Matière à débattre & décider

Land Use and Food Security in 2050: a Narrow Road

Agrimonde-Terra

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éditions Quæ

7. Climate Change: Impacts and Mitigation

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Introduction

AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU) is at the forefront of climate change issues as it is both concerned by its impacts and will be a major actor in its mitigation. AFOLU is responsible for just under a quarter (~10-12 $GtCO_2eq/yr$) of anthropogenic greenhouse gas (GHG) emissions, mainly from deforestation and agricultural emissions from livestock, soil and nutrient management, and among the economic sectors has one of the most important mitigation potentials. In particular, AFOLU offers the possibility of producing negative emissions, which will be essential to limit global temperature changes below 2°C or 1.5°C above pre-industrial levels.

There is also evidence of the impacts of historical and recent climate change on food production, with a global net loss in average wheat and maize yields of –3.8% and –5.5% respectively relative to what would have been achieved without the climate trends in 1980-2008 (Lobell *et al.*, 2011). Extreme weather events played an important role in the food crisis of 2007-2008 and continue to multiply. While it is too early to attribute these phenomena to anthropogenic activities, major changes in temperature and precipitation due to the increased concentration of greenhouse gases could greatly disrupt agricultural production systems and threaten world food security.

Food security is a complex issue, which has several dimensions and should not be confused with food production. Evaluating the impact of climate change on food security is particularly challenging as it results from a complex process of estimations involving four main sources of uncertainty: the emissions scenario, the climate scenario, the induced variation in crop yields and cultivable area, and the impact on food security. Assessing the interactions between climate mitigation and food security is even more challenging as they depend fundamentally on the way mitigation options are implemented.

As a contribution to the ongoing reflection, this chapter presents the three narratives for climate change impacts and mitigation in 2050 used in the Agrimonde-Terra foresight exercise. Before, to contextualize these narratives, we first present a literature review on the impacts of climate change on agriculture and then a brief overview of the agricultural mitigation pathways and the international negotiation process that should drive them.

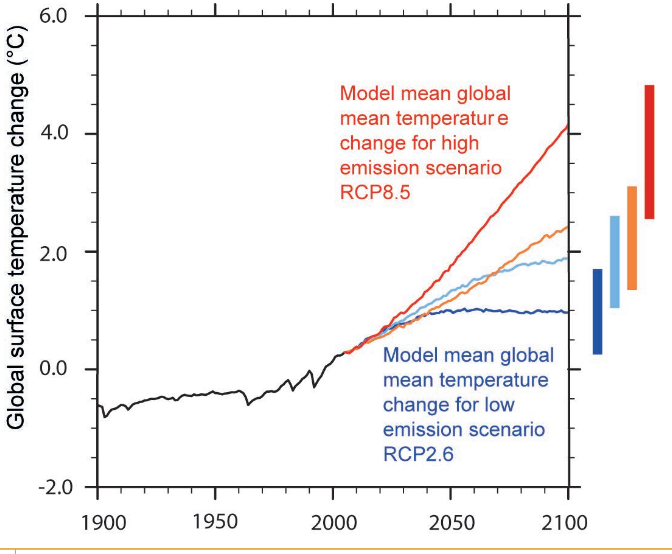
Overview on the impacts of climate change on agriculture

Projected impacts of climate change on agriculture

The IPCC (Intergovernmental Panel on Climate Change) scenarios

Climate projections made within the IPCC Fifth Assessment Report (AR5) are based on a set of four 'Representative Concentration Pathways' (RCP). The RCPs are scenarios that specify radiative forcing (expressed in watt/m²) and corresponding emissions, but are not directly based on socio-economic storylines like the previous Special Report on Emissions Scenarios (SRES) (IPCC, 2013). Four RCP scenarios were selected from the published

Figure 7.1. Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (relative to 1986–2005) for the four RCP scenarios.



Source: IPCC (2013), FAQ 12.1, Figure 1, pp. 1037.
Note: RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red). Likely ranges for global temperature change by the end of the 21st century are indicated by vertical bars.

literature: the lowest pathway RCP2.6 (also referred to as RCP3-PD) which peaks at 3 W/m^2 and then declines to approximately 2.6 W/m^2 by 2100; the medium-low RCP4.5 and the medium-high RCP6 aiming for stabilization at 4.5 and 6 W/m^2, respectively around 2100; and the highest scenario, RCP8.5, which implies a radiative forcing of 8.5 W/m^2 by 2100.

Projected changes in global mean surface air temperature in 2046-2065 range from +1.0°C (confidence interval = 0.4°C-1.6°C) in RCP2.6 to +2.0°C (1.4°C-2.6°C) in RCP8.5 (Figure 7.1). AR5 models project a gradual increase in global precipitation over the 21st century: +0.05 mm/day in RCP2.6 to +0.15 mm/day in RCP8.5, with, however, a relatively large spread in model projections. In spite of these uncertainties, surface soil drying is projected with high confidence, especially under RCP8.5, in some regions: the Mediterranean, Northeast and Southwest South America, Southern Africa and Southwestern USA.

Projected impacts on potential agricultural land

Assessments of the suitability of land for agricultural use under climate change conditions at the global scale demand large amounts of data and for this reason are relatively sparse. We present here the study conducted by Zabel *et al.* (2014) which is used in the quantification of the Agrimonde-Terra scenarios.

Zabel *et al.* (2014) evaluate land resources based on ecological rules relating to the suitability of land for agricultural use based on eight parameters (mean temperature, precipitation, texture, coarse fragments, gypsum concentrations, base saturation, pH, organic carbon, salinity, sodicity and slope). The projections presented in Zabel *et al.* (2014) are made under the A1B climate scenario, which lies between RCP6.0 and RCP8.5. According to their results, climate change leads to a 560 million hectare (Mha) increase in suitable cropland area until 2100, which comes mostly from high latitude countries such as Canada, Russia and China. This result is consistent with previous estimates from Ramankutty *et al.* (2002). Net loss of suitable areas is expected in some regions, most notably sub-Saharan Africa, Middle East-North Africa and Australia-New Zealand. Also a strong decrease in multiple cropping area is projected in Brazil (–160 Mha) and sub-Saharan Africa (–150 Mha). In spite of a larger area suitable for agriculture, the overall productive capacities of global ecosystems will not necessarily be expanded by climate change as the actual crop yields should also be taken into account (see following paragraph).

Projected impacts on crop yields

Based on the abundant literature on the impact of climate change on crop yields published since AR4, the AR5 report comes to the following conclusions: (i) crop yields of wheat, maize and rice in both tropical and temperate regions are negatively affected beyond 3°C of local warming without adaptation, even with the benefits of higher carbon dioxide (CO_2) and rainfall; (ii) crop yields of wheat and maize in tropical regions diminish significantly even with a slight rise in temperature (1 to 2°C); (iii) there is a potential for yield loss in all three temperate crops at low temperature changes.

The potential benefits of adaptation are clear for wheat and rice, but have not been demonstrated for maize. The gains from incremental crop-level adaptation are estimated at 7-15% on average (Challinor *et al.*, 2014). Among the possible adaptation strategies studied (planting date, fertilizer, irrigation, cultivar or other agronomic adjustment), cultivar adjustment appears to be the most effective, with irrigation also showing benefits.

South Asia and Southern Africa are the two regions that, in the absence of adaptation, would suffer the most negative impacts on several important crops (Lobell and Burke, 2008; IPCC, 2014a).

Projected impacts on livestock

Production of meat and milk may be impacted by climate change in many ways: changes in the quantity and quality of feed, heat stress and water scarcity, increased incidence of livestock disease, loss of genetic diversity etc. However, there are important knowledge and data gaps on the future impact of climate change on livestock production (Thornton *et al.*, 2009), especially in the tropics and sub-tropics, making it difficult to assess each of these potential effects.

The actual impact on livestock production is also difficult to assess because of the large range of possible adaptations available. Extensive livestock systems occur over a huge range of biophysical and socio-ecological systems, with a consequent large range of potential adaptations. In many cases, these livestock systems are highly adapted to past climate risk, which should provide a sound starting point for climate change adaptation (Thornton *et al.*, 2009). In developed countries, livestock systems are generally adaptable and resilient. In developing countries, in contrast, households which are dependent on keeping livestock may be much more vulnerable to changes in climate and climate variability, with the potential for increased poverty and decreased food security (Thornton, 2008).

Projected socio-economic impacts

In response to changes in temperature and precipitation, AR5 reports estimates of increases in food prices ranging from 3-84% to 2050 (IPCC, 2014a).[34] However, these results are difficult to interpret as they depend to a large extent on the adaptation capacities represented in the models: for the same shock, the more flexible the model (in terms of technology, farming practices, trade etc.), the lower the impact on food prices (Nelson *et al.*, 2014). For this reason, biophysical models are considered to project higher impacts than economic models, in which adjustments to changing environmental conditions by farmers are easier (Mendelssohn, 1994).

Beyond the impact on food prices, some studies have tried to directly estimate the impact of climate change on undernourishment. To do so, Baldos and Hertel (2014) incorporated

34. Most of these studies did not include the CO_2 fertilization effect, considering that it balances the bias of omitting the negative effect of elevated ozone and increased weed and pest damage (IPCC, 2014a).

into a partial equilibrium model of global agriculture a food security module linking changes in prices to changes in average dietary energy intake and to shifts in the full caloric distribution. Using the yield estimates from Müller *et al.* (2010), they show that climate change could result in an increase of +27 million in the global malnourished population in 2050, compared to a baseline scenario. Sub-Saharan Africa and South Asia are the two regions the most severely hit, with the incidence of malnutrition increasing by more than +20% (compared to the baseline) in both regions. When the effects of CO_2 fertilization are added, the number of malnourished people declines by around −35 million compared to the baseline. Overall, the contribution of climate change to the malnutrition headcount is nonetheless of a secondary order compared to socio-economic drivers such as population and per capita income. This conclusion about the prevailing role of non-climate drivers on food security is shared by the academic literature and the IPCC.

A drawback of many socio-economic assessments is their consideration of incomes as exogenous, while they may be a more important driver of food insecurity than commodity price changes themselves (Hertel *et al.*, 2010). In so doing, they neglect some of the various mechanisms that limit access to food. If producers are price-takers for outputs and if the farm-level demand is inelastic, then a reduction in supply will boost incomes with potential benefits for food security for this category of household. Therefore, the actual impact of climate change on poverty and food security depends crucially on where households earn their income. To study this effect, Hertel *et al.* (2010) use the general equilibrium model GTAP to account for the feedback between prices and incomes, combined with the distribution of households aggregated into groups based on their primary source of earnings over a sample of 15 developing countries. They showed that if the poor are mostly self-employed in agriculture, poverty can be reduced by a modest adverse shock in productivity, while it will be increased by the same shock if poverty is dominated by wage earners and urban poverty.

Ricardian analysis is used as an alternative approach to economic models for estimating the impact of climate change on agriculture, especially in West Africa. The Ricardian approach measures the relationship between net revenues from crops and climate using cross-sectional evidence.

Impact of changes in climate variability on food security

Changes in the inter-annual variability of yields are seen by many authors to be a major driver of food insecurity by undermining the resilience of food systems and affecting the stability of food availability and access (IPCC, 2014a).

However, only a few estimates of climate variability are available in the literature and studies on the effects of climate variability and extreme climatic events on food systems are also scarce (Thornton *et al.*, 2014). There is, for example, no mention of studies assessing the impact of climate variability on food price and food security in AR5. In a review of possible impacts of changes in climate variability, Thornton *et al.* (2014) stress that the treatment of the impacts of climate variability is a heavily under-researched area, particularly how harvest failures in one continent may influence food security outcomes in others.

Based on the global gridded crop model LPJmL, Müller and Robertson (2014) simulated the year-to-year variability for the 2000s (1980-2009) and 2050s (2040-2069) expressed as the coefficient of variation (CV) in the RCP8.5 climate scenario. Their results indicate an increase of more than +5% in CV in 64% of grid cells and a decrease of more than –5% in 29% of cases. However, it is difficult to draw conclusions in terms of food security from these results as there is no indication on the geographical distribution of impacts. Furthermore, increases in CV can be due to reductions in mean yields and/or increases in the standard deviation of yields, and often simulated changes are a combination of the two (IPCC, 2014a).

Devereux (2007) shows that food crises triggered by extreme climatic events can be schematically described as a sequence of "entitlement failures". This hypothesis implies that food crises do not generally result from isolated weather shocks, but from a succession of shocks, that progressively undermine the capacity of societies to respond to climatic events (*e.g.*, by selling farming equipment). At each new shock, the societies reach gradually a new step in the sequence of "entitlement failures", until experiencing a food crisis.

Studies at the local scale provide some insights on the potential impacts of climate variability on food security. A survey conducted in three communities in Ghana shows how extreme climatic events are impacting food security (Codjoe and Owusu, 2011). Flooding and cold conditions hamper food storage, while extreme dryness facilitates it. Excessive flooding may also destroy feeder roads that link food production area and major markets, cutting some regions off from access to food. Adaptation strategies that enhance transportation and storage facilities can therefore adequately alleviate food insecurity. Providing farmers with early warning systems, extending credit to farmers and the use of supplementary irrigation are other effective adaptive options.

Mitigation pathways

Main insights from AR5

The AFOLU sector is responsible for around a quarter of anthropogenic GHG emissions (~10-12 $GtCO_2$-eq/yr) on average over the decade 2000-2009, with global emissions of 5.0-5.8 $GtCO_2$eq/yr from agriculture and around 4.3-5.5 $GtCO_2$eq/yr from forestry and other land uses (IPCC, 2014b). AFOLU emissions have stabilized since the decade 1990-1999 thanks to a reduced rate of deforestation, most notably in Brazil, and afforestation, most notably in China, Vietnam and India. Net annual baseline CO_2 emissions from AFOLU are projected to decline over time, partly driven by technological change and partly by the projected declining rates in the expansion of the agriculture area related to the expected slowing in population growth (IPCC, 2014b). Historical and projected trends of AFOLU emissions are, however, particularly uncertain due to specific measurement difficulties in the AFOLU sector.

Land-based mitigation represents a potential large share of the total cumulative abatement (20 to 60% to 2030, and 15 to 40% to 2100; IPCC, 2014b) and is therefore essential to limit global temperature changes to 2 or 1.5°C above pre-industrial levels. In contrast to the transport and energy sectors, a significant share of AFOLU's mitigation potential is located in developing countries, which may raise possible issues in terms of food security. Mitigation in the AFOLU sector can be carried out both by reducing the GHG emission intensity per kg of output (through improved cropland and livestock management), and by conserving or enhancing carbon stocks in soils or vegetation (through afforestation/reforestation and BECCS: bioenergy with carbon capture storage). Trade-offs between both strategies may appear in some cases, because a reduction in emission intensity may lead to lower yields and fewer areas for carbon sequestration.

The development of integrated environment/climate/agricultural production practices, such as agroecology or sustainable intensification, is a way to bridge this conflict by optimizing crop production per unit area, taking into account the sustainability aspects. Consumption-based measures, such as changes in diet or a reduction in food loss and waste, are another way to bridge this conflict by reducing the overall tension on land. They may enable both lower use of inputs and larger areas for afforestation/reforestation or bioenergy production. Therefore they offer a substantial mitigation potential (1.5-15.6 $GtCO_2$-eq/yr), greater than supply-side measures (1.5-4.3 $GtCO_2$-eq/yr at carbon prices between 20 and 100 US\$ tCO_2-eq/yr) (Popp *et al.*, 2010). However, they seem particularly complex to enforce as they are considered to impinge on individual liberties in many countries. Given these difficulties, some authors recommend that they should be designed to contribute to other policy agendas, such as improving environmental quality (Smith *et al.*, 2012) or improving dietary health (Macdiarmid *et al.*, 2011).

Important barriers to the implementation of supply-side measures also exist as it implies profound changes in agricultural practices and land-use in some regions. Among the main obstacles, AR5 mentions access to market and credits, technical capacities to implement mitigation options, accurate monitoring of emission levels and institutional frameworks and regulations. Large-scale bioenergy production raises many issues about possible adverse effects on biodiversity, food security, water use and access to land, and the scientific debate on the overall benefits of specific bioenergy pathways remains unresolved (IPCC, 2014b).

AFOLU mitigation measures may be associated with socio-economic and environmental co-benefits provided that they are sustainably implemented. For bioenergy, for example, this means it must be integrated with food production, notably through suitable crop rotation schemes, or use of by-products and residues (Berndes *et al.*, 2013). Mitigation options designed to enhance carbon stocks in soils may also have a positive impact on food security by improving land quality (Lal, 2004). Other potential co-benefits include, for example, human health and well-being through more adapted diets, clarification of land tenure, synergies with other international agreements, including the United Nations Convention to Combat Desertification (UNCCD, 2011), or the Convention on Biological Diversity (CBD).

The climate negotiation process

Climate negotiations were initiated at the Earth Summit in Rio de Janeiro in 1992 with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) as the first pillar of the international climate regime. The convention established general principles of the climate regime: Article 2 calls for the prevention of "dangerous anthropogenic interference with the climate system" and Article 3 establishes an equity principle based on common but differentiated responsibilities (CBDR).[35] Since its ratification in 1994 by 194 countries (the so-called parties to the Convention), the convention proceeds through annual diplomatic meetings called Conference of the Parties (COP).

The Copenhagen Conference (COP15 held in 2009) was supposed to achieve an ambitious global treaty and launch a new round of negotiations for the next decade. The conference gave rise to high expectations among civil society but finally led to a simple agreement signed by 28 countries, whose content was officially institutionalized in Cancun (COP16 held in 2010). Reasons for the failure include geopolitical factors (limited room for manoeuvre of the US administration), clumsiness of the Danish presidency and the unwillingness of developing countries to back a global agreement without, in turn, significant commitments from developed countries (Bodansky, 2010; Grubb, 2010; Rajamani, 2010). The increasing role of the BASIC countries (Brazil, South Africa, India and China) has reflected a new balance of power in international relations since the early 2000s.

However, the Copenhagen agreement represents a turning point in climate negotiations. First, the 2°C target appears for the first time as an ultimate global objective for emission reduction. Second, while the Kyoto Protocol reflected a top-down approach in climate negotiations, that is to say starting from a common global objective deriving into domestic commitments, the Copenhagen Accord emphasizes a bottom-up approach through a nationally-determined pledge (Bodansky, 2010). For the first time, developing countries committed to reduce their emissions, with both domestic efforts and the help of developed countries. Developed countries committed to a financial target of $100 billion per year by 2020 and on the creation of a Green Climate Fund (GCF) designed to channel a significant share of this financial backing. A monitoring system called MRV (Measuring, Reporting and Verification) regarding the mitigation measures was planned but its modalities remained a controversial issue with China and India.[36]

35. The CBDR means that all parties to the convention recognize their responsibilities in climate change but some countries are more responsible than others. In practice, industrialized countries (mostly in the Northern hemisphere) are considered more responsible.

36. China and India rejected all kinds of binding system but ultimately agreed on a voluntary monitoring system of 'measurement, reporting and verification' in accordance with guidelines adopted by the COP (paragraph 5) communicated each year.

From Copenhagen to Paris (COP21), discussions followed an incremental process of adjustment of the climate regime while laying the foundations for a global agreement. In particular, the Durban platform (COP17 held in 2011) initiated a negotiation process aimed at producing a 'protocol, or other juridical instrument' and adopted the second phase of commitment of the Kyoto protocol (2013-2020). The Warsaw conference in 2013 invited parties to communicate before the Paris conference their Intended Nationally Determined Contributions (iNDCs) (Decision 1/CP.19, Para. 2b).

The adoption of the Paris Agreement on 12 December 2016 (UNFCCC, 2016) institutionalized a new paradigm of climate negotiations initiated at Copenhagen (Bodansky, 2016). It is a global agreement, which applies not only to developed countries, like the Kyoto Protocol, but also to developing countries, accounting for a growing share of global emissions. It calls for a limit to the increase in the global temperature well beyond the 2°C target and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels (Art 2) and recognizes the necessity to "foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production" (Art 2). To achieve these objectives and fill the gap with the current content of iNDCs renamed NDC (National Determined Contributions) it institutionalizes an iterative process every five years (Art 14). This global stocktaking will review collective progress and put forward emission reduction plans for the next five-year period. Although the agreement does not include any type of compliance system, it establishes a common transparency and accountability framework. The 100 billion $/yr target by 2020 to finance adaptation and mitigation measures is confirmed and will be a floor by 2025 (Decision, paragraph 54).

COP 21 is an important step from the food security point of view, as for the first time in a global climate agreement, the fundamental priority of food security and its vulnerability to climate change have been recognized. COP21 also marked the official launch of the '4 per 1000' international initiative which aims to address in an integrated way the issues of food security, adaptation to climate change and mitigation of anthropogenic emissions by increasing the soil carbon stock by 4‰ per year.

Future climate change impacts and mitigation in 2050

Based on the available literature, three narratives for climate change impacts and mitigation in 2050 have been developed.

Hypothesis 1: Stabilization of Global Warming

Ambitious targets on temperature changes to 2100 set by the COP21 have created a momentum towards strong mitigation efforts. Nationally Determined Contributions (NDC) decided at COP 21 have been the basis for much more ambitious action plans. Through a proactive political approach and a strong commitment from civil society, a broad range of options are deployed to stabilize climate change. Instruments for emissions reduction

– carbon tax, cap-and-trade systems, low-carbon standards etc. – are implemented in most countries of the world, steering investments towards low-carbon goods and technologies. The total consumption of fossil energy is significantly reduced through energy efficiency measures and efforts to encourage greater moderation. At the same time, the production of renewable energy (solar, wind, hydro and biomass) increases significantly. Climate mitigation is also facilitated by relatively low climate sensitivity (*i.e.*, the temperature change in response to the change in radiative forcing).

The agriculture, forest and other land-use (AFOLU) sector plays a key role in mitigation efforts. All mitigation options are considered, including carbon storage in agricultural soils (through, for example, the 4 per 1000 initiative) and resource use efficiency measures, especially concerning the use of synthetic nitrogen. These strategies are adapted to local situations to create synergies with yield increases and the limitation of land degradation. The global production of modern biomass energy[37] reaches 102EJ/yr in 2050, mostly used for producing electricity in association with carbon capture and sequestration (Chapter 14 for more details). The development of first-generation biofuel ceases because of its poor environmental assessment. In this scenario, as in the two others, the evolution of forest areas mirrors the evolution of agricultural areas, which are themselves driven by our hypotheses for the future of the other drivers of the 'land use and food security' system: global context, food diets, rural-urban relationships, cropping systems and livestock systems as described in chapters 6, 8, 9, 11 and 12 respectively.

As a result, global temperature changes are maintained well below +2°C to 2100 (and +1°C to 2050) and changes in precipitation remain limited (<+0.05 mm/day in 2100). In this context, the agricultural system does not experience any major change compared to the current situation due to climate conditions. Crop yields are not significantly affected by climate change in both temperate and tropical zones. Similarly, elevated CO_2 and O_3 concentrations have few impacts on crop yields and crop protein content. The area of cropland suitable for agricultural production does not notably change compared to the current situation.

Hypothesis 2: Runaway climate change

International agreements adopted under the United Nations Framework Convention on Climate Change (UNFCCC) do not lead to significant effective emission reductions. NDCs are not actually enforced in most countries, especially in the largest emitting ones, because of the lack of political will and the influence of fossil energy producers. At the local, national and regional scales, citizens' initiatives do not balance the influence of the oil industry and the belief that technical change will solve the climate issue. The world's economies remain dependent on fossil energies whose availability is still high thanks to

37. We use the expression 'modern biomass energy' as opposed to the traditional use of biomass energy such as firewood for cooking and heating.

the exploitation of shale and unconventional resources, fossil energy reserves in the Arctic and deepwater drilling. Agriculture is based on the conventional development model with large consumption of synthetic fertilizers and pesticides. No specific measure to increase the carbon storage in soils or vegetation is taken. The production of modern biomass energy (60 EJ/yr in 2050 – Chapter 14 for more details), used as second-generation biofuel or bioelectricity, is encouraged by government subventions to develop additional industrial and agricultural capacities based on past experiences of bioenergy (deployment of ethanol from maize in the USA, ethanol from sugar cane in Brazil and biodiesel in Europe). Production of first-generation biofuel is constant at its 2015 level, hindered by the cheap price of fossil fuel.

In this context, greenhouse gas emissions continue to rise sharply positioning the climatic system in a scenario corresponding to the RCP8.5. Global temperature changes reach +4°C in 2100 (+2°C in 2050) and changes in precipitation amount to +0.15 mm/day in 2100. Under this scenario, there are strong impacts on the agricultural system. The area of cropland suitable for agricultural production increases by approximately 600 Mha by 2100 (Zabel *et al.*, 2014; including +120 Mha for moderately suitable to very suitable land). However, this increase is unevenly allocated, as it mainly concerns Northern latitudes while arable cropland areas decrease in tropical regions. The average suitability of cropland areas also decreases significantly. On average at the global scale, wheat yield decreases by –13% between 2010 and 2050, maize yield by –14%, rice yield by –16%, soybean by –30% and groundnut by –21% (Müller and Robertson, 2014). Extreme events (heat waves, floods etc.) become more frequent, leading to increased inter-annual variability in crop yields. Increases in CO_2 and O_3 concentrations may also have a direct impact on crop yields (positive for CO_2, negative for O_3) and on the protein content of crops (negative for CO_2, positive for O_3).

Hypothesis 3: Moderate warming

In a context characterized by the collapse of the international governance system, the UNFCCC negotiation process has eventually failed to provide an effective action plan towards emission reductions. NDCs are progressively abandoned by the States and climate change mitigation is now considered only as a co-benefit of adaptation measures, as well as reduced food and energy consumption due to lower economic activity and/or energy independency strategies. The latter strategies concern, for example, the development of biomass energy, whose production reaches 150 EJ/yr globally in 2050. The rise in bioenergy production is especially strong in regions without abundant fossil resources. Two variants of bioenergy production are considered, differing due to the share of dedicated energy crops and wood biomass (Chapter 14 for more details).

Global temperature changes reach +2°C in 2100 (+1°C in 2050) and changes in precipitation amount to +0.08mm/day in 2100. The moderate warming assumed in this scenario generates discernible impacts on the agricultural system.[38] On average, at the global scale, wheat yield decreases by –6% between 2010 and 2050, maize yield by –7%, rice yield by –8%, soybean by –15% and groundnut by –10%. Yield losses will be greater in tropical regions than in Northern latitudes. The area of cropland suitable for agricultural production increases by +100-200 Mha by 2050 (+60 Mha for moderately suitable to very suitable lands). However, this increase is unevenly allocated as it mainly concerns Northern latitudes while arable cropland areas decrease in tropical regions. The average suitability of cropland areas decreases moderately. The frequency of extreme weather events increases (heat waves, floods etc.), leading to a moderate rise in the inter-annual variability in crop yields. The biogeochemical composition of the atmosphere changes (CO_2, O_3), but without significantly affecting yields and crop quality.

Conclusion

In spite of some uncertainties and research gaps, particularly on climate variability and impact on livestock, scientific literature agrees that climate change, whether through impacts or mitigation, will be a major driver of world agriculture in the coming decades. Based on these conclusions, we have endeavored in this chapter to construct narratives representative of the possible futures in terms of impact and mitigation of climate change. Because we are still at the crossroads where most options remain possible, we built a set of hypotheses covering a large range of pathways, from the most optimistic one ('Stabilization of global warming') to the most pessimistic ('Runaway climate change').

38. Climate change impacts on agriculture under this climate pathway are supposed to be half those under the 'Runaway climate change' pathway (for more details, Chapter 14).