvested area (A) multiplied by per-hectare yield (Y):

$$Prod_{vjt}=A_{vjt}{*}Y_{vjt}$$

For all products, the domestic feed use is a linear function of the domestic production of reference animal products ($a \in I$)[21]:

$$Feed_{ijt} = \sum_a \beta_{iajt} * Prod_{ajt}$$

Where β_{iajt} is the fixed transformation coefficient of product i into animal product a in region j for year t. β_{iajt} are thus what we call the feed-to-output ratios. For each animal product (e.g. milk), they are a weighted average of the corresponding feed-to-output ratios observed in the various production systems co-existing in the sector concerned (e.g. mixed, pastoral, urban and other systems co-existing in the dairy sector). For the five sectors under consideration (dairy, beef, small ruminants, pork and poultry), the various production systems are those suggested by Herrero *et al*. (2013). The way the feed-to-output ratios are computed at the production system level and at the sector level is described in detail in Dumas (2014).

Finally, for all products i, imports are written as a fixed share of total domestic use:

$$Imp_{ijt} = a_{ijt} * (Food_{ijt} + Feed_{ijt} + Oth_{ijt} + Waste_{ijt} + VStock_{ijt})$$

Where α_{ijt} is the import dependence coefficient of region j for product i in year t. In other words, GlobAgri-AgT assumes that when total domestic use of one product increases in region j, a fixed share of the additional need is covered by imports from abroad, while the remaining share is covered by increased domestic production, provided that region j's maximum cultivable area is not binding (see below).

Exports of product i by region j are written as a fixed share of the world market size of product i:

$$Exp_{ijt} = \sigma_{ijt} * (\sum_j Imp_{ijt})$$

Where σ_{ijt} is the world export market share of region j for product i in year t.

20 For Grass, Occasional feeds and Stover, there is no international trade and no stock change. The only utilization is feed. The *Feed* variable (linked to livestock production) determines alone, through the balance, the domestic production (*Prod*).

21 In the case of co-products, such as 'milk' and 'bovine meat' or 'oil' and 'cake', one co-product is chosen as a reference product while the other becomes a by-product

Import and export specifications in GlobAgri-AgT imply some rigidity in international trade: each region imports a fixed share of its domestic use and regional world export market shares are constant. Such rigidity may result from several factors such as the slow change in regional comparative advantages, and slow change in transport infrastructures and commercial channels. However, such specifications are rather restrictive when dealing with mid- to long-term analysis. We should emphasize, however, that import dependence coefficients (α_{ijt}) and/or world export market shares (σ_{ijt}) may be changed exogenously as part of simulated scenarios and may change endogenously as part of the scenario simulations in regions where the maximum cultivable land area is binding (see below). In both cases such adjustments of import dependence coefficients and world export market shares may figure changes in regional comparative advantages or transport or trade costs potentially implied by trade, agricultural and/or environmental policies for instance.

Finally, when replacing in the balance equations all variables by their respective expression in the additional equations, provided that *Vstock* is fixed, *Food*, *oth* and *Waste* are the model's exogenous variables while the area harvested (A) is the model's endogenous variable.

The model closure

The model is closed firstly adding a world trade equilibrium equation for each product and secondly adding an agricultural land constraint equation in each region.

For each product i, the world trade equilibrium equation is written:

$$\sum_j Imp_{ijt} = \sum_j Exp_{ijt}$$

While for each region j, the agricultural land constraint equation is:

$$\sum_v Surf_{vjt} \leq \sum_j \overline{Surf_{jt}}$$

This agricultural land constraint may be defined for various sets of products v so that the *Surf* and $\overline{Surf}$ may have different meanings: the land constraint may be defined for the cropland area, for the pastureland area or for the total agricultural land area for instance, or for all other sets of products. In GlobAgri-AgT, because of the lack of data regarding the maximum pastureland area in each region, we defined the agricultural land constraint on the cropland area. Hence $Surf_{vjt}$ is the cultivated area devoted to crop product v in region j during year t and $\overline{Surf_{jt}}$ is the maximum cultivable area in region j in year t. Let us emphasize at this stage that defining the land constraint on the cropland area has important implications since it means that pastureland may adjust freely to all the shocks introduced into the model. This limit does not result from the GlobAgri-AgT model since the latter can very easily deal with other levels of agricultural land constraints. It results from the lack of data on potential maximum areas, which could be shifted to permanent pasture in each region.

Finally, as in the balance equations the domestic production of each crop v in each region j is linked to the harvested area and the per-hectare yield of corresponding products and regions, we need an additional equation linking the harvested area to the cultivated area for each crop in each region:

$$\sum_v Surf_{vjt} = e_{jt} * (\sum_v A_{vjt})$$

Where e_{jt} measures the ratio of total cultivated area over total harvested area in region j for year t. This ratio is lower than one when the cultivated area is lower than the harvested area, indicating the extent of multi-cropping (or the level of cropping intensity) in the concerned region. In contrast, the cropping intensity coefficient is greater than one when the cultivated area is greater than the harvested area, indicating the extent of fallow land or of harvest abandonment due to difficult climatic, economic or geopolitical conditions.

The model solving

In the initial '2010' situation, domestic resources utilizations and world trade are balanced for all products and the observed cropland area is lower or nearly equal to the maximum cultivable area in all regions.

Let us assume that food consumption of product i increases in region j. According to our model specification, this increase is covered partly by rising imports and partly by expanding domestic production. This results in an expansion of cropland and, possibly, pastureland areas in region j. At this stage two situations may arise:

— Region j's cropland area is still lower than region j's maximum cultivable area, then the resolution of the model stops.
— Region j's cropland area becomes greater than region j's maximum cultivable area, then two stages are considered:
  - 1. Region j's exports are first evenly reduced (through equi-proportional decrease in its world export market shares σ_{ijt}) until the domestic cropland area falls below the maximum cultivable area. At this stage, the resolution of the model stops.
  - 2. If, even with zero exports, region j still needs more cropland area than its maximum cultivable area, then region j starts increasing its imports (through increases in import dependence coefficients α_{ijt}). In other words, region j increases the share of its food needs which is covered by imports in order to reduce the required rise in domestic production and save some cropland area. As initial regional import dependence coefficients vary widely across products, we defined intervals of initial levels upon which the α_{ijt} coefficients are increased evenly, making it possible to differentiate the level of increase by band.

Therefore, in the last case, the world export market shares and import dependence coefficients of regions constrained by their maximum cultivable land area become endogenous.

The results presented in the main text closely depend on the modelling approach and adopted quantitative hypotheses in simulated scenarios. Both the model and hypotheses have several limits. These limits, which relate to the general limits of the model and those of the general rules adopted to translate the scenarios into quantitative inputs to the model, are presented and discussed in Le Mouël *et al*. (2018).

Adaptation of initial TYFA hypotheses to the GlobAgri-AgT framework

Before running the simulations and analysing the effects of an agroecological EU on the rest of the world, we need to couple the TYFA modelling exercise with our global simulation tool GlobAgri-AgT. In order to be consistent with TYFA hypotheses, we reconfigured EU yields, feed to output ratios, oilseed-crushing coefficients, food diets and waste in GlobAgri-AgT. For some parameters such as products classification, food diets and waste, some adjustments had to be made.

Regarding products classification, every crop and processed product existing in TYFA has been associated with a crop or processed product present in GlobAgri-AgT. Most of the time this association is easy since the same product is present in both simulation tools. In a few cases however, due to the relatively more detailed TYFA classification, we had to match several TYFA crops to one single GlobAgri-AgT aggregate. In such a situation, average yield for the considered set of TYFA crops in the EU was computed using TYFA 2050 areas as weights. A group of minor crops present in TYFA whose land area is kept constant between 2010 and 2050 (Tobacco, Hops, Flax and hemp, Other industrial crops, Cotton fibre, Other permanent crop, Seeds and seedlings, Kitchen gardens, Nurseries, Flower and ornamental plants, Aromatic medicinal and culinary) takes a default yield and is associated to the aggregate "other plant products" in GlobAgri-AgT.

Food diets and waste configuration in TYFA and GlobAgri-AgT are slightly different. In the first case, diets are expressed in terms of human caloric intake and waste is a sort of black box representing 20% of EU final food consumption. In the second one, food diets integrate the losses at the consumption and processing levels, while the variable waste in the balance equations includes the losses resulting from storage, distribution and transport operations. In order to get comparable variables for the EU relative to the other regions in GlobAgri-AgT, we used TYFA gross food production integrating all kind of waste as food consumption, and we set to zero the variable waste for the EU in GlobAgri-AgT.

TABLE 10. Agri-food aggregates in GlobAgri-AgT

Aquatic animals	Fibres etc.	Other oilcrops	Grass (grass from direct grazing and as silage of permanent pastures)
Bovine meat	Fruit and vegetables	Cake other oilcrops	Grass-like forages (mixed grass and ryegrass from temporary pastures)
Dairy	Pulses	Oil other oilcrops	Other forages (alfalfa and fodder crops: beats, vegetables, sorghum, maize etc.)
Eggs	Roots and tubers	Oilpalm fruit	Occasional feeds (food leftovers, cut-and-carry forages and legumes, roadside grasses)
Pork meat	Maize	Palm product oil	Stover (crop residues)
Poultry meat	Other cereals	Palm kernel cake	
Small ruminant meat	Rice	Rape and mustard seeds	
	Wheat	Rape and mustard cake	
	Sugar plants and products	Rape and mustard oil	
	Other products	Soybeans	
		Soybean cake	
		Soybean oil	
		Sunflower seeds	
		Sunflower seed cake	
		Sunflower seed oil	

TABLE 11. Broad geographic regions in GlobAgri-AgT

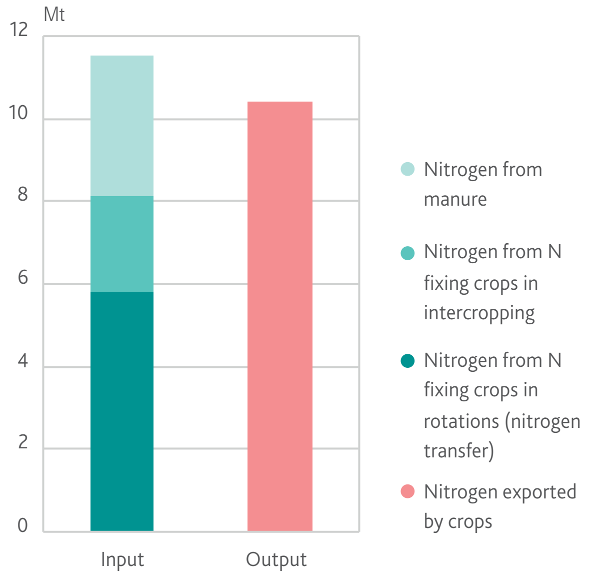
Brazil/Argentina	Canada/USA	China	North Africa
Rest of America	EU-27	India	West Africa
Rest of Europe	Oceania	Rest of Asia	East, Central and Southern (ECS) Africa
	Former Soviet Union	Near and Middle East	

ANNEX 3: THE EU NITROGEN BALANCE FOR THE ALONE SCENARIO

Figure 32 summarizes the components of the nitrogen balance for cultivated land for the ALONE scenario. We employed the nitrogen compartment of TYFAm model (Poux and Aubert, 2018) to make an *ex-post* calculation of this balance based on GlobAgri-AgT simulation results.[22] The balance indicates a slight nitrogen surplus, with an input/output ratio of 111% meaning that the phase-out of mineral fertilisation is compatible with the hypothesis of the scenario.[23]

This ratio is similar to the one of the original TYFA scenario published in 2018 (109%). More in detail, higher nitrogen exports in ALONE (increased crop production to satisfy the export requirements) are offset by higher nitrogen inputs (greater amount of N from manure and nitrogen fixing crops).

FIGURE 32. Nitrogen balance in the ALONE scenario



Source: TYFAm

22 The nitrogen balance should be tested at finer levels than EU, and especially at territorial level. However, this is not possible with the current version of TYFAm

23 Radical improvements in nitrogen use methods and loss limitation remain essential in order to reach the required level of nitrogen use efficiency

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An agroecological Europe by 2050: What impact on land use, trade and global food security?

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The Institute for Sustainable Development and International Relations (IDDRI) is an independent think tank that facilitates the transition towards sustainable development. It was founded in 2001. To achieve this, IDDRI identifies the conditions and proposes the tools for integrating sustainable development into policies. It takes action at different levels, from international cooperation to that of national and sub-national governments and private companies, with each level informing the other. As a research institute and a dialogue platform, IDDRI creates the conditions for a shared analysis and expertise between stakeholders. It connects them in a transparent, collaborative manner, based on leading interdisciplinary research. IDDRI then makes its analyses and proposals available to all. Four issues are central to the institute's activities: climate, biodiversity and ecosystems, oceans, and sustainable development governance.
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