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Biofuels and World Agricultural Markets: Outlook for 2020 and 2050

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1. Introduction

The possibility to produce biofuels from different agricultural feedstocks has raised huge interest during the last decade. This interest can be related to the parallel increase in fossil oil prices and the growing awareness about the need to reduce greenhouse gas (GHG) emissions worldwide. Biofuels are also seen by many governments as a means to contribute to the diversification of energy supply and sustain agricultural incomes by creating new outlets for several agricultural products, notably cereals, vegetable oils and sugar plants.

Ambitious public policies aiming at developing biofuel production and consumption in replacement of fossil fuels used in road transport have thus been set up all around the world. Policy instrumentation varies depending on the country. Altogether, policies aim at encouraging the supply of agricultural feedstocks used as raw materials for biofuels, the industrial production of biofuels and/or their domestic consumption by setting blending mandates and/or subsidizing biofuel use.

A period of keen interest was witnessed in the first years of the current decade which has led many countries such as the United States (US), the European Union (EU), Brazil and also several countries in Asia to set very ambitious policy targets for biofuels. But the boom in agricultural prices and the following food crisis in 2007-2008 have severely depreciated the public image of biofuels because of their potential negative impact on world food security in a context of land scarcity. Simultaneously, the issue of the impact of biofuel crops on GHG emissions due to induced land use changes has progressively emerged; it is today a matter of considerable controversy. In addition, concerns have risen about the relatively low energy yield of current biofuels and the budget cost of public policies aiming at encouraging their development. Initially, the debate about these interrelated issues has been confined to a narrow audience, mainly in the academic sphere. However, over the past three years, many stakeholders including environmental organizations, farmers' unions, the media, etc., have shown a considerable interest in the matter leading to a very lively debate worldwide, and more particularly in the EU.

First-generation (1G) biofuels produced from traditional food and feed crops are increasingly criticized for their adverse impacts on world food security and GHG emissions, essentially because they can divert land from food and feed, as well as land forest uses. As a result, hopes turn to a quick development of second-generation (2G) biofuels produced from various sources of biomass that do not directly compete with food and feed crops and,

furthermore, are expected to be more efficient in transforming biomass into bioenergy. However, the fact that there is no direct competition does not mean the absence of indirect competition when land is required for growing biomass, even for 2G biofuels.

Our research objective is then to analyze to what extent the development of biofuels and, within this general framework more specifically the development of 2G biofuels in line with the first one, could affect world food security and the environment (GHG emissions and biodiversity protection). The chapter is structured as follows.

In Section 2, we present a general framework of GHG emissions and energy uses worldwide, 1G and 2G biofuels produced today and that could be produced on an industrial scale in the future. We summarize the potential benefits of 1G biofuels that are used for justifying public support, and we recall the main criticisms against them. We then analyze the theoretical arguments in favor of 2G biofuels, and again why there might be discrepancies between theory and reality.

Section 3 depicts the worldwide increase in 1G biofuel production and consumption over the last decade. The analysis distinguishes bioethanol obtained from cereals and sugar crops, and biodiesel obtained from vegetable oils. We also depict the current weight of agricultural products used for biofuel production as compared to total uses of agricultural products, and we analyze the current trend for these crops in terms of areas, yields and prices.

As far as prospects are concerned, two time horizons are considered, 2020 in Section 4 and 2050 in Section 5. For each horizon, we analyze the potential impact of several scenarios for biofuel development on world food security, focusing on cereals and oilseeds used for food, feed and energy. These scenarios differ in terms of assumptions concerning, firstly the total supply and demand in biofuels in 2020 and 2050, secondly the substitution rates of 1G biofuels by 2G ones, thirdly the yields of biomass used for biofuel. The co-products of the process of transforming biomass into biofuels are taken into account since 1G biofuels jointly produce large amounts of co-products that can be used for animal feed, which is not the case with 2G biofuels. Concerning the 2050 horizon, we also analyze the impact of biofuel development and the replacement of the first generation of biofuels by the second on world GHG emissions and biodiversity protection.

The 2020 analysis is based on original simulations performed using a world agricultural partial equilibrium model called OLEOSIM while the 2050 analysis is a review of literature. They both show that the development of 1G biofuels will have a negative impact on world cereal production used for food and feed. However this negative impact is partially alleviated by the production of co-products associated with the supply of 1G biofuels from cereals and oilseeds. The replacement of 1G biofuels by the second generation will alleviate this negative impact. However it will not suppress it, notably if large amounts of 2G biofuels have to be produced from dedicated energy plants that require land and thus, indirectly, compete with other land uses: food, feed, environment protection, urban and transport infrastructures, etc. In the same way, the partial replacement of the 1G of biofuels by the second will reduce the negative impacts of biofuels on GHG emissions and biodiversity linked to land use changes; but it will not eliminate them. More generally, the increase in agricultural production required for food, feed and fuel worldwide should associate an expansion in cultivated area and, more importantly, a significant improvement in yields, notably in world regions where they are very low and low today.

The challenge is then to develop agricultural practices, techniques and systems that make it possible to achieve high levels of land productivity and simultaneously protect the environment and preserve natural resources.

2. The general setting: why are first- and second-generation biofuels subject to criticisms?

2.1 Competition between food and non-food uses of agricultural products

Besides traditional uses, including food, feed, firewood and cooking, biomass can be used for energy production (bioenergy) and other industrial uses (bioproducts). Bioenergy comprises uses for transport, including biofuels, as well as for heat and electricity production. Bioproducts comprise biomaterials and biomolecules. Biomaterials include biodegradable polymers or biopolymers (bio plastics), fiber and composite materials (agrimaterials), paper and paperboard; biomolecules include surfactants, solvents, lubricants and cosmetics.

In 2005, total use of biomass represented about 13.4 billion metric tons (Bt) of dry matter produced from a total of 7.7 billion hectares (Bha). Out of these 7.7 Bha, about 5.2 (1.6 Bha of crops and 3.6 Bha of pastures) were used for food, directly or indirectly through the filter of animal feed; 2.6 Bha corresponding to forest areas, including 2.4 Bha of natural or semi-natural forests, were used for wood production and only a few tens of million hectares (Mha) were mobilized for the production of bioenergy and bioproducts (Wirsenius 2008). Beyond the uncertainties and inaccuracies in the figures due to missing or unreliable data, leading to difficulties in evaluating land surfaces dedicated to any particular use, orders of magnitude are robust: they clearly show the modest part of non-food uses of agricultural production compared to food uses, at least until 2005.

In 2007, global emissions of CO₂ attributable to petroleum products and their use amounted to 10.9 giga metric tons (Gt). The transport sector with 6.6 Gt accounted for 60% of this total, most of which (4.8 Gt) for the road transport sector only (IEA 2009). In the short and medium terms, beyond energy savings and improved vehicle technologies, biofuels produced from biomass are seen as the major, if not the sole, alternative to the use of fossil oil in road transport.

More generally, the production of energy from renewable resources should grow sharply over the next decades in the context of both a rising energy demand and a gradual dwindling of non-renewable energy resources. Food demand will also increase due to population growth as our planet will host more than 9 billion people by 2050, nearly 2 billion more than today, economic growth and increased urbanization. These last two elements will result in a shift in food consumption at the expense of plant products - cereals, roots and tubers - and in favor of animal products that are less effective at converting solar energy into food calories. Hence, the question of the ability of our planet to simultaneously satisfy nutritional needs and non-food uses, mainly for energy production, is raised in a context where development must necessarily be sustainable from an economic, social and environmental point of view, at the very least much more sustainable than today. The challenge is huge but it is not insurmountable as long as all stakeholders join forces and act quickly (see, for example, Guyomard 2009; Guillou 2010).

In that general perspective, it is important to analyze the competition for land between food and non-food uses, particularly for energy. More specifically, we will assess to what extent the replacement of a part of 1G biofuels made from plant storage organs also used for human food and animal feed by 2G biofuels that use residues and waste, wood from forests or dedicated crops, could respond to two criticisms against 1G biofuels, namely a negative impact on food security and GHG emissions. But in a first step, we will recall why 1G biofuels and government policies aiming at encouraging their development are the subject of an increasing questioning and to what extent 2G biofuels could bring an answer to this questioning.

2.2 Promises of the second-generation of biofuels in response to criticisms of the first one

In 2008, global biofuel production amounted to 46 million tons of oil equivalent (Mtoe), slightly more than 2% of total fuel used in road transport, mainly in the form of bioethanol in the US and Brazil and biodiesel in the EU. This production used 320 million metric tons (Mt) of sugar crops (17% of world production), 100 Mt of cereals (5%) and 11 Mt of vegetable oils (9%). It mobilized 28 Mha, i.e., 3% of world surfaces in sugar plants, cereals and oilseeds (authors' estimations). These figures show that the use of agricultural commodities for biofuel production is still relatively modest today. However there has been a rapid development since the early 2000s, and acceleration in the more recent years. In 2008/09, the increase in the world cereal demand for bioethanol production was higher than the demand for food, respectively, 28 Mt and 13 Mt (authors' estimations from data of the United States Department of Agriculture).

2.2.1 From criticisms addressed to the first generation of biofuels...

First-generation biofuels are subject to criticism on the basis of two main arguments: firstly, they could be a threat for global food security; secondly, their energy, environmental and economic balance could be not as favorable as initially hoped.

First-generation biofuels are made from storage organs of terrestrial plant materials also used for food, directly or indirectly through animal feed: sugar crops (cane and beet), grains (mainly corn and wheat) and oilseeds (mainly soybean, rapeseed, sunflower and palm). The fear of excessive competition with food uses is therefore immediate: in the recent past, it reached a climax when farm prices soared at the end of 2007 and the beginning of 2008; it is still with us today in the previously recalled context of feeding 9 billion people by 2050 while respecting the environment and natural resources.

This Malthusian fear is doubled with the criticism that the environmental balance of 1G biofuels in terms of reducing GHG emissions can become negative once the changes in land use are recorded. The GHG balance of 1G biofuels is positive, with however large variations depending on the feedstock used as input, when the analysis is made for a given area. It is much less positive, and even can be negative, when the surfaces of sugar crops, grains and oilseeds involved in biofuel production are obtained from former grassland or by cutting down forest surfaces (Fargione *et al.* 2008; Searchinger *et al.* 2008).

The calculation for a given surface means in practice to record only the direct environmental benefit, i.e., the reduction of GHG emissions allowed by the use of one liter of biofuel instead of an equivalent volume of fossil fuel. It is of course necessary to complete this partial picture by taking into account the environmental cost. The latter is mainly related to land use changes, and more specifically to the loss of carbon storage in grassland and forests when the mobilization of one hectare of crops for energy requires, directly or indirectly, the "sacrifice" of one hectare of grassland or forest. This instantaneous effect is coupled with a dynamic loss of organic production from grassland and forests. Finally, the environmental dimension cannot be reduced to GHG emissions. The potentially negative effects of land conversion for energy objectives in terms of loss of biodiversity, use of fertilizers and pesticides beyond the absorptive capacity of agro-ecosystems, etc., should also be taken into account.

The energy efficiency of 1G biofuels per area unit used is also generally considered as modest, except for bioethanol produced from sugar crops, primarily sugar cane. Finally, production costs remain high today, especially when prices of raw plant materials used as resources are high too.

In this strongly questioning, if not critical, context, more and more voices are calling for a halt in the production of 1G biofuels, at least as long as we have not made sure that their development is not detrimental to food production, and would like 1G biofuel farming to be allowed only if it has been proved to have a positive effect on the environment, energy and economic balances. Beyond the scientific and technical progress that can be made on these three points, hopes for the longer term focus on later generation biofuels. In this chapter, we focus solely on 2G biofuels to the extent that those of the so-called third generation are still today at the research stage: they include, for example, hydrogen or oil production from macro- and micro-algae.

2.2.2 ...to the promises of the second generation

While 1G biofuels are produced from crop storage organs, 2G biofuels are produced from lignocellulose. The latter is the main component of plant cell secondary walls and is, therefore, the most abundant biomass constituent in terrestrial areas (Cormeau and Ghosse 2008).

Three main sources of lignocellulosic biomass can be mobilized for 2G biofuels, namely (i) waste and residues from agricultural, forestry, industrial, urban and/or household activities, (ii) forestry resources, i.e., wood from forests, and (iii) dedicated crops of annual plants (wheat, corn... used as a "whole plant") or perennial plants (forage plants like fescue, orchardgrass or ryegrass, herbaceous plants like miscanthus or switchgrass, and shrubs like short and very short rotation poplar, willow, eucalyptus or black locust plants harvested every three to ten years). Two ways of transforming lignocellulosic biomass can be used: a thermo-chemical process which consists in cracking molecules under the action of heat, and a biochemical pathway in which once the raw material has been disintegrated, the complex carbohydrates of lignocellulose are hydrolyzed into simple sugars which are then transformed into ethanol by fermentation. While the thermo-chemical process requires large facilities and significant investments in order to benefit from reduced costs, the biochemical pathway can use the facilities currently used for 1G biofuels. Second-generation biofuels are being experimented in research and demonstration platforms, with hopes for industrial applications and marketing in a decade's time.

Second-generation biofuels appear promising for at least three reasons: (i) the potential raw material is quite abundant, (ii) there is no direct competition with food crops when the resource is a waste, a residue, forest wood or a non-food dedicated crop, and (iii) their energy efficiency, and hence their economic efficiency, appears greater in terms of biomass yield per unit area used as well as in terms of conversion efficiency of this biomass into liquid energy. However the step from promises to reality should be cautiously taken.

When the raw material is a waste and/or a residue, the question of competition with food use does not arise. However it is important to note the potentially negative impact of removing agricultural and forestry residues on the microbiological and physical properties of soils. For example, Powlson *et al.* (2008) come to the conclusion that the energy savings associated with the burial of wheat straw in arable soils are greater than those generated by their removal to produce biofuels or electricity. In practice, the two interrelated questions raised by an energy-oriented use of residues and waste are the potential biomass availability and the cost of mobilizing this biomass (collection and storage costs).

But if the raw material is a dedicated culture (even if it cannot be used for food), the question of competition with food uses of land arises under the same theoretical terms as for

1G biofuels. Supporters of 2G biofuels derived from dedicated crops suggest growing them on “marginal” land, in some way unsuitable for food crops (including for economic reasons). But the potential for land to be mobilized in this way is uncertain because the need for a minimum profitability will likely require that, at least, some of these dedicated crops are located on sufficiently good land to obtain sufficient returns. In summary, the issue of allocating land to different uses (food and non-food, but also recreational, environmental, urban, etc.) also arises with 2G biofuels from dedicated crops.

3. World production of first-generation biofuels and impact on agricultural prices

3.1 World production of first-generation biofuels

3.1.1 The 2009 picture

In 2009, world production of 1G biofuels¹ is 51.8 Mtoe versus 45.9 Mtoe in 2008, that is an increase of 5.9 Mtoe or 13% in one year. Biofuel production is dominated by three countries: the US (22.0 Mtoe, 42% of world production), Brazil (13.9 Mtoe, 29%) and the EU (10.0 Mtoe, 18%). Other countries (5.9 Mtoe, 11%) are more recent players and some of them show very strong annual growth: China (1.3 Mtoe), Argentina (1.1 Mtoe), Canada (0.83 Mtoe), Thailand (0.69 Mtoe), Colombia (0.42 Mtoe) and India (0.35 Mtoe). The rest of the world corresponds to approximately 1.2 Mtoe (Figure 1).

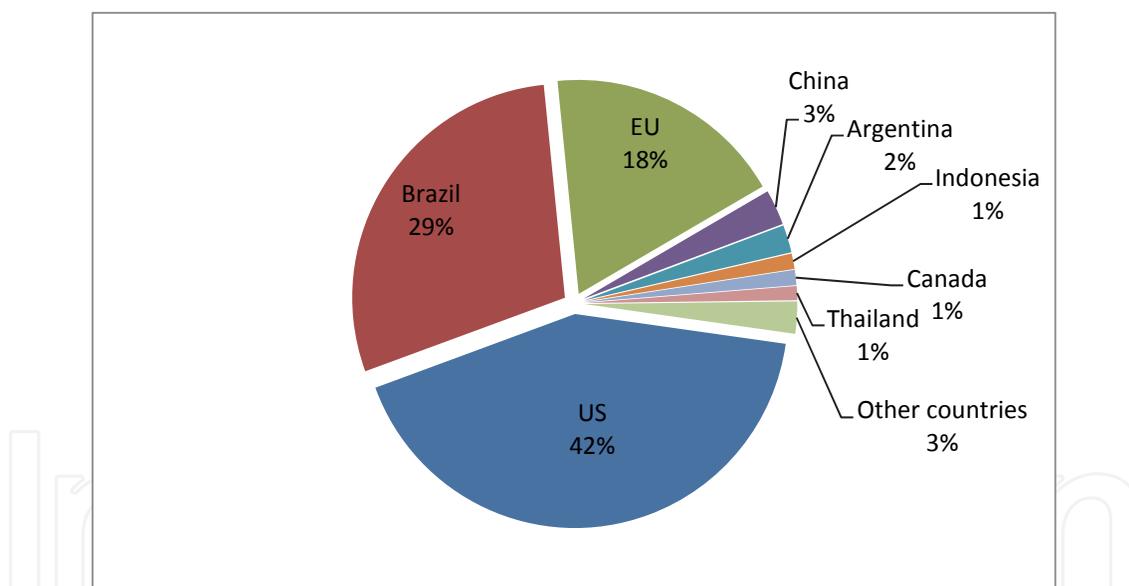


Fig. 1. Geographical distribution of world biofuel production in 2009, in Mtoe; Source: INRA from the Biofuels Platform

According to the Biofuels Platform, their production in 2009 is made of 74.0 billion liters (Bl) of bioethanol (approximately 37.7 Mtoe², 73%) and 17.9 Bl of biodiesel (14.1 Mtoe³, 27%). In

¹ World production figures vary significantly according to the sources. In addition, comparison between sources is made difficult by the use of different measure units (liters, gallons, barrels, metric tons, tons of oil equivalent, etc.).

² The conversion factor is 0.51 toe for 1,000 liters of bioethanol.

³ The conversion coefficient is 0.78 toe for 1,000 liters of biodiesel.

terms of production location, the structure of the world market for bioethanol is very different from that of biodiesel (Figure 2). The bioethanol market is overwhelmingly dominated by the US (40.1 Bl) whose production now largely exceeds that of Brazil (24.9 Bl). The third world actor, the EU, is a much more modest (2.9 Bl) and furthermore less dynamic producer than several other players. The rest of the world produces over 6 Bl; China, with 2.1 Bl, is an increasing player, followed by Canada, Thailand, Colombia and Australia. As far as biodiesel is concerned, world production is largely dominated by the EU (8.7 Bl out of a total 17.9 Bl, i.e., 49%). Several countries have also strongly developed their production in the more recent years, often for export: the US (2.1 Bl), Brazil (1.5 Bl) and Argentina (1.3 Bl). The rest of the world, mainly Thailand, China, Colombia and South Korea, produces 4.3 Bl.

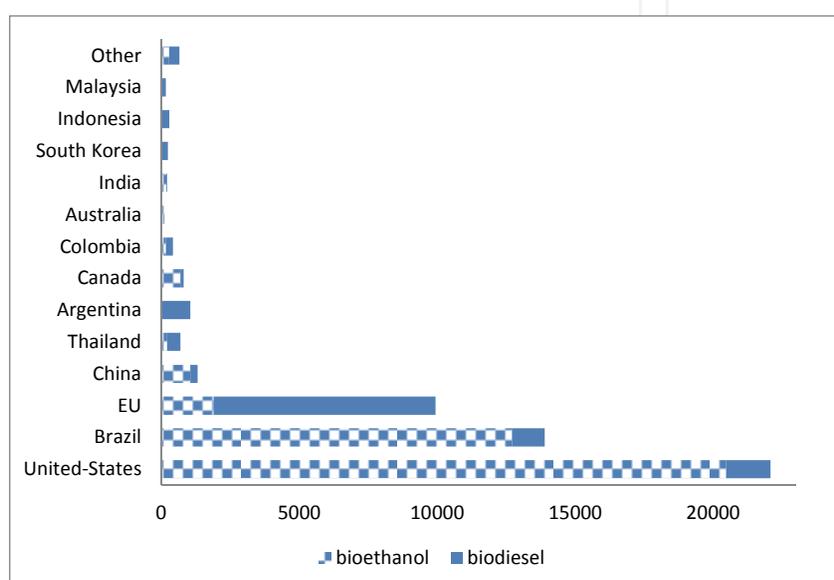


Fig. 2. Bioethanol and biodiesel world production in 2009, in toe; Source: INRA from the Biofuels Platform

In 2009, world biofuel production increased by 5.9 Mtoe (+13%), with 4.4 Mtoe for bioethanol (+13%) and 1.4 Mtoe for biodiesel (+12%). More than half of this overall growth came from the US (+2.7 Mtoe which corresponds to an increase of domestic production of +14%) and the EU (+1.6 Mtoe, +19%). Brazilian production increased more slowly, by 0.55 Mtoe (+4.1%). Production in the rest of the world increased sharply (+1.1 Mtoe, +22%) with very strong growth rates in Canada, China, Thailand, Colombia and South Korea. Among the main producing countries, only Indonesia experienced a decrease in production in 2009 with respect to 2008.

3.1.2 Evolution over the last twenty years

Biofuel production is influenced by both public policies aiming at encouraging their development and relative prices of fossil oil and agricultural products used for biofuel production. The importance of each factor varies according to countries, and, to some extent, the sub-periods considered over the last two decades.

World biofuel production started developing between 1975 and 1985, mainly in the form of bioethanol with Brazil as the main producer. It increased very slightly from 1985 to 2000 when it was equal to 9.4 Mtoe. Since then it has soared to 51.8 Mtoe in 2009. It is expected to

reach 57.8 Mtoe in 2010. Biodiesel production was negligible until the beginning of this century (less than 7% of total biofuel production in oil equivalent in 2000). Since then its share has continuously increased to reach 26% in 2009. This share is expected to be 27% in 2010 (Figure 3).

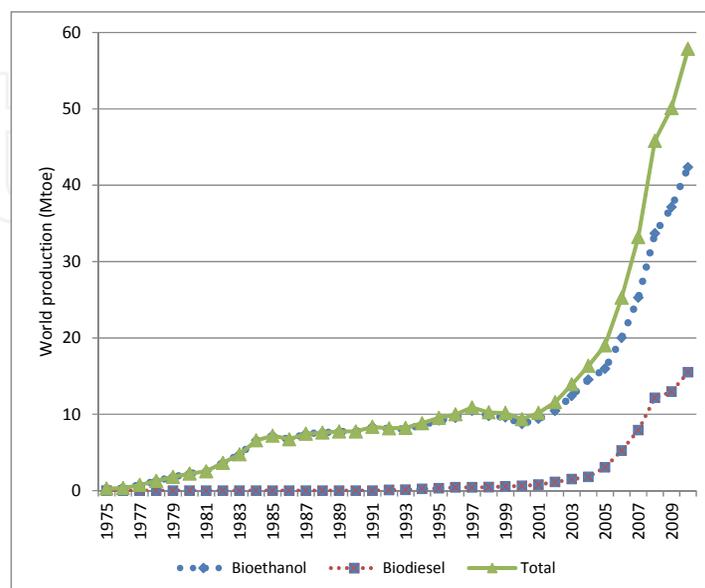


Fig. 3. World bioethanol and biodiesel production, 1975-2010, in Mtoe; Source: INRA estimations from various sources ⁴

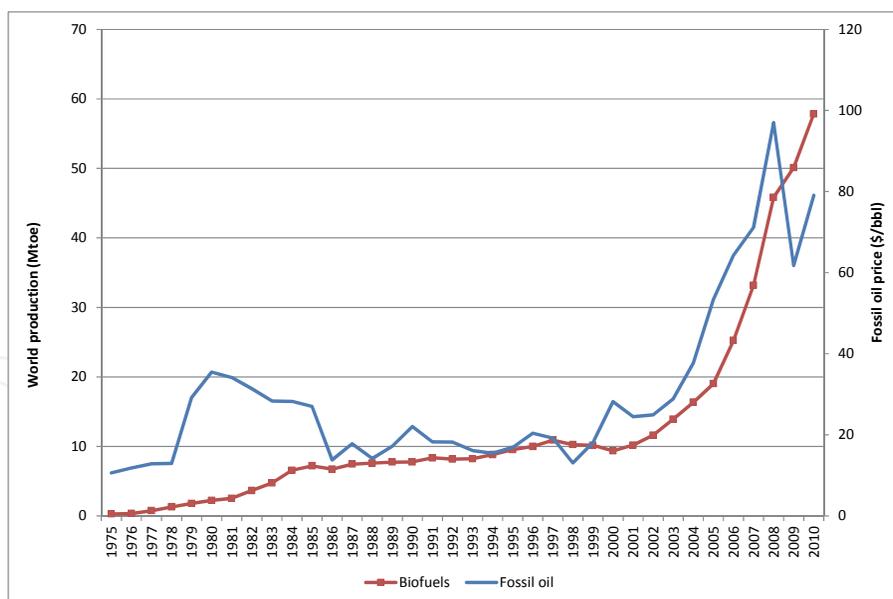


Fig. 4. Evolution of world biofuel production in Mtoe and fossil oil prices in \$/bbl; Source: INRA estimations from various sources for biofuels (see footnote 4) and UNCTAD for fossil oil prices (mean Brent/Dubai/Texas)

⁴ The main sources used for constructing Figures 3 to 12 are the Biofuels Platform, the European Biodiesel Board (EBB), the Earth Policy Institute, the FAO, the OECD, FO Licht, the International Energy Agency (IEA) and the Renewable Fuel Association (RFA).

As long as fossil oil prices remained close to US \$20 per barrel (bbl), biofuel production stagnated around 10 Mtoe. When fossil oil prices started to soar as from 2000, biofuel production followed the same pattern. It is however noteworthy that the 2009 decline in fossil oil prices had no effect on the upward trend of biofuel production (Figure 4). This means that biofuel development worldwide cannot be explained by fossil oil prices only; other factors are playing, notably public policies.

Bioethanol

Brazil is the most ancient producer of bioethanol. In 1984, its production already reached 11.3 Bl. At that date, Brazil held 87% of the world bioethanol market, followed by far by the US but with 1.6 Bl only. In 2000, while Brazilian production had returned to 10.5 Bl after a peak at 15.4 Bl in 1997, the US production reached 6.2 Bl. Following the adoption of an ambitious mandate in 2004, the US production exceeded that of Brazil for the first time in 2005 (Figure 5).

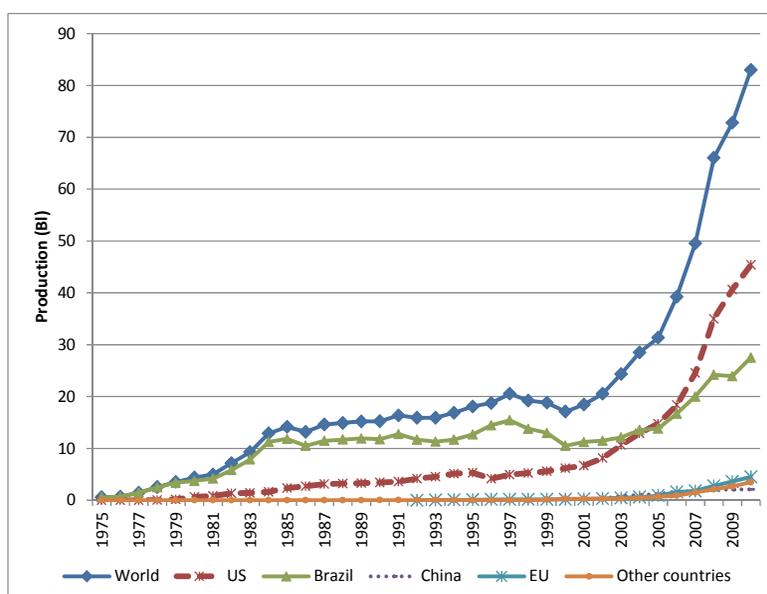


Fig. 5. Bioethanol production in Bl, 1975-2010, in the world and main producing countries; Source: INRA estimations from various sources

In the US, bioethanol production started in 1999 when fossil oil prices began to rise; since then, it has continued to do it regularly except in 2009 (Figure 6). As a result, it can be of some interest to consider in parallel three evolutions over the last decade, that of bioethanol production, that of fossil oil prices and that of corn prices (corn is the raw material used for bioethanol production in the US). More specifically, Figure 7 depicts the annual growth rate of bioethanol production and the evolution of the price ratio of petrol oil on corn. This ratio was low and stable over the 1990 decade. Since 2000, the two curves evolve in parallel with a time lag of two or three years which corresponds to the delay needed to build and start up new bioethanol production plants. The record progression of 10 Bl registered in 2008 despite a very high corn price (US \$165/ton) can then be explained by the fact that two years before, the price of oil (US \$404 for 1,000 l, i.e., 64\$/bbl) was five times higher than the price of corn (US \$79/ton). The corn price increase in 2008 and the resulting price ratio of 3.7 have been followed by lower increases in bioethanol tonnages in 2009 and 2010.

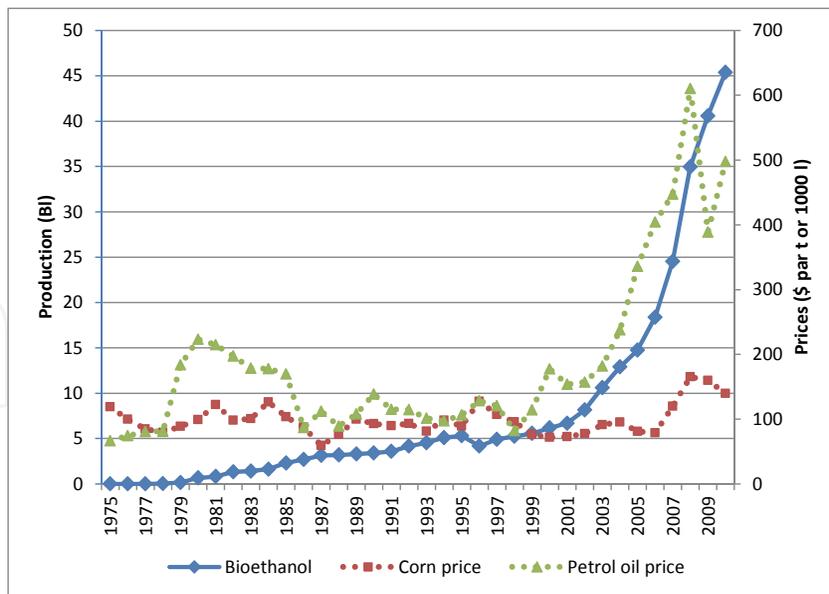


Fig. 6. Evolution of bioethanol production in the US in Bl, in parallel with fossil oil and corn prices; Source: INRA estimations from various sources for bioethanol, UNCTAD for fossil oil prices (in \$ per 1,000 l) and USDA for corn prices paid to farmers (in \$ per metric ton)

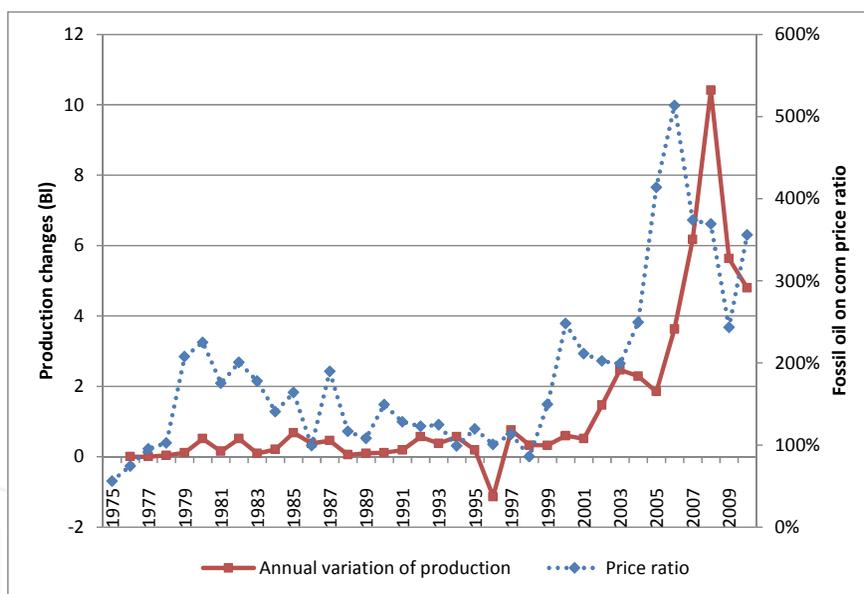


Fig. 7. Annual variation of bioethanol production in the US and parallel evolution of the petrol oil on corn price ratio; Source: INRA estimations from various sources for biofuel, UNCTAD for fossil oil prices (in \$ per 1,000 l) and USDA for corn prices paid to farmers (in \$ per metric ton)

In Brazil, bioethanol production increased sharply between 1975 and 1985, from 0.55 Bl to 11.8 Bl. This happened despite a very high price of sugar in 1980 and 1981 because of the simultaneous rise in fossil oil prices and also because of the biofuel development policy in place at that date (Pons 2007). Between 1985 and 2000, production increased more slowly because of a low fossil oil price and a relatively high sugar price for sugar. Ethanol production rose again in 2001 with both an increase in fossil oil price and a decrease in sugar

price. It has continued to rise in the following years from that date. Production was multiplied by more than 2.5 between 2000 and 2010 (Figure 8).

As in the US where bioethanol production growth rates are influenced by the fossil oil on corn price ratio, Brazilian bioethanol production growth rates are related to the fossil oil on sugar price ratio (Figure 9). But contrary to what can be observed in the US, it appears that Brazilian bioethanol production annual changes precede those of the fossil oil on sugar price ratio by about one year. This can be explained by the dominant position of Brazil on the world sugar market: when an increased part of Brazilian sugar production is devoted to bioethanol production, sugar prices decrease the year after, and vice-versa.

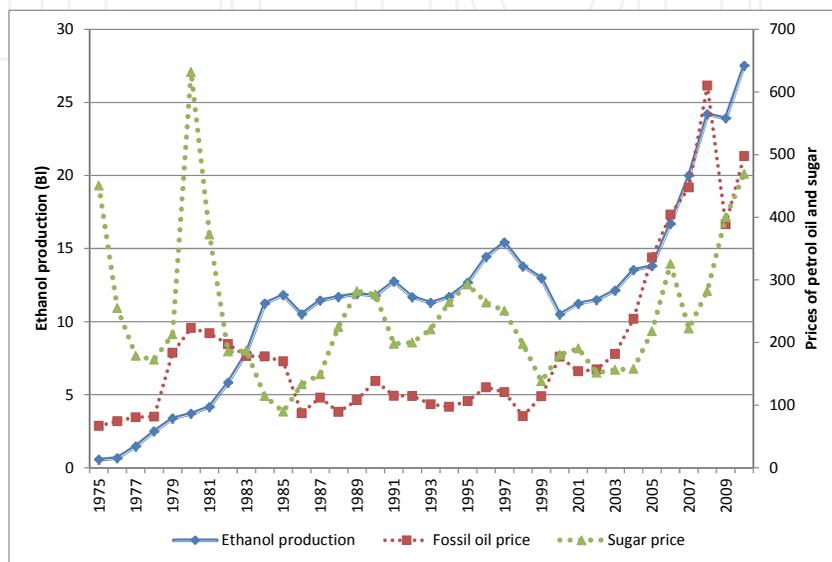


Fig. 8. Evolution of bioethanol production in Brazil in BI, in parallel with fossil oil and sugar prices; Source: INRA estimations from various sources for biofuel, UNCTAD for fossil oil prices (in \$ per 1,000 l) and sugar prices (mean of ATS Caribbean port prices in \$ per 100 kg)

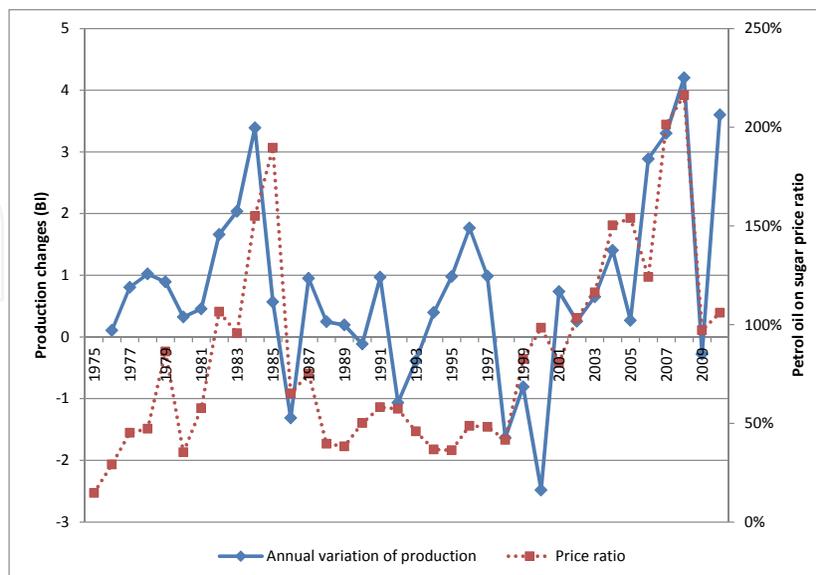


Fig. 9. Annual variations of bioethanol production in Brazil and evolution of the fossil oil on sugar price ratio; Source: INRA estimations from various sources for biofuel, UNCTAD for fossil oil prices (in \$ per 1,000 l) and sugar prices (mean of ATS Caribbean port prices in \$ per 100 kg)

Biodiesel

World production of biodiesel was equal to 0.8 Bl in 2000. It reached 4 Bl five years later and more than 16 Bl ten years later. Even if the EU is still the main producer with a market share around 55% today, several other countries did also record significant rises over the last five years: non-EU biodiesel production was equal to 0.16 Bl in 2004 and 7.7 Bl in 2009. Increases have been particularly marked in Argentina, Brazil and the US, a large part of production from these three countries being exported, notably towards the EU. Other bioethanol producers are Indonesia, Malaysia and Thailand. Because of the EU anti-dumping policy, US production and exports of biodiesel significantly decreased in 2009 and 2010 (Figure 10).

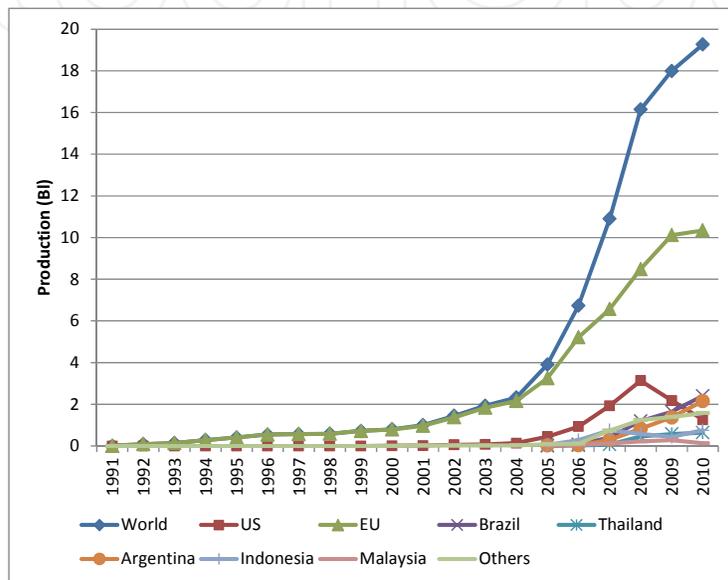


Fig. 10. Biodiesel production in Bl, 1991-2010, in the world and main producing countries; Source: INRA estimations from various sources

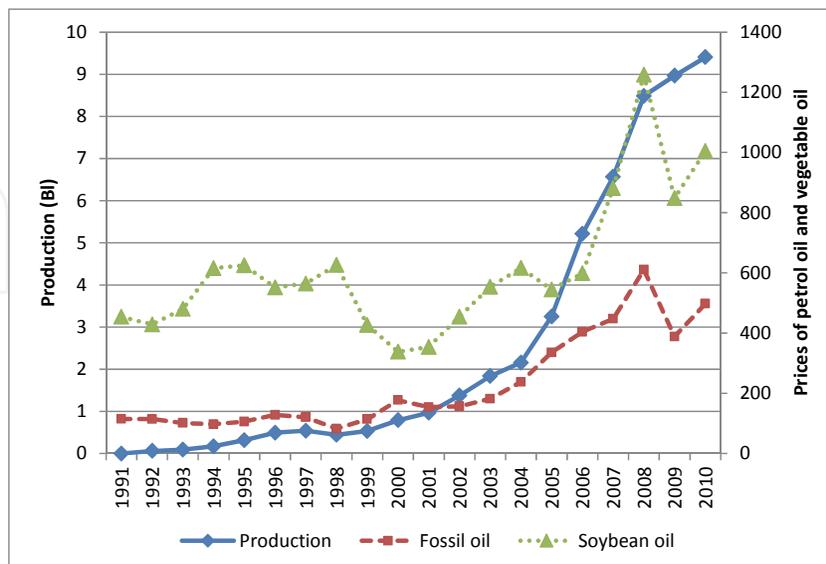


Fig. 11. Evolution of biodiesel production in the EU in Bl, in parallel with fossil oil and soybean oil prices; Sources: INRA estimations from various sources for biodiesel, UNCTAD for fossil oil prices (in \$ per 1,000 l) and soybean oil prices (Dutch FOB ex Mill in \$ per ton)

In the EU, biodiesel production started at the beginning of the 1990 decade (Figure 11). It increased at a very moderate rate during fifteen years to reach about 2 Bl in 2004. Annual growth rates were much higher during the 2005-2008 years. They were more modest in 2009 and 2010 (Figure 12). In 2010, EU biodiesel production was equal to 9.4 Bl.

EU biodiesel production is influenced by the domestic biofuel policy, the prices of fossil oil and vegetable oils and the fossil oil on vegetable oil price ratio⁵. From Figure 12, one sees that the high growth rates in EU bioethanol production observed from 2005 to 2008 corresponded to high fossil oil on vegetable oil price ratios. In 2009 and 2010, bioethanol production growth rates were lower although the price ratio remained at high levels: this can be explained by the fact that vegetable oil price levels were also high (Figure 11).

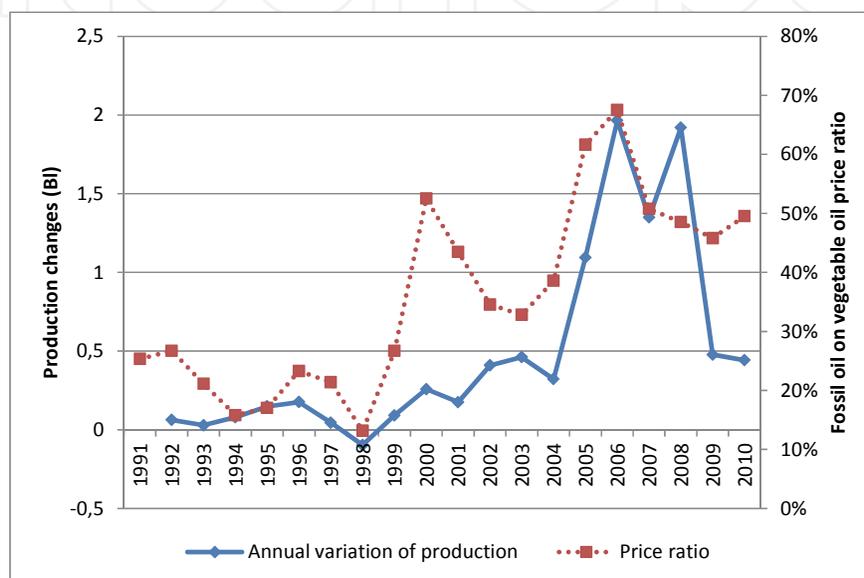


Fig. 12. Annual variations of biodiesel production in the EU and evolution of the fossil oil on soybean oil price ratio; Source: INRA estimations from various sources for biodiesel, UNCTAD for fossil oil prices (in \$ per 1,000 l) and soybean oil prices (in \$ per ton)

3.2 The role of first-generation biofuels in the 2007-08 agricultural price peak

When lower amounts of agricultural products are available under the effect of, for example, adverse weather conditions, this has a positive impact on prices. In the same way, any increase in demand has a positive effect on prices. As a result, we can state that the increase in 1G biofuel production is partly responsible for the soaring of cereal prices in the 2007-2008 period due to the expansion of bioethanol production in the US, mainly from corn, and for the soaring of vegetable oil prices due to the expansion of biodiesel production in the EU, mainly from rapeseed.

The story is far from straightforward however. It is essential to place the development of biofuels in perspective with all other supply and demand factors that influenced agricultural prices in 2007-2008. It is also important to follow the chronology of events and to differentiate between products by taking into account substitution and complementary effects between commodities, on both the supply and demand side.

⁵ EU biodiesel production is essentially made from rapeseed oil. The price of this vegetable oil and the price of soybean oil are highly correlated. As a result, it is possible to use the soybean oil price as the "reference" price for all vegetable oils.

It would be dangerous to consider separately the corn-bioethanol situation in the US and the rapeseed-biodiesel situation in the EU for at least two reasons. Firstly, because the US have also developed a domestic biodiesel production and the EU a local production of bioethanol. Secondly, and more importantly, because the expansion of bioethanol-devoted corn crops in the US, particularly during the 2007/08 crop year, was carried out at the expense of domestic surfaces in soybeans. This in turn had an impact on oilseed prices and, because of substitution and complementary relationships between products, on the prices of all cereals and vegetable oils. Similarly, the development of EU biodiesel production did have an impact not only on rapeseed oil prices, but more generally on prices of all vegetable oils. The global context of weak agricultural supply since the early 1990s and increased world food demand, notably in large emerging countries, led to decreases in cereal and oilseed stocks. The petrol oil price was rising since 2000 and the US dollar was depreciating with respect to a growing number of currencies. This was combined with increasing biofuel production, mainly in the US in the form of bioethanol (Figure 13). However, the use of stocks and the record harvest in 2004 contained cereal and oilseed price rises in 2003, 2004 and 2005; their international prices even slightly decreased in 2005.

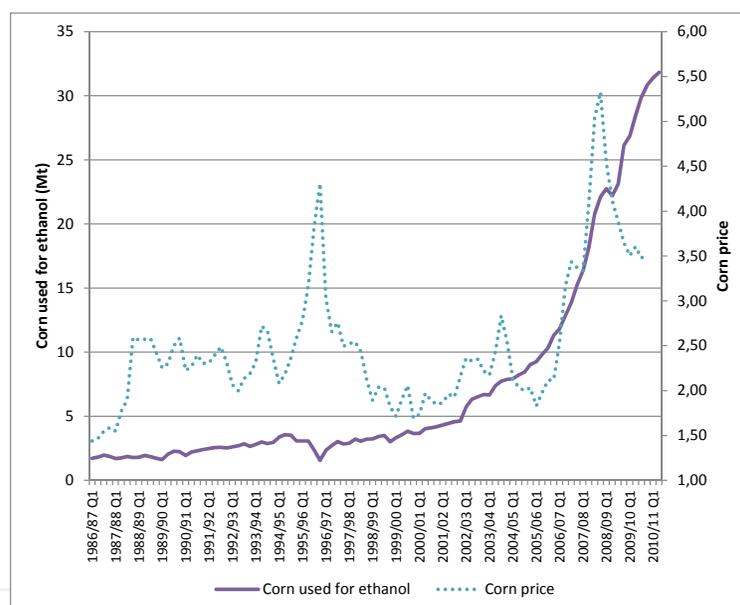


Fig. 13. Corn volumes used for bioethanol production in the US and corn prices paid to US farmers (quarterly data 1986/1987 to 2010/2011); Sources: INRA from USDA

In early 2004, the increase in fossil oil prices accelerated and the US dollar depreciated further. Cereal and oilseed stocks that had grown slightly in 2004 diminished again in 2005 and 2006, when, due to unfavorable weather conditions, world cereal production slightly decreased. From 2005, with low corn stocks and insufficiently dynamic domestic corn production, the US were unable to meet their bioethanol mandate from local feedstocks. They looked abroad, especially to Brazil. As a consequence, the international price of sugar rocketed, from 128.4 in June 2005⁶ to 189.3 in December 2005 (+47% in six months), and to 254.3 in February 2006 (+34% in two months). In response to high sugar and ethanol prices, surfaces dedicated to sugar cane increased in Brazil. At the same time, US bioethanol

⁶ According to the FAO monthly food price index (100 in 2002-2004).

producers gradually returned to the use of corn. As a result, the international price of sugar dropped from March 2006 and throughout 2007.

In a context of world stocks at their lowest level, the development of biofuels in the US and the EU played upward on the prices of cereals and vegetable oils as from the second semester of 2006.

In practice, the US sought to encourage bioethanol production from domestic plant resources, that is corn. Figure 14 depicts the growth of corn use for bioethanol production in the US over the period 2001/02 to 2010/11. In 2003/04, corn used for ethanol production was 30 Mt (11.1% of total US corn production). In 2006/07, the same use was 54 Mt (20.1%). In 2007/08, it reached 77.5 Mt (23.4%) and 8 Mha of corn of a total of 35 were used for the production of bioethanol in the US. These statistics suggest that the development of bioethanol production in the US is largely responsible for the upswing in the prices of corn in that country. As the US is, by far, the largest exporter of corn, the upward movement of US corn prices rapidly spread to world corn prices.

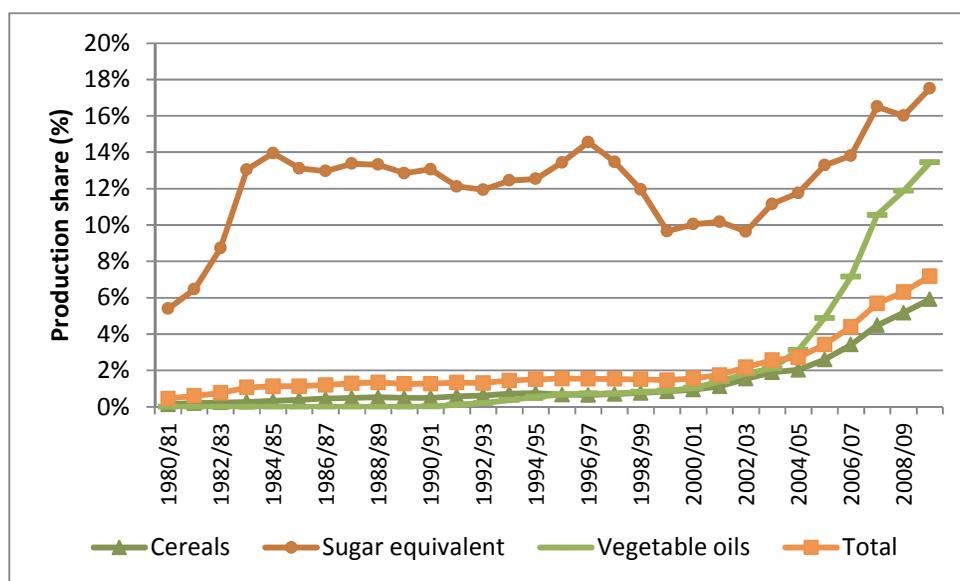


Fig. 14. Corn production in the US (Mt), corn used for bioethanol (Mt) and share of corn used for bioethanol (%); Source: INRA from USDA

The first impact of bioethanol production increase in the US was to raise the world price of sugar from June 2005 to February 2006. The second impact was to increase the international price of corn from spring 2006 and, incidentally, to cause the downward adjustment of the world price of sugar because, in a way, of an “excess supply” of sugar. The increase in the world price of corn peaked during the 2006/07 crop year. The high price of corn compared to other cereals and oilseeds prompted US and world producers to increase corn acreage, especially during the 2007/08 crop year. The world surface of corn, which decreased by 3% over the period 1996/97 to 2002/03, increased by 14% from 2002/03 to 2007/08; half of that increase took place during the 2007/08 campaign only, mainly at the expense of oilseeds (Abbott *et al.* 2008). Undoubtedly this decline in global oilseed surfaces in 2007/08, primarily in the US, contributed to exert additional upward pressure on prices of oilseeds and vegetable oils. Between June 2007 and June 2008, the FAO price index of vegetable oils rose by nearly 80%. By comparison, over the same period, world corn prices increased by slightly more than 20%, rice prices by nearly 50% and wheat prices by a little more than 90% (Figure 15).

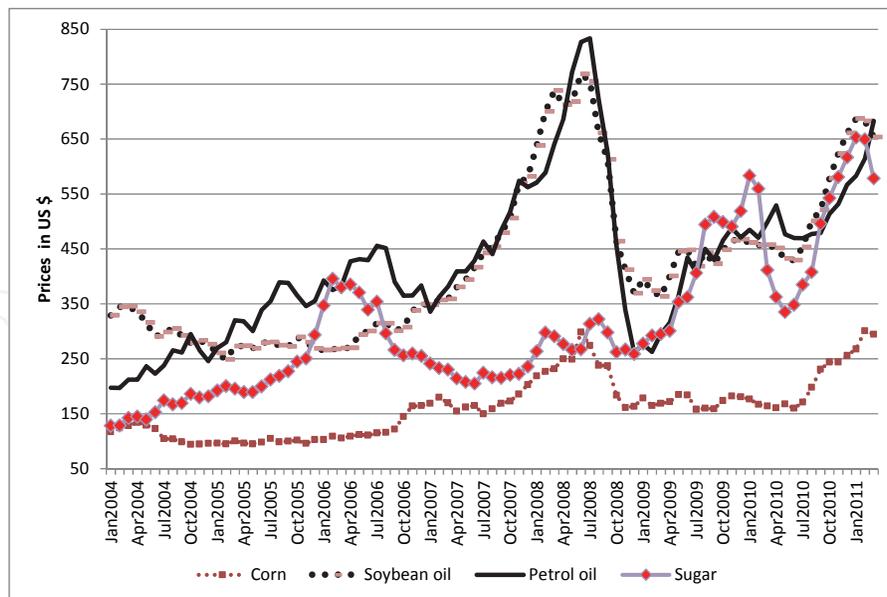


Fig. 15. Evolution of monthly prices for corn, soybean oil, sugar and fossil oil; Source: INRA from UNCTAD data; prices in US \$/ton for corn, US \$/500 kg for soybean oil, US \$/10 kg for sugar and \$/1,000 liters for fossil oil

The third impact of bioethanol development in the US was thus to increase the 2007/08 world corn area, including in the US, at the expense of the world sole in soybean in response to high corn prices and also in anticipation that demand for corn would remain firm in the years to come. This substitution effect on the supply side helped increasing the upward pressure on prices of soybeans and soybean oil, and by extension on prices of other vegetable oils that are highly substitutable on the demand side. This contagion effect on the prices of various cereals and vegetable oils was particularly strong because it took place in a context of medium- and short-term factors that played simultaneously in the direction of a general increase in agricultural prices (weak agricultural supply, disappointing harvests, dynamic food demand, low stocks, high fossil oil prices, weak US dollar, speculation on agricultural commodities, uncoordinated trade policies aiming at discouraging exports and encouraging imports of agricultural goods, etc.). In the specific case of vegetable oils, the concomitant development of the EU biodiesel production constituted an additional factor of upward pressure on prices, especially on the price of rapeseed oil.

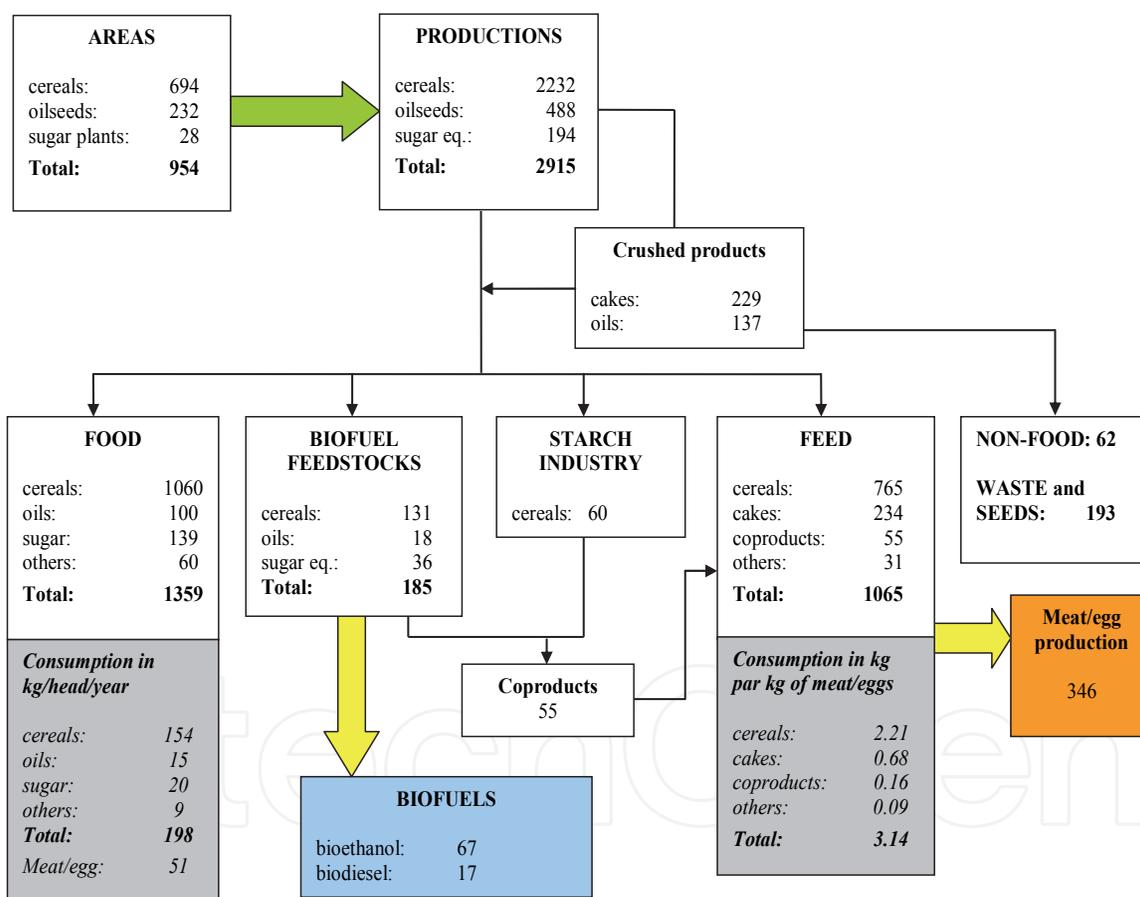
Several studies have attempted to quantify the role played by biofuels in the 2007-08 increase in agricultural prices. Differences in terms of methodologies and models, data, product and country coverage, scenario definition or simulation horizons make it difficult to compare results. Nevertheless, according to these studies, it appears that the development of bioethanol production in the US can be held highly responsible for the rise in corn prices in the first place and then, through the play of substitutions in supply and demand, for the rise in the prices of the various cereals and vegetable oils (including, according to the IFPRI study based on the IMPACT model, the world price of rice even though rice is not used to produce bioethanol). Based on a survey of several studies and additional ad-hoc analyses, Collins (2008) concludes that 25 to 50% of the increase in the corn price in the US and worldwide between the 2006/07 and 2008/09 crop years can be attributed to the growth of the US bioethanol market.

4. Cereals, oilseeds and sugar: production and uses

4.1 The 2009/10 situation

In 2009/10, cereals, oilseeds and sugar crops were cultivated on 954 Mha worldwide (Figure 16). They produced about 2.9 Bt of primary products: 2.2 Bt of cereals (76%), 488 Mt of oilseeds (17%) and almost 200 Mt of sugar equivalent (7%). The bulk of oilseeds produced 229 Mt of oil cakes and 137 Mt of oil, palm oil included. The rest of oilseeds were used directly for food (60 Mt), feed (14 Mt) or seeds (11 Mt).

Food consumption is by far the largest use with more than 1.3 Bt of cereals, vegetable oils, oilseeds and sugar. These global amounts correspond to average consumptions per capita of 200 kilograms. Feed consumption arrives at the second rank with more than 1Bt (cereals, oil cakes, co-products of cereals and oilseeds, and others). Considering a production of 346 Mt of beef, pork and poultry meat and eggs, this feed use corresponds to an average consumption of 3.1 kilograms of annual crops per kilogram of animal products. The third



POPULATION: 6.85 billion people

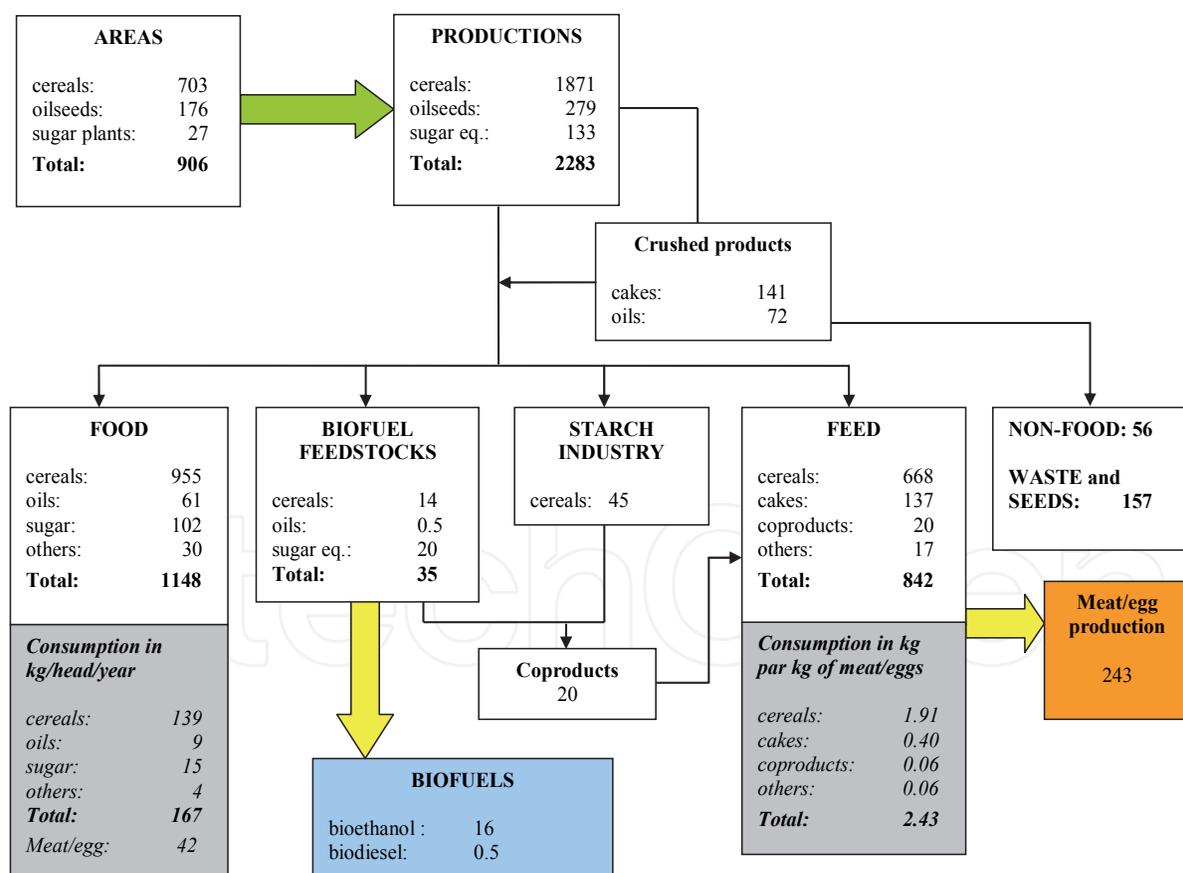
Fig. 16. Food, feed, fuel and other uses of cereals, oilseeds and sugar crops worldwide in 2009/10 (Mt). Source: INRA from various sources, notably the USDA/PSD database and FAO statistics⁷

⁷ Concerning “crushed products”, palm oil production is included. For the “starch industry”, cereal use is estimated from data on corn-gluten-feed production (Oil World 2010) and bioethanol production.

use is biofuel with approximately 185 Mt of cereals, vegetable oils and sugar. Biofuels represent 6% of the world production of cereals, oilseeds and sugar, and amounts to 60 Mha of agricultural land. Other uses include starch production, oil for soap production, lubrication, paint and varnish, lipid chemistry, etc. Ethanol production from cereals and starch produce 55 Mt of co-products used for animal feed under the form of, for example, corn gluten feed (CGF) or dried distillers grains and solubles (DDGS). Co-products from biodiesel production amount to 10 Mt; they are included in the category 'total oil meal'.

4.2 Changes between 1996/97 and 2009/10

When comparing the supply-demand balance for crops in 2009/10 with the same figure thirteen years earlier, in 1996/97, one notes first that the surfaces in cereals, oilseeds and sugar plants have increased by 5.3% (+48 Mha) while world population has increased by nearly 19% (+1 billion people). The area devoted to cereals has slightly decreased, the area in oilseeds has increased by more than 55 Mha. Despite area contraction, world cereal production has increased by 19% thanks to improvements in yields (+21%). World production of oilseeds has increased much more importantly (+75%) thanks to area expansion (32%) and improvements in yields (+32%). This increase in oilseed production is matched by a corresponding increase in vegetable oils, oil meals and oil cakes used for food, feed and fuel (Figure 17).



POPULATION: 5.76 billion people

Fig. 17. Food, feed, fuel and other uses of cereals, oilseeds and sugar crops worldwide in 1996/97 (Mt). Source: INRA from various sources, notably the USDA/PSD database and FAO statistics

World production of cereals has increased by 361 Mt (+19%) between 1996/97 and 2009/10, out of which 115 Mt (32%) have been used for biofuels, 100 Mt (28%) for food, 100 Mt (28%) for feed and 46 Mt for other uses: it appears thus that the first outlet of additional cereals has been biofuel use. World production of vegetable oils has increased by 65 Mt (+90%), out of which 39 Mt (60%) have been used for food, 17 Mt (26%) for fuel and 9 Mt (14%) for other uses: by contrast with cereals, the first outlet of additional vegetable oils has been food uses. As a result, while cereal consumption per capita has increased by only 11%, from 139 to 154 kilograms, that of vegetable oils has increased by 66%, from 9 to 15 kilograms. World production of sugar has increased by 61 Mt (+46%), out of which 37 Mt for food and 16 Mt for fuel. Sugar consumption per capita has increased by 33%, from 15 to 20 kilograms. Coupled with significant increases in individual consumption of meat and eggs (from 42 to 51 kilograms/head/year), these figures show that average individual food consumptions have increased significantly over the thirteen-year period 1996/97 to 2009/10. They also show that increases have been heterogeneous between products, much more important for vegetable oils and sugar than for meat and eggs, and cereals. This means that biofuel production development over the period, from 17 Mt to 84 Mt, has had an impact of food security here defined in terms of cereals, oilseeds and sugar available for food consumption: this impact has been more pronounced for cereals than for oilseeds and sugar.

4.3 Areas, yields and production

Figures 18 and 19 display the evolution of surfaces devoted to the set of cereals, oilseeds and sugar plants from 1980/81 to 2010/11. One can distinguish two main sub-periods. From 1981 to 2003, upward movements phases have been followed by downward movements so that the area in 2003 is practically equal to that of 1981, about 880 Mha. One also notes that annual changes can be significant, +17 Mha in 1997 or -15 Mha in 2003. From 2004, the trend is clearly increasing: in eight years, the area of cereals, oilseeds and sugar plants has increased by nearly 80 Mha (+9%). The area increase was particularly important in 2004 (+27 Mha) partly in compensation for the decrease in 2003. The increase was also important in 2008 (+17 Ma) and 2009 (+14 Mha) in response to the 2007-08 agricultural price peak. The increase was negligible in 2009 in reaction to the 2008-2009 agricultural price decline and the 2008 financial crisis.

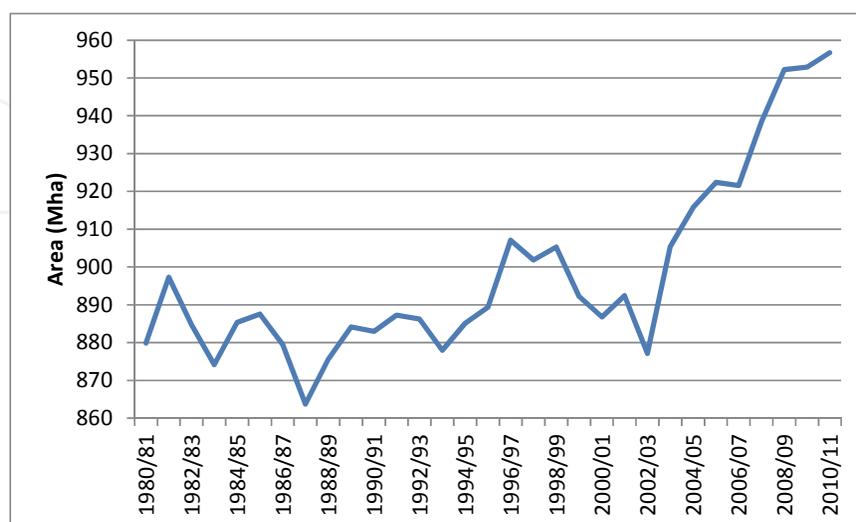


Fig. 18. World areas in cereals, oilseeds and sugar plants, 1980/81 to 2010/11, in Mha;
Source: INRA from USDA/PSD and FAOSTAT data

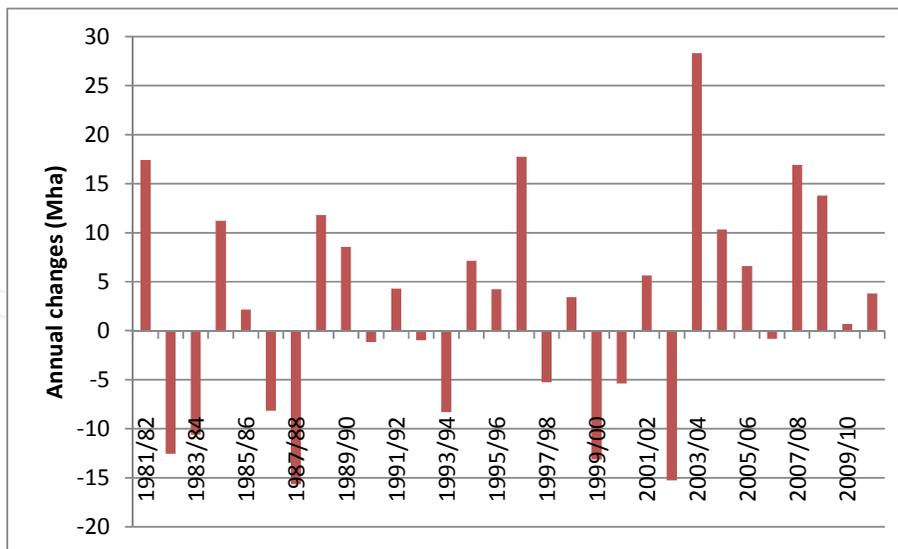


Fig. 19. Annual changes in the world area in cereals, oilseeds and sugar plants, 1981/82 to 2010/11, in Mha; Source: INRA from USDA/PSD and FAOSTAT data

While Figure 20 below depicts the evolution of areas, yields and production in cereals, oilseeds and sugar crops considered as one aggregate, the following figures display the same information for cereals (Figure 21), oilseeds (Figure 22) and sugar crops (Figure 23). From Figure 20, one notes that production and yields in cereals, oilseeds and sugar plants considered as one single aggregate have increased at the same rate than world population from 1981 to 2003. During this first sub-period, the contribution of area evolution to production growth was negligible; production increases were essentially the result of increases in yields. During the second sub-period, from 2004 to 2011, increases in yields and area expansion play together so that the production growth has outweighed that of world population. Finally, it is worthwhile noting the slowing down of growth in yields at the end of the period, from 2009.

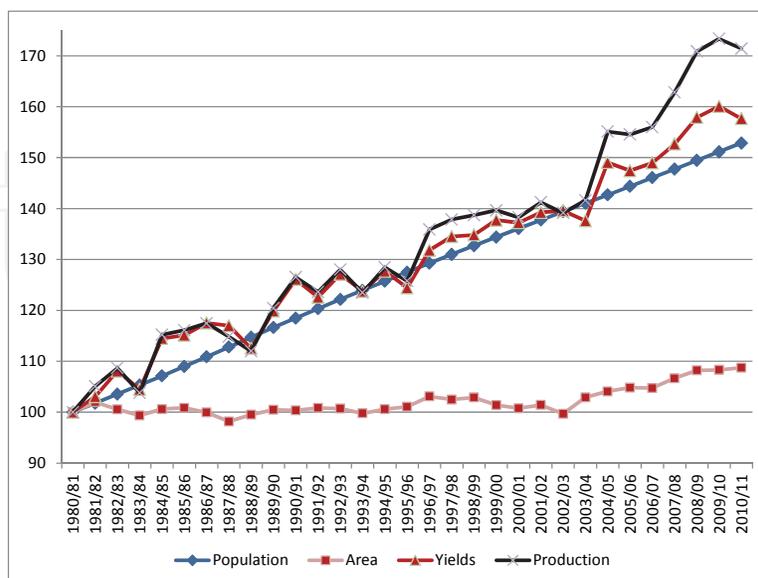


Fig. 20. World population and world areas, yields and production in cereals (including rice), oilseeds and sugar plants (in sugar equivalent), 1980/81 to 2010/11, base 100 in 1980/81; Source: INRA from USDA/PSD and FAOSTAT data

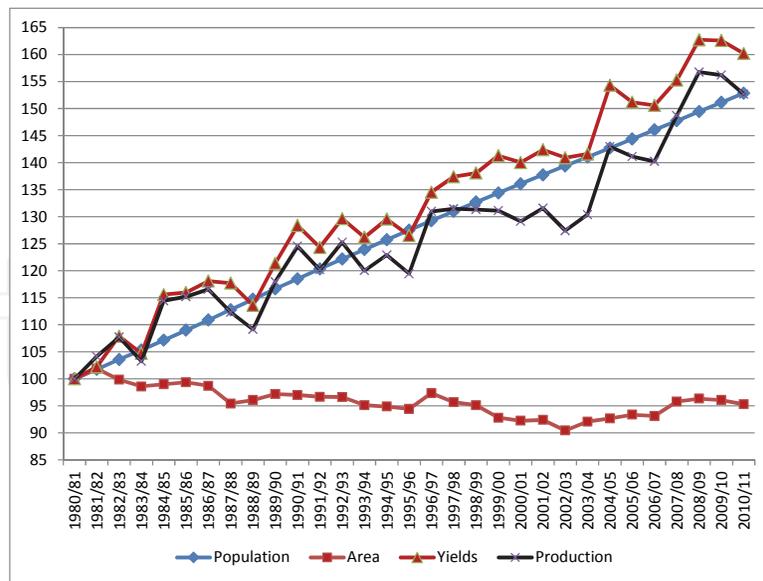


Fig. 21. World population and world areas, yields and production in cereals (including rice), 1980/81 to 2010/11, base 100 in 1980/81; Source: INRA from USDA/PSD and FAOSTAT data

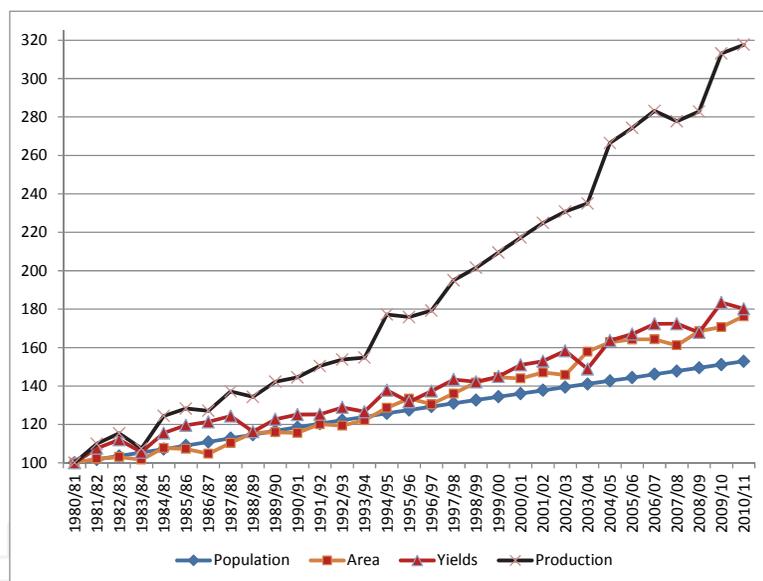


Fig. 22. World population and world areas, yields and production in oilseeds, 1980/81 to 2010/11, base 100 in 1980/81; Source: INRA from USDA/PSD and FAOSTAT data

This global picture masks huge differences between cereals on the one hand, oilseeds and sugar crops on the other hand. From Figure 21, it appears that cereal production growth was lower than that of world population from 1997 to 2008 because of the area contraction since yield growth rates were greater than those of population during this sub-period. The area devoted to cereals increased in 2008 and 2009 in response to the 2007-08 agricultural price peak. It decreased again in 2010 and 2011. One also notes the decrease in cereal yields in the very recent years. This contrasts with the case of oilseeds. As Figure 22 shows, for oilseeds, production growth exceeds that of world population from 1990 onward thanks to both improvements in yields and area expansion: for the two factors, growth rates exceeded that of population. In the same way, world sugar production is increasing at a much greater rate

than world population again thanks to both improvements in yields and area expansion even if, by contrast with oilseeds, each determinant raises more slowly than population (except yields in the more recent years).

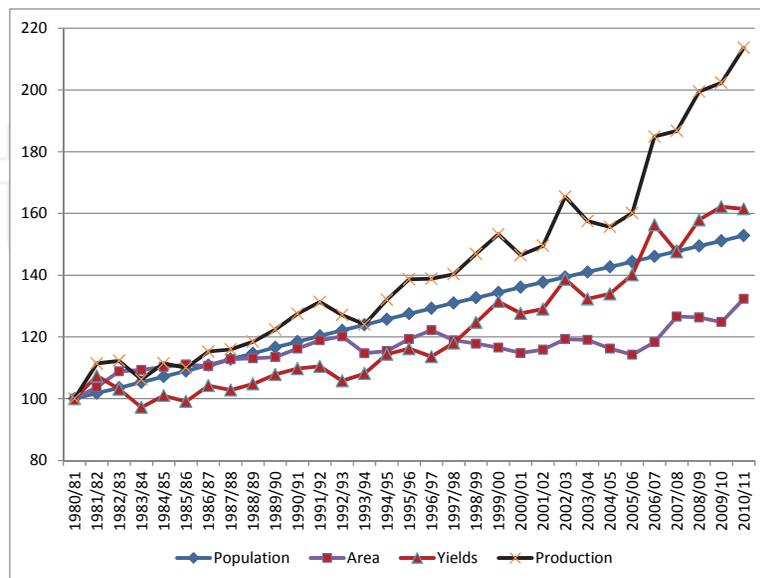


Fig. 23. World population and world areas, yields and production in sugar crops, 1980/81 to 2010/11, base 100 in 1980/81; Source: INRA from USDA/PSD and FAOSTAT data

4.4 Uses for biofuel production

The three main feedstocks used for 1G biofuels are cereals, oilseeds and sugar plants. Quantities used for biofuel were very low up to 2000/01. They have considerably increased over the last decade, from around 40 Mt in 2002/03 to more than 180 Mt in 2009/10 (Figure 24). By contrast with cereals and oilseeds, the share of world production of sugar used for biofuel was already significant in the 1990s, around 14%; after a decrease to 10% at the end of the nineties, it has increased over the 2000 decade to reach around 18% in 2009/10 (Figure 25). The share of cereals and vegetable oils used for biofuel were negligible until the years 2000 (around 1%). They have considerably increased from that date, first for vegetable oils (more than 13% in 2009/10), to a lesser extent for cereals (around 6% in 2009/10)⁸.

5. Biofuel outlook by 2020 and 2050: to what extent second-generation biofuels could alleviate some of the negative consequences of first-generation biofuels?

The 2007-2008 peak of world agricultural prices was the result of a large combination of factors including 1G biofuels (see sub-section 3.2). In the structural context of strong food demand, weak agricultural supply and decreasing inventories over more than a decade,

⁸ Data on cereals, oilseeds and sugar plants used for biofuel production are very partial. They are estimated using technical coefficients from data of biofuel production expressed in tons. They vary in function of feedstocks used. For bioethanol in Brazil, we have considered that 16 tons of sugar cane containing 10% of sugar are needed to produce 1 ton of ethanol; the technical coefficient is thus 1.6 to compare with a mean coefficient of 3.2 for bioethanol in other countries (Canada, China, EU, United States...). For biodiesel, we have estimated that 1.02 ton of vegetable oil is needed to produce 1 ton of biofuel in all countries.

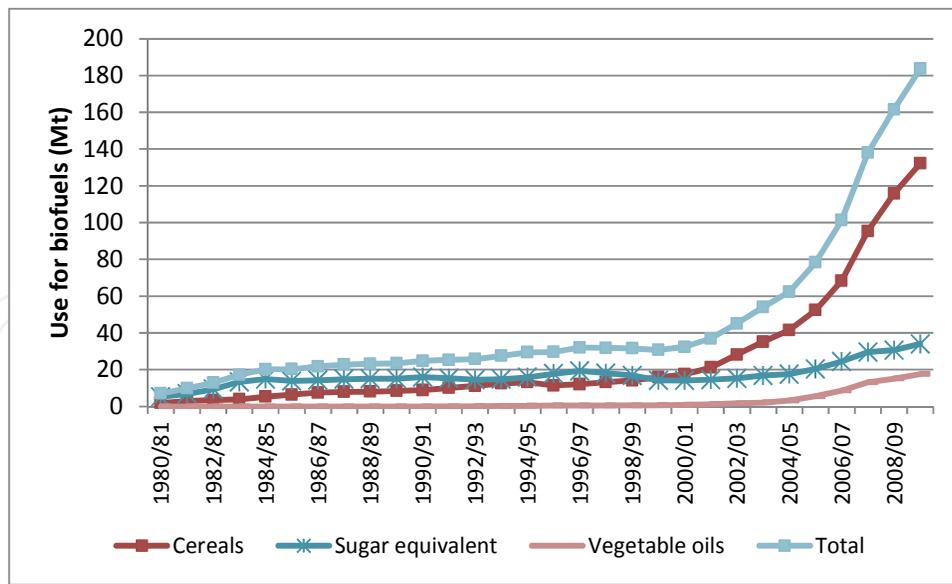


Fig. 24. Quantities of cereals, vegetable oils and sugar crops (in sugar equivalent) used for biofuel production, 1980/81 to 2009/10, in Mt; Source: INRA estimations from various sources

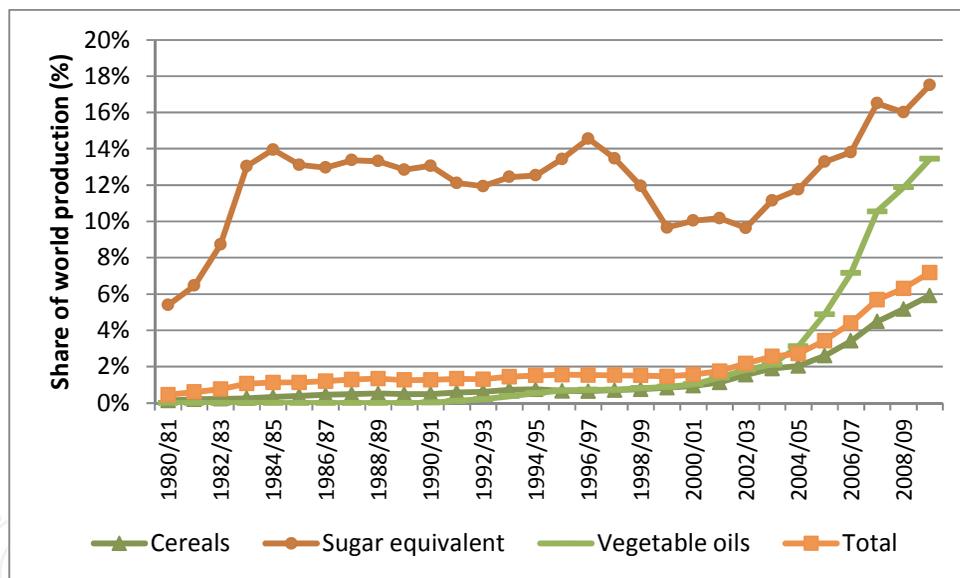


Fig. 25. Shares of world production of cereals, vegetable oils and sugar plants (in sugar equivalent) used for biofuel production, 1980/81 to 2009/10; Source: INRA estimations from various sources

some cyclical factors played negatively on quantities available for world markets (climatic accidents and restrictive export policies), others played positively on demand (biofuel production development, speculation, import encouragement policies and US dollar depreciation), and others played positively on agricultural production costs (fossil oil price increase). The very sharp correction that occurred from mid-2008 can then be explained by the fact that several factors that had pushed agricultural prices upwards in 2007-2008 returned: good weather conditions, US dollar appreciation, fossil oil price decrease, speculator exit from agricultural commodity markets because of the financial crisis. In

addition, the high agricultural prices of 2006 and 2007 encouraged producers to increase their acreage in field crops at the expense of fallow land or land previously devoted to forest or grassland, in Latin America, including Brazil, but also in Southeast Asia, sub-Saharan Africa, the United States and Europe. They also led farmers to seek the highest yields. In such a context of temporarily renewed dynamism in agricultural supply, the occurring downward adjustment of agricultural prices allowed stocks to (slightly) increase and countries to stop their exceptional import encouragement and export restriction policies. As the story is never ending, it is because several factors again return and exert a positive influence on prices that they are on an upward trend from the second part of 2010: bad weather conditions notably in Russia and Australia, US dollar depreciation, fossil oil price increase, unilateral restrictive export policies and speculation on agricultural commodities.

What was true yesterday will be true tomorrow. As a result, the issue of competition between food and non-food uses of agricultural products, and the induced questions of impacts of this competition on agricultural prices, food security or the environment, cannot be analyzed independently of the economic context. More specifically, the development of biofuels and uses of biomass for biofuel production cannot be analyzed solely in terms of growth perspectives and theoretical availability of land resources. The economic dimension must be taken into account insofar as non-food uses of biomass are ultimately determined by prices and incomes, which are directly influenced by policies, scientific progress and technical innovations, etc. The importance of the economic dimension can be illustrated by relating the increase in the world utilized agricultural area (UAA) in 2007 and 2008 in response to high agricultural prices (about +15 Mha each year) to the growth of the same area during the past thirty years (+2.5 Mha per year between 1976 and 2006).

First-generation biofuels are criticized on three main grounds: (i) their low energy efficiency in the current production conditions, (ii) the economic cost of policies put in place for promoting their development, and (iii) increasing doubts about their environmental impact, particularly in terms of GHG emissions when they involve land use changes (see sub-section 2.2.1). It is now suitable to examine the extent to which 2G biofuels can silence such criticisms, or at least dampen them. Let us first examine this question by 2020 on the basis of original simulations performed using the OLEOSIM model (Dronne *et al.* 2009). Before that, let us remind the following point already outlined in sub-section 2.2.2. If the raw material used for 2G biofuel production is a residue and/or a waste, the question of competition with food uses does not arise. But when it is a forest resource and/or a dedicated energy crop, competition with food uses of land occurs under the same theoretical terms as for 1G biofuels: are then at stake the questions of land availability, including marginal land areas, productivity of forest and dedicated crops and efficiency of transforming this biomass into 2G biofuels.

5.1 Analysis in 2020

Dronne *et al.* (2009) analyze the impacts of biofuel development by the year 2020 for cereals, oilseeds and sugar crops. Three scenarios are considered. In the "baseline" scenario, world biofuel production is held constant at its 2006 reference level, that is 37.3 Mt (31.4 Mt of bioethanol and 5.9 Mt of biodiesel) or 25 Mtoe. In the second scenario called "1G", the political objectives of incorporation for the year 2020 are attained and satisfied by 1G biofuels only, at a level of 175 Mt (125.1 Mt of bioethanol and 49.8 Mt of biodiesel) or 143 Mtoe. In the third scenario called "X% 2G", the development of biofuels reaches the same

level as in the "1G" scenario, but with varying shares of 2G biofuels replacing 1G biofuels: different blend rates and energy efficiency yields are considered defining seven "X% 2G" scenarios.

In the "baseline" scenario, the increase in cropland (+41 Mha, from 914 Mha in 2006 to 955 Mha in 2020) mainly favors cereal production despite a strong demand increase for oilseeds (oil and meals) for both food and feed. In the "1G" scenario, the arable land dedicated to the three considered crops is 960 Mha, that is +46 Mha relative to 2006 but only +5 Mha relative to the situation in the "baseline" scenario in 2020. On these 960 Mha, 68 Mha (7%) are used for biofuel production: 33 Mha of cereals (4% of world area in cereals), 27 Mha of oilseeds (13% of world area in oilseeds) and 8 Mha of sugar crops (28% of world area in sugar plants). In practice, the development of 1G biofuels leads to a sharp decline in cropland dedicated to other uses than biofuel production, including those dedicated to food: these are 893 Mha in 2020 which is 46 Mha less than in the "baseline" scenario without biofuel development. This means that the development of 1G biofuels by 2020 as simulated by Dronne *et al.* would have a doubly negative effect on world food security as it would result in a decrease in cropland surfaces dedicated to food (and feed) and an induced increase in crop prices, as compared to the situation in 2020 without biofuel development.

To what extent could the replacement of the first generation of biofuels by the second one change the picture briefly described above? In the seven "X% 2G" scenarios, 2G biofuels are gradually introduced from 2015 onward under different assumptions regarding blend rates in fossil fuel and energy efficiency yields of dedicated bioenergy crops. The first lesson is that the (partial) substitution of the first generation by the second should make it possible to limit the negative impacts of biofuel development on world food security. Crop areas devoted to food and feed are more important in the seven "X% 2G" scenarios when compared to the "1G" scenario in which only the 1G biofuels are available. The gain reaches 25 Mha in the most favorable "X% 2G" scenario in which 35% of 1G biofuels are replaced by 2G biofuels in 2020⁹ and the yields of dedicated bioenergy crops are rather high (25 tons of dry matter per hectare). However the gain is limited to 10 Mha in a variant with a replacement rate of 1G biofuels by 2G biofuels of 20% at world level in 2020¹⁰ and rather conservative assumptions regarding yields for 2G dedicated crops (12 tons of dry matter per hectare).

However, even in the most favorable scenario considered by Dronne *et al.*, the hectares devoted to cereals, oilseeds and sugar crops for food and feed uses in 2020 (910 Mha) are significantly lower than the corresponding surfaces at the same time horizon in the "baseline" scenario without biofuel development (939 Mha). This means that the development of 2G biofuels can only mitigate the negative impacts of biofuels on world food security, defined here in terms of crop surfaces for food and feed as well as world crop prices; it cannot eliminate them. Furthermore, the decline in the production of co-products associated with 1G biofuels penalizes the animal sector insofar as the increased availability in cereals and oilseeds induced by the replacement of 1G biofuels by 2G biofuels does not compensate for the more important decline in the availability of meals and co-products associated with the production of 1G biofuels.

⁹ 35% is the 2020 world percentage for both bioethanol and biodiesel. In the EU, the replacement rate of 1G biofuels by 2G biofuels is much higher, that is 70% for both bioethanol and biodiesel. We acknowledge that the EU figure is unrealistic.

¹⁰ The replacement rate is 25% in the EU.

5.2 Analysis in 2050

5.2.1 Estimation of the potential demand for biomass

The International Energy Agency (IEA) has attempted to estimate total primary energy demand by 2050 according to various effort levels aiming at reducing GHG emissions (IEA 2008). This demand ranges from 640 Exajoules (EJ), that is 153 Btoe, in the most constrained scenario (“Blue Map 2050”) to 950 EJ, that is 227 Btoe, in the “business as usual” scenario (“Baseline 2050”). The “Blue Map 2050” scenario corresponds to a limitation of the atmospheric concentration in CO₂ at 450 parts per million (ppm) in 2050 which requires a halving of 2005 GHG emissions (and a 77% cut compared to the situation in 2050 in the “Baseline 2050” scenario). In this “Blue Map 2050” scenario, the total demand from energy-devoted biomass is 147 EJ; this corresponds to 23% of the total primary energy demand in 2050 and is three times the amount of biomass used for energy production in 2006. In the two other scenarios, the intermediate “Act Map 2050” scenario and the “Baseline 2050” scenario, the total demand from energy-devoted biomass also increases sharply compared to 2006, respectively +68 and +35 EJ (Figure 26).

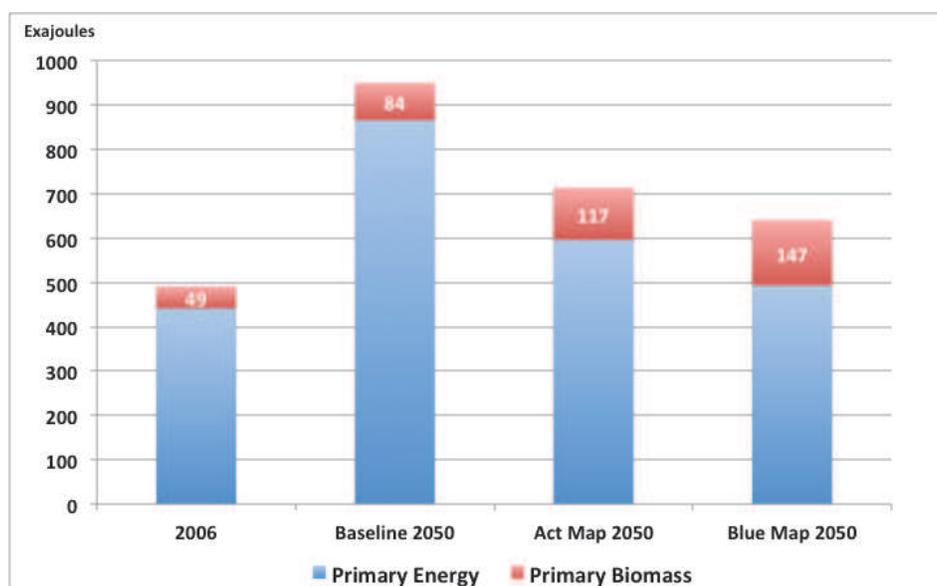


Fig. 26. Demand for primary energy and biomass used for energy production in 2050 in the three IEA scenarios, in EJ; Source: INRA estimations from IEA (2008)

In the “Blue Map 2050” scenario, 52% of reductions in GHG emissions in the transport sector are expected to be obtained through improved efficiency in the use of fuels, and 48% by replacing fossil fuels by alternatives including electricity, hydrogen and biofuels. Biofuels are expected to attain 30 EJ in 2050 (0.7 Btoe), that is 26% of the total fuel use at that date. To achieve this very ambitious result, the IEA assumes that 1G biofuels made from cereals and oilseeds will have disappeared by 2040-2045, with the exception of bioethanol produced from sugar cane for 3 EJ in 2050 (10% of biofuels at that date). The remaining, that is 90%, will be 2G biofuels made from ligno-cellulosic resources. In the intermediate “Act Map 2050” scenario, biofuels would reach 24 EJ (0.6 Btoe) in 2050. In the “Baseline 2050” scenario, the use of biofuels in 2050 would be significantly lower at 4.2 EJ (0.1 Btoe), but still substantially up compared to today.

To sum up, it appears that energy uses of biomass are expected to grow very significantly over the decades to come. The increase in energy uses of biomass will be highly correlated to

the political mobilization aiming at reducing GHG emissions. After having assessed the demand for biomass by 2050, the next step consists in analyzing whether the supply of biomass will be sufficient to meet this demand.

5.2.2 Estimation of the potential supply of biomass

A literature review (Forslund *et al.* 2010) suggests that the potential supply of biomass for energy purposes is more than sufficient to meet the needs by 2050. According to some estimates, the potential supply would even be more than total energy demand in 2050. For example, Smeets *et al.* (2007) estimate that the potential supply of biomass for energy production will be more than 1500 EJ, out of which 1200 EJ from dedicated crops. Hoogwijk *et al.* (2003) quantify the same potential to slightly more than 1100 EJ, with again the largest share coming from dedicated crops. Two other studies, Fischer and Schrattenholzer (2001) and Berndes *et al.* (2003), are less optimistic with a potential of about 400 EJ, which is still quite a sizeable figure considering the current uses of biomass for energy purposes and total energy demand in 2050 in the different scenarios of the IEA.

The high variability in potential biomass supply estimates is mainly due to two key parameters, the land area that could be used for energy on the one hand, yields of energy crops on the other (in terms of both biomass yields per hectare and efficiency of transforming this biomass into energy). Land that could be used for energy depends on the total land area available and on land needs for other purposes than energy, first of all food and feed use, but also forestry, environmental, recreational, urban uses, etc.¹¹ Land needed for food depends on many parameters both on the demand side (demography, urbanization, incomes and prices...) and on the supply side (crop yields, importance of animal products relative to crops...). The equation has thus many unknowns, at least many uncertainty factors.

Just as there is variability about the total potential of biomass as an energy source according to studies, there is variability concerning the different types of biomass that could potentially be used: residues and waste, forest resources and dedicated crops. Nevertheless, the ranking of the three types of biomass is generally identical: first dedicated crops that represent up to 97% of the total potential for Hoogwijk *et al.* (2003) - 1098 EJ out of 1130 - and at least 44% for Schrattenholzer and Fischer (2001) - 200 EJ out of 450 -, second forest resources and residues and third residues of agricultural origin.

To sum up, despite the high variability of estimates about the biomass that could potentially be used for energy production, it appears that it would be sufficient to meet bioenergy demands in general, biofuel demands in particular, in 2050 and later on. Nevertheless, the

¹¹ According to FAO data, world emerged land is about 13.1 Bha. Excluding cropland (annual and perennial crops), forest areas, deserts and areas under human influence, that leaves a "surplus" of about 4.5 Bha (35%). Out of these 4.5 Bha, slightly more than 50% (2.4 Bha) are unsuitable for agricultural production (unproductive, marginal, steep and/or protected lands). That leaves 2.1 Bha of land potentially suitable for crops currently allocated to grass, shrubs and forest plantations outside forests. Out of these 2.1 Bha, researchers from the Land Use Change (LUC) program at the IIASA (International Institute for Applied Systems Analysis) consider that 60 to 70% of the biomass produced would be used for animal feed, which leaves a theoretical potential of 600 to 800 Mha for bioenergy production. This potential is only theoretical, first because it will be implemented only if it is economically profitable to do so, second because it will have to compete with increasing food uses in the years to come. For example, the FAO estimates that cropland should increase by about 120 Mha by 2050 in developing countries, essentially in Latin America and sub-Saharan Africa (FAO 2009).

potentially available biomass is estimated at a global scale without taking into account its geographical distribution and the necessary adaptation of local supply to regional demand at the scale of countries or groups of countries. The most widespread resources are not necessarily located in areas where consumption will be important. As a consequence, international trade will be indispensable. Moreover, it is also necessary to distinguish the potential supply of energy-devoted biomass from the prospects of biomass that should effectively be used for that usage.

These opportunities arise from supply-demand interactions on bioenergy markets. Supply and demand conditions are both under multiple influences (public policies, strategies of actors, scientific and technical progress...). Furthermore, the analysis cannot be restricted to bioenergy markets. It must be conducted taking into account, jointly and simultaneously, alternative uses of land and their corresponding applications (food and feed, environment, recreation, infrastructures, etc.). This is the purpose of the next sub-section that focuses specifically on assessing the impacts of bioenergy development on food security and the environment measured in terms of GHG emissions and biodiversity preservation.

5.2.3 Impacts of biofuel development on food security and the environment by 2050

As the main source of biomass for 2G biofuels is expected to be dedicated crops (see sub-section 5.2.2), the competition for land between food and non-food uses, already emphasized for 1G biofuels, is likely to remain a debated topic for 2050.

With this in mind, Fischer (2009) discusses the consequences of biofuel development in 2050 on world food security measured by food and feed uses, cereal prices and the number of people suffering from hunger. Fischer defines two main scenarios corresponding to two distinct blend rates of biofuels into fuels used for road transport, respectively 6% (225 Mtoe) and 11.3% (424 Mtoe). Both rates are implemented under three assumptions concerning the replacement of 1G biofuels by 2G biofuels at 26, 35 and 55%, respectively. Simulation results show that the development of biofuels would have a doubly negative impact on world food security, by lowering cereal quantities available for food and feed and by raising their international prices. As a result, the number of people suffering from hunger would increase in 2050 in all scenarios considered relative to the baseline scenario at the same date. Far from being negligible, these negative effects on world food security would increase in parallel with the total share of biofuels blended into fuels used for road transport and with the slowest rate of incorporation of 2G biofuels. In the "worst" scenario corresponding to a high incorporation rate of biofuels (11.3%) out of which only 26% are ligno-cellulosic biofuels, world cereal production would increase by 313 Mt and land dedicated to cereals by 48 Mha, relative to the baseline. But as the needs for energy cereals would be 446 Mt, the amount of cereals available for food and feed would shrink to 127 Mt, which, combined with rising prices (+27%), would have the ultimate effect of increasing the number of people suffering from hunger by more than 140 million in 2050, relative to the baseline. A faster development of ligno-cellulosic biofuels would reduce land needs for energy-devoted cereals, increase cereal quantities for food and feed and ultimately reduce the growing number of people suffering from hunger: in the same scenario of an 11.3% incorporation rate, but with 55% of ligno-cellulosic biofuels, the increasing number of people suffering from hunger would be "limited" to 70 millions in 2050, again relative to baseline.

For their part, Melillo *et al.* (2009) are particularly interested in environmental issues. More specifically, they compare the impacts of two scenarios for biofuel development aiming, at

least in theory, at contributing to the same reduction in global GHG emissions. In 2050, all biofuels would be of the second generation and would all be produced from dedicated crops. In the first scenario called "deforestation", all surfaces can be mobilized for the production of biofuels as well as other uses, including agricultural production for food when this is economically beneficial. In the second scenario called "intensive", unmanaged land (e.g. tropical forests) can be mobilized only partially, that is by respecting the rates of land use changes observed in the past. In both scenarios, the economic development of 2G biofuels would be important and at an equivalent level (141 EJ in the "deforestation" scenario and 128 EJ in the "intensive" scenario, which in both cases is more than 10% of the total projected energy demand in 2050); the surfaces mobilized for that purpose would be significant and of similar magnitude (1.48 and 1.39 Bha, respectively).

In the "deforestation" scenario, cultivated agricultural land would increase by 1.73 Bha between 2000 (4.2 Bha) and 2050 (5.93 Bha) under the double pressure of increases in cropland for food and feed (from 1.61 to 2.0 Bha) and, more importantly, of increases in land areas devoted to dedicated energy crops (from 0 to 1.48 Bha) not compensated for by the very small decrease in grassland (from 2.58 to 2.45 Bha). The development of biofuels would have a negative impact on GHG emissions with a carbon debt¹² of 103 Pg C¹³ over the 2000-2050 period mainly due to the deforestation of tropical forests in Latin America, sub-Saharan Africa and Southeast Asia. The impact on biodiversity would also be negative, particularly in Latin America (-520 Mha of natural and semi-natural forests and -60 Mha of other wooded land) and in sub-Saharan Africa (-310 Mha of natural and semi-natural forests and -120 Mha of other wooded land).

In the "intensive" scenario, cultivated agricultural land would be 4.98 Bha in 2050, that is 0.79 Bha more compared to the base year 2000 but 0.95 Bha less compared to the "deforestation" scenario in 2050: the sharp decline in grassland (from 2.58 to 1.79 Bha) is insufficient to offset the double increase in cropland for food (from 1.61 to 1.8 Bha) and in land devoted to dedicated energy crops (from 0 to 1.39 Bha). The reduction of biodiversity, measured in terms of reduction of natural areas now devoted to food crops, energy crops or pasture, is lower in the "intensive" scenario than in the "deforestation" scenario. However it is still significant with, for example, over 160 Mha losses of forest and wooded lands in Latin America and 270 Mha in sub-Saharan Africa. Furthermore, a more complete analysis would require taking into account, first the conversion of 800 Mha of grassland into food or energy crops, second the environmental consequences of the intensification of agricultural technologies and practices. The "deforestation" and "intensive" scenarios differ mainly in terms of carbon debt: from 2000 to 2050, the carbon debt would be more than three times lower in the "intensive" scenario (34 Pg C) than in the "deforestation" scenario (103 Pg C). This means that while one has to wait until the mid-century to observe the first net cuts in GHG emissions resulting from the substitution of fossil fuels by biofuels in the "deforestation" scenario, these become visible before 2035 in the "intensive" scenario.

¹² The decrease in terrestrial carbon stock, associated with biofuel development and induced land use changes, is commonly called the "carbon debt". During a lapse of time, and for unchanged land uses, the carbon debt decreases and can even be cancelled if GHG emissions linked to the production and the use of biofuels are lower than emissions from replaced fossil fuels.

¹³ 1 Pg = 10¹⁵ g = 1 Gt = 10⁹ metric tons.

6. Conclusion

The objective of this chapter was to analyze the interactions between biofuel development worldwide and the agricultural markets for cereals, oilseeds and sugar plants in terms of quantities (supply and demand), prices and impacts on land use. More specifically, the aim was to determine the degree of competition between food and non-food uses, notably for biofuels, uses of agricultural land and products, and its consequences.

First-generation biofuels are criticized for their negative impact on world food security and their environmental performance, notably in terms of GHG emissions, that is often considered as negative when induced land use changes are taken into account. Furthermore, their technical efficiency is low and the cost of public policies aiming at encouraging their development is high relative to market and non-market profits. In this context, hopes are turning to second-generation biofuels produced from various wastes and residues, wood from forests or dedicated crops that do not compete directly with land uses for food and/or feed. Nevertheless, the absence of direct competition for land use does not mean that there is no indirect competition, as dedicated crops and forests, in the case of an expansion of forest areas to meet energy demands, require surfaces too.

Analyzing this indirect competition is all the more important as the demand for biomass for energy purposes should considerably increase over the coming decades and as the main source of biomass mobilized for that purpose should be dedicated crops. Our analysis shows that replacing first-generation biofuels by second-generation ones would only mitigate the adverse effects of the development of first-generation biofuels on world food security (analyzed in terms of agricultural products available for food and feed and in terms of agricultural prices) and the environment (notably in terms of GHG emissions and biodiversity preservation).

This mitigation will be stronger if the biomass used for second-generation biofuels is provided by dedicated crops grown on “marginal” land currently unoccupied by crops and forests. This point raises the related issues of quantifying these “marginal” land areas and of their sustainable exploiting. This is a vast domain with many parameters still unknown. Research and development should also focus on the transformation of ligno-cellulosic residues and waste from various sources in order to reduce collection and storage costs, and on the sustainable management of forests for enhancing their full potential in terms of uses of wood, surplus growth and residues for both energy and environmental features.

The food challenge (feeding 9 billion people by 2050) is associated with an environmental challenge (defining sustainable agricultural practices and systems) and an energy challenge related to the gradual depletion of fossil fuels. In connection with this third issue, it is more than likely that energy uses of terrestrial biomass will be significant in 2050. Can we quantify these energy uses? That is difficult, if not impossible, given the considerable uncertainties surrounding estimates of total energy consumption in 2050 (e.g. from simple to double, 550 to 1000 EJ per year, according to Clarke *et al.* 2007).

The food challenge requires actions on both the demand and supply side. As far as demand is concerned, developed countries (and rich households worldwide) need to reduce waste and losses at distribution and final consumption stages. They also need to change their consumption patterns to reduce overweight and obesity, and related diseases. On the supply side, in addition to reducing post-harvest losses, it will be necessary to increase crop yields, notably in regions where they are currently low, but in a sustainable way. Agricultural practices and systems used worldwide should radically change.

Quantifying the increase in agricultural production by 2050 is as difficult as quantifying the energy demand and its distribution among the different potential sources. In both cases, prices will ultimately determine supply and demand conditions. There is no doubt that these conditions are and will be influenced by policy measures. But in this area too, uncertainties are numerous. However there is a large consensus for recognizing that agricultural production will have to increase to satisfy food needs of an growing, increasingly urbanized and (on average) richer population. There is also a consensus that, as in the past, the increase in agricultural production volumes will be achieved mainly by increasing yields.

The required increase in yields across the world will necessarily be associated to sustainable farming practices and systems. This twofold aim calls for heavy investment in generic and systemic research, in farms' upstream infrastructure, notably in the objective of providing better access to machinery, water, fertilizers and crop treatment products for farmers in developing countries. It also calls for investment in downstream infrastructures, more specifically to storage and transportation in facilities to reduce post-harvest losses. It requires adopting a holistic approach based on an integrated management of agricultural ecosystems and the use of techniques aiming at conserving natural resources (Pretty *et al.* 2006). In this perspective, practices and systems will necessarily be diverse, adapted to local constraints and environmental resources, and capitalize on the knowledge and expertise of local actors supported by strong public policies.

Concerning biofuels, should we reject first- and second-generation biofuels because they could have a negative impact on world food security, because their environmental record in terms of GHG emissions and/or biodiversity preservation could be negative when induced land use changes are (too) important and/or because public promotion policies would be (too) costly with respect to market and non-market benefits? We do not think so, as the food and environmental challenge should not obscure the energy challenge related to the depletion of fossil resources. To meet the energy challenge, we must act on demand by promoting energy savings, and on supply by developing alternatives to fossil fuels as long as they are environmentally friendly and economically cost-effective, knowing that costs will vary depending on fossil oil prices. In other words, it is jointly and simultaneously necessary to examine our planet's capacity to meet the food, environment and energy challenges.

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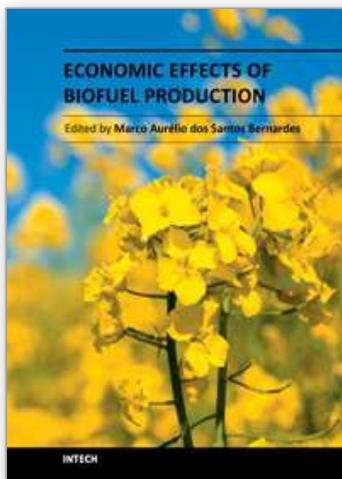
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This book aspires to be a comprehensive summary of current biofuels issues and thereby contribute to the understanding of this important topic. Readers will find themes including biofuels development efforts, their implications for the food industry, current and future biofuels crops, the successful Brazilian ethanol program, insights of the first, second, third and fourth biofuel generations, advanced biofuel production techniques, related waste treatment, emissions and environmental impacts, water consumption, produced allergens and toxins. Additionally, the biofuel policy discussion is expected to be continuing in the foreseeable future and the reading of the biofuels features dealt with in this book, are recommended for anyone interested in understanding this diverse and developing theme.

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