Chapter 2

Ensuring global food availability

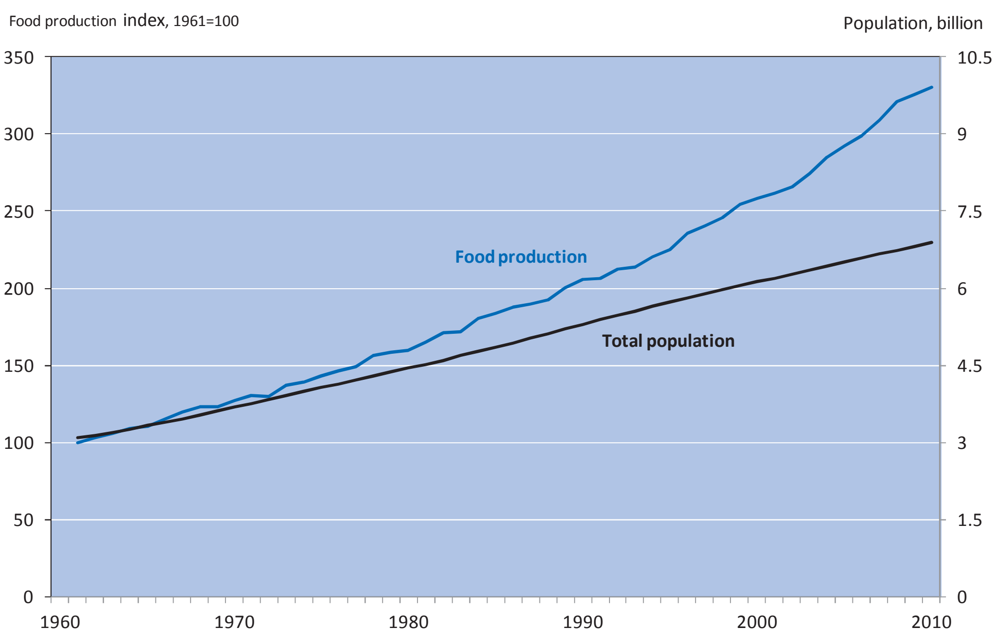
The chapter considers the ways in which governments can improve the availability of food sustainably. While food production will respond to the needs of a rising and more affluent world population, there are steps that governments can take to improve the availability of food, either by stimulating supply sustainably or by constraining demands that are detrimental to nutritional outcomes.

2.1. The challenge of ensuring global food availability

"The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race." – Malthus T.R. 1798. An essay on the principle of population. Chapter IX, p. 72.

Despite Malthus's gloomy prediction, the overall availability of food has not historically posed a problem for global food security. While demand has increased as a result of population growth and rising incomes, production has kept pace and there has been no sustained period over which population growth has outstripped supply. Over the past 50 years, the amount of food available per person has increased by 20% (Figure 2.1). Availability has more commonly been an issue at the national level, but even then it has not been the dominant cause of famine. The broad evidence confirms Sen's overall assessment that food access matters most: "Starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there being not enough food to eat" (Sen, 1980).

Figure 2.1. Global food production and population growth



Source: FAOSTAT.

The key issue with respect to global food availability is the prospect of tighter world food markets, with demand increases, deriving principally from income and population growth, outpacing expected supply gains coming from productivity improvements and increased mobilisation of land, water and other resources. Tighter world markets imply higher, and possibly more volatile, food prices. Thus, the problem of availability becomes one of access for those who can no longer afford food.

Increases in food availability, which contain or reverse upward pressure on food prices from population and income growth, can be achieved by stimulating supply, or by restraining demands that do not correspond to improved "utilisation" of food. The main channels through which governments can improve global food availability are noted in Table 2.1.

Table 2.1. Ways of increasing global food availability

Increasing food supply	Limiting food demand
Improved agricultural productivity (more efficient use of inputs, such as labour, land and water)	Modified tastes and preferences (including less meat consumption, reduced over-consumption)
Expansion of land area	Reduced consumer waste
Reduced supply chain (especially post-harvest) losses	
Climate change adaptation	
Less diversion of crops to non-food uses (e.g. biofuels)	

Conventional agricultural policies, such as price and farm income support and credit subsidies, also have effects on the supply side, while food taxes and consumer subsidies affect demand. Trade also has an important role to play in increasing aggregate food availability, with open trade enabling food production to locate to areas where it can be undertaken relatively efficiently and providing a mechanism through which food can be allocated from surplus to deficit countries and regions. The role of trade in contributing to global food availability is taken up in Chapter 3. Yet the objective of increasing food availability cannot be viewed in isolation. Those increases need to be generated efficiently (i.e. policies need to be cost-effective) and sustainably.

In terms of efficiency, the basic questions are: First, what changes to the supply and demand factors listed above are likely to occur and to what extent can they be influenced by policies? Second, how much would it cost to effect those changes? Answering such questions should enable governments to prioritise.

In terms of sustainability, there may be complementarities. The broad challenge of "sustainable intensification" is to exploit those complementarities, i.e. to increase agricultural productivity growth without imposing greater strain on natural resources, in a context of growing competition between agriculture and other uses for finite land and water resources, and uncertainties associated with climate change and other environmental problems (FAO, OECD et al. [for G20], 2012). It will require adopting technologies and farm management practices that reduce GHG emissions, sequester carbon, adapt to climate change and provide environmental co-benefits. Recent OECD work explores how the cultural and social changes, effected for example via education and the provision of information, can facilitate adaptation to, and mitigation of, climate change by farmers (OECD, 2011a).

However, it is important to note that there may also be unavoidable trade-offs. In particular, farmers may be located in areas where production is not inherently sustainable. Relatedly, there may be cases where production is occurring without effective pricing of natural assets, and without taxing negative externalities. For example, case studies commissioned by the International Sustainability Unit provide several examples where the market price of food is lower than the true costs of its production. In particular many production practices impose negative externalities and erode natural capital, depriving future generations of natural resources (ISU, 2011). The sources of loss include greenhouse gas emissions, air and water pollution, soil degradation, water depletion and losses in biodiversity. A common problem is unsustainable irrigation practices. For example, IFPRI modelling work suggests that over-exploitation of water resources in Punjab and Haryana (partly attributable to free electricity, which leads to excess use of electric pumps) may lead to a decline in wheat production of around 15% by 2020. The net present value of this loss is estimated at about USD 1.2 billion (ISU, 2011).

These examples indicate that the pursuit of environmental sustainability may not always be consistent with raising food production. If policy makers are reluctant to tax negative externalities or to price natural capital because of the implications for a particular constituency's livelihoods, then it is important that any trade-offs are at least made clear. The costs of not pricing resources for sustainable use can then be viewed as an implicit subsidy to farmers (and indirectly to consumers), necessary to guarantee their short term food security. Over time, it should be possible to phase that subsidy out as income growth outweighs the burden of higher costs and food prices, and as farmers are encouraged to transition to more sustainable farm practices or to alternative livelihoods that can generate higher incomes.

The benefits from changes to the factors in Table 2.1 would go beyond increased food availability and lower prices.[1] Most of the supply side changes would also lead to higher farm incomes; while on the demand side, reduced over-consumption and a shift to more balanced diets in some countries would lead to improved health. Likewise, reducing waste on either the producer or consumer side would reduce resource pressures. These additional impacts are taken up in later sections.

In terms of prioritising among policies, it is helpful to take stock of what world food availability would look like under a plausible "business as usual" scenario, then consider the scope for policymakers to shift the basic supply and demand determinants and the implications of doing so. Section 2.2 presents the main characteristics of the outlook for world food and agricultural markets over the next ten years, drawing on the OECD and FAO *Agricultural Outlook* and the underlying Aglink-Cosimo model. It also distils the main findings from a range of modelling efforts which address expected changes in food availability over the coming decades – out to 2050 and in some cases beyond. Following that, Section 2.3 looks at the main supply shifters, and considers the nature of the link to food security outcomes and potential policy responses. Section 2.4 does the same for the demand shifters.

2.2. Outlook for world food availability

OECD works with FAO to produce an annual OECD–FAO *Agricultural Outlook*, which provides projections for world agricultural markets over the medium term (i.e. with a ten-year horizon) on the basis of a jointly maintained model (Aglink-Cosimo). At the same time, OECD participates in the Agricultural Model Inter-comparison and Improvement Project (AgMIP), which forms the basis for longer term scenario analysis.[2]

Aglink-Cosimo is a global partial equilibrium model of world agricultural markets which provides the baseline projections for agricultural commodity supply, demand, trade, and prices reported in the annual *Agricultural Outlook*. The strength of Aglink-Cosimo comes from its extensive country and commodity coverage, with 39 individual countries, 19 regions and 17 products or groups of products for which market clearing prices are specified (covering wheat, rice, coarse grains, oilseeds, oilseed meal, vegetable oil, sugar, beef, pork, poultry, eggs, and milk and key milk products; and in the most recent version, ethanol and biodiesel). The current *Outlook* is summarised in Box 2.1.

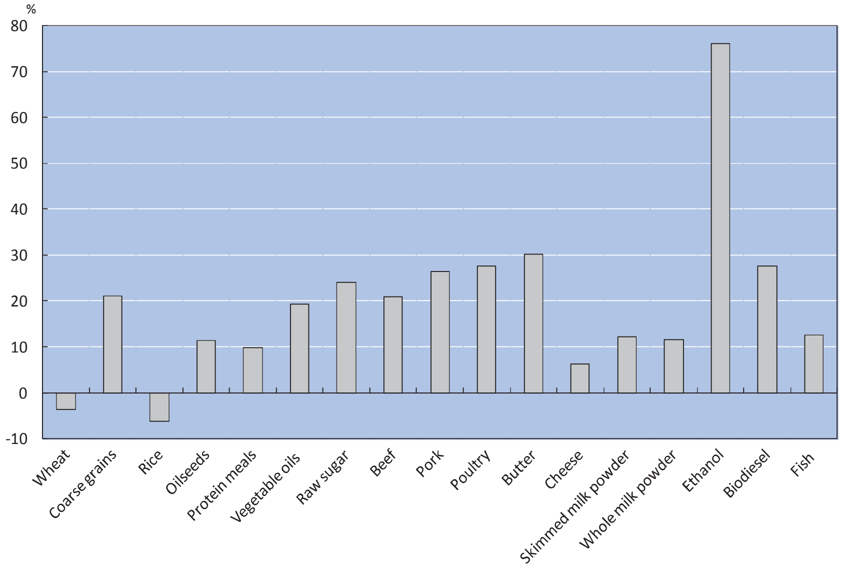
AgMIP seeks to clarify the links between market developments, climate change and food security. AgMIP participants include multiple groups working with crop models, agricultural economics models and world agricultural trade models. Within the overall AgMIP framework, the global economic models take inputs from crop and more detailed regional economic models. They then seek to harmonise core assumptions across the various models in order to make comparisons across different modelling approaches meaningful. These assumptions produce a reference scenario, and form the basis for an exploration of alternative scenarios. The models take a longer term perspective, exploring the implications of different scenarios through to 2050. The inter-comparison work of the AgMIP global economic models group contains both partial equilibrium and general equilibrium models. The AgMIP models typically have less commodity detail than Aglink-Cosimo but a more explicit treatment of factor markets, and are better placed to handle issues such as land and water constraints and climate change effects. Beyond AgMIP, a range of other modelling efforts are also underway, exploring the long term implications of alternative policy scenarios (e.g. Alexandratos and Bruinsma, 2012; Hertel, 2010; Paillard et al. 2011).

The different models shed light on different elements of the food availability issue, and are used to analyse a wide range of possible future developments and their driving factors. It is not possible to summarise all these modelling efforts or discuss their strengths and weaknesses. Instead, this section distils what they have to say about the core forces driving world food availability over the coming decades and the scope for raising food availability via each channel.

Box 2.1. Summary of the OECD and FAO Agricultural Outlook

Under the baseline assumptions, agricultural commodity prices will remain high throughout the next decade. High prices are driven by the eventual strengthening of global economic growth and stronger demand for agricultural products, along with growing biofuel demand and slowing production growth. Higher oil prices (foreseen to increase from USD 111 per barrel to USD 142 per barrel by 2021, an average annual growth rate of 2.9%) raise the costs of fertiliser and chemicals, and contribute to slowing productivity growth. Resource pressures, which include limited land and water availability, also imply that area expansion slows. The combined result is slower production growth and less accumulation of stocks. Aglink-Cosimo projects that prices of all commodities covered in the *Outlook* will be higher in nominal terms in 2012-21 than in the previous decade. When expressed in real terms (i.e. adjusted for inflation) all commodity prices apart from wheat and rice will be higher than their average in the previous decade 2002-11. When comparing the *Outlook* period with the averages of 2009-11 all crops show prices below the peak reached in 2011.

Figure 2.2. Percentage change of real commodity prices in 2012-21 relative to the previous decade (2002-11)



Source: OECD and FAO (2012).

The projected real price increases over the coming decade are higher for livestock products than for crops. The *Outlook* suggests that one reason is that many of these products did not experience a surge in 2007/08 as occurred for cereals and oilseeds. The smaller rise in feed costs relative to projected meat prices will improve margins in the livestock sector, which together with increased demand, will provide incentives to increase livestock inventories over the *Outlook* period. Rising per capita consumption of fish products will push up fish prices from both capture and aquaculture, the latter expected to increase more rapidly due to higher input costs. Despite strong meat prices, meat imports of developing countries are expected to increase, driven by population and income growth, in conjunction with high income elasticities of demand (OECD and FAO, 2012).

After the turbulence in recent years, the large rebound in supplies of major crops in response to high prices has helped to restore market balances. The projected higher prices are expected to encourage producers of crop and livestock products to increase area harvested and animal inventories; and to achieve higher productivity through further investments (e.g. use of improved seed varieties, inputs and high quality feedstuffs, adoption of productivity enhancing technologies in the face of rising energy prices). With increased commodity supply expectations and rising stocks, the risks of high price volatility are expected to abate in the near term. However, the *Outlook* notes that any unforeseen production shortfalls or trade restricting measures in major producing and trading countries could quickly provoke price rebounds and higher volatility (OECD and FAO, 2012).

Food demand

The core drivers of rising food demand are population and income growth. The rate of population growth is expected to slow, with the world population peaking shortly after 2050. The latest UN figures suggest the world population reaching 9.3 billion by 2050, but there is a wide range of uncertainty, with a low estimate of 6.1 billion and a high of over 15 billion, depending on assumptions about fertility and mortality (United Nations, Department of Economic and Social Affairs, Population Division, 2011). The central projection has the annual rate of population increase falling from 1.2% in 2012 to 0.3% in 2050. This increase would raise global food demand by about one-third, even though most of the population growth will be in poorer countries with correspondingly lower per capita food consumption. Almost half of the additional population will be in Africa, with 40% in Asia. This demographic change raises specific issues with respect to availability (and access) in these two regions.

Rising incomes will lead to increases in food demand. Weak demand in much of the OECD area is slowing growth in the large emerging countries and the developing world, but ultimately strong growth is expected in developing countries, with incomes converging towards those in developed OECD countries (OECD and FAO, 2012). Hertel et al. assume a global per capita income growth rate of 2.25% per year (Hertel et al., 2012).

Higher incomes will also change the composition of food demand, with more demand for livestock products in particular, but also for fruit and vegetables, as well as for sugar and vegetable oils. Tweeten and Thompson (2008) calculate that the combined impact of growing incomes and changing diets has been stable growth in per capita demand for food and fibre of around 0.27% per annum (measured over the period 1961-2000). Over the 45 years to 2050 this adds just 13% to aggregate food demand. However, the FAO (FAO, 2012a) suggests a per capita increase of around 30% over the same period, while Tilman et al. (2011) provide an estimate of 60%, showing the range of uncertainty.[3]

Taking population and income growth together, FAO estimate that, by 2050, global agricultural production will need to increase by 60% overall compared with 2005-07, and by 77% in developing countries, to meet rising demand, with per capita calorie consumption reaching 3 070 per day – considerably higher than a healthy level (FAO, 2012a). This implies an additional annual consumption of 940 million tonnes of cereals and 200 million tonnes of meat by 2050.

Supply response

Demand for feedstocks for biofuels has been an important factor behind renewed growth in cereal demand (Figure 2.3). These changes have been driven by a combination of high oil prices, changes in technical regulations, government mandates and other public policies. But if oil prices increase at the rates projected in the IEA's *World Energy Outlook*, Hertel et al. (2012) argue that in the long run biofuels will be competitive without subsidies and greenhouse gas emissions targets.

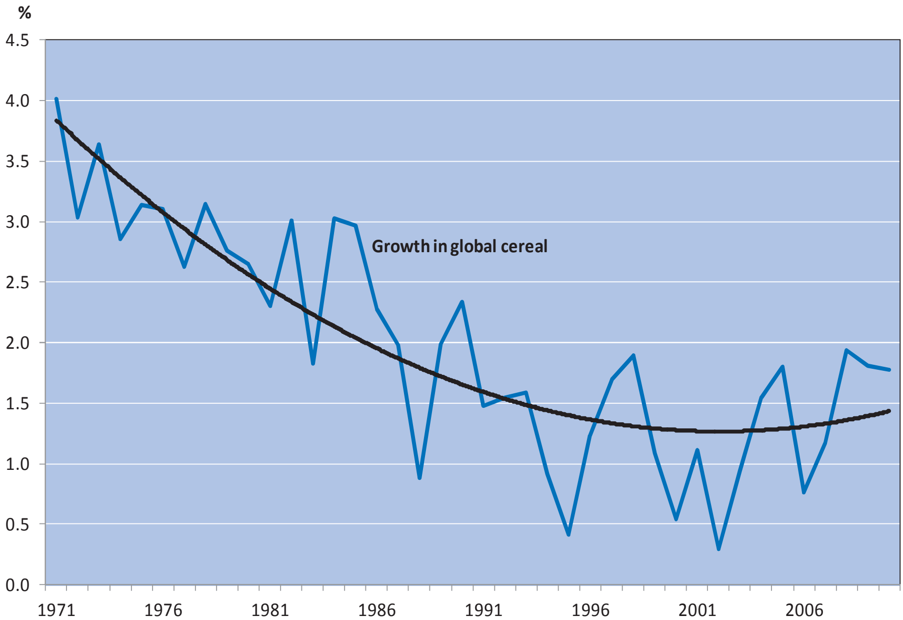
There is growing evidence that climate change has had and will have negative effects on agriculture, especially in developing countries.[4] In the near term, climate variability and extreme weather shocks are projected to increase (FAO, 2011). However there is a high level of uncertainty regarding the magnitude and direction of different effects.

The indirect effects of increased GHG emissions will differ widely across different regions. For example, high latitude areas could see an increase in their agricultural potential because of warmer temperatures, while regions near the equator will experience more frequent and severe droughts, excessive rainfall, and floods which can destroy and put food production at risk. At the same time, the capacities of economies to adjust to the effects of climate change depend on the socio-economic and technological conditions and political processes (Foresight, 2011). Moreover, increased GHG emissions are expected to have a direct effect on agricultural production through the positive response of plant growth to higher carbon dioxide concentrations; but increases in temperature above a given level lead to a decrease in efficiency of photosynthesis and an increase in respiration, hence a decline in productivity (FAO, 2011).

Modelling all these aspects is highly complex, and estimates of the magnitude of impacts vary according to models and scenarios. Tubiello and Fischer (2007) found impacts on world cereal production ranging between -18% and +18% for different regions by 2080. On the other hand, Fischer concludes that the impacts by 2050 on world cereal production will be modest, with declines by between 0.2% and 0.8% overall, and by between 0.2% and 4.2% in developing countries (Fischer, 2009). Estimates for crops vary depending on whether they are rainfed or irrigated. For example, according to IFPRI simulation results (Nelson et al., 2010), global yields would fall by about 7% in the case of irrigated maize, and by 12% for rainfed maize, between 2000 and 2050 in the absence of mitigation or adaptation policies. For rice the global yield reductions would be about 12% for irrigated rice but almost zero for rainfed rice. These global averages mask large disparities between developed and developing countries:

reductions in maize yields range between about 12% (irrigated) and 30 % (rainfed) in developed countries compared with 3% (irrigated) and 0.5% (rainfed) in low-income developing countries.

Figure 2.3. Growth in global cereal demand



Note: The annual growth rates are calculated as ten-year averages for the ten years up to and including the year for which the annual growth rate is shown. The trend is fitted as an exponential curve to the annual growth rates.

Source: FAOSTAT.

The FAO's projections from 2006 did not take explicit account of the emergence of biofuel demand, or factor in the impacts of climate change. Fischer (2009) found strong effects from biofuels, with these adding between 4% and 35% to cereal prices, depending on the scenario. The price impacts are sensitive to the share that first-generation biofuels are mandated to contribute to total transport fuel consumption. On the other hand, climate change effects did not much alter the projected level of world prices in 2050, with changes of between -2% (with CO2 fertilisation) and +5% (without CO2 fertilisation).

Over the medium term, the Aglink-Cosimo baseline projects that real agricultural prices will be higher in 2012-20 than in 2002-11, with recent price spikes a harbinger of structural change in world food markets. But over the longer term, there are huge uncertainties about each of the core drivers of supply and demand, which make forecasting hazardous. There are wide divergences between upper and lower bound estimates on population and income growth. As noted in the sections below, there is wide scope for improving productivity, changing dietary patterns, and reducing waste on both the producer and consumer sides. Outside the agriculture system, the availability of new energy sources, such as shale gas, could have profound implications for food markets. In terms of prices, the possibilities include real prices going either down or up. But there is clearly a risk of much higher prices. IFPRI's pessimistic scenario, using their IMPACT model, suggest that by 2050 rice prices could be 78% higher than in 2010, wheat prices 59% higher, and maize prices 106% higher. With perfect climate change mitigation (but with the same pessimism on other factors) those increases would drop to 20% for rice, 24% for what and 34% for maize (Nelson, et al., 2010).

On the positive side, the world food system is flexible and contains important built in stabilisers (Hertel, 2010). A large increase in demand, which would cause prices to rise, will not only bring more land into production (the extensive margin), it will lead to increased yields on land (the intensive margin). Higher prices will also curb demand. Hertel argues that many of the models currently in use underestimate the importance of these built-in stabilisers by using relatively lower short-term elasticities rather than more appropriate higher long-term elasticities. Moreover, it is useful to bear in mind that projected population growth and consumption pattern changes suggest a 60% increase in food production between 2005-07 and 2050 (Alexandratos and Bruinsma, 2012). That translates into annual growth of 1.1% per year, which, as described in the next section, is lower than recent productivity growth. To summarise, increasing food demand imposes a daunting supply-side challenge, but one to which the evidence suggests the world's agricultural system is capable of responding.

Price volatility

Beyond the level of prices, a range of factors may contribute to increased price volatility. One is the prospect of a closer link between food prices and oil prices. Oil prices affect agricultural input prices directly and indirectly (through the price of fuel and fertiliser). In addition, depending on the relative prices of agricultural crops and oil, biofuel production may become profitable (without government support) in some OECD countries. At the same time, biofuel mandates can contribute to food price volatility by creating a supply for non-food use that is unresponsive to price. Other factors that could contribute to increased price volatility include lower stocks-to-use ratios than in the past, climate change impacts, the shift of production to new areas with more uncertain yields, and growing pressure on scarce resources (FAO, OECD et al. [for G20], 2011).

There is plenty that can be done to mitigate price volatility. Deeper integration of global and regional markets, better defined safeguard mechanisms and improvements in the competitive environment will bring increased trade volume and more suppliers and buyers to markets that are currently shallow. Local or regional supply shocks could more easily be absorbed, leading to lower volatility on domestic and international markets, and food could more easily flow from surplus areas to rapidly urbanising food-importing countries. Successful conclusion to the WTO Doha Development Agenda negotiations would be an important step, along with complementary policies that improve supply capacity and ensure the benefits of open and competitive markets are widely spread (FAO, OECD et al. [for G20], 2012). The extent to which financial speculation might be a determinant of agricultural price volatility is subject to disagreement, but well functioning futures markets for agricultural commodities, could play a significant role in reducing or smoothing price fluctuations – indeed, this is one of the primary functions of commodity futures markets.

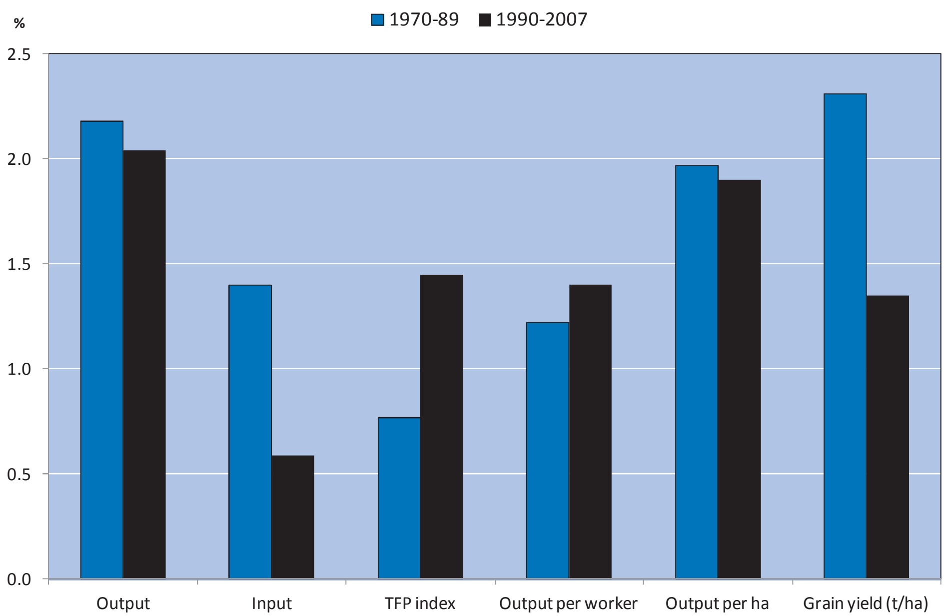
2.3. Easing supply constraints

Achieving sustainable agricultural productivity growth

Increased productivity offers more scope for increasing food production than mobilising more resources. Fuglie (2012) estimates that increases in total factor productivity (TFP), broadly defined as total outputs over total inputs, accounted for three-quarters of global output growth in 2001-09. This compares with less than 7% in 1961-70 when output growth was mainly driven by increases in land and other input use. In OECD exporting countries, growth in output is almost all due to TFP growth, not to higher input use. According to World Bank and FAO estimates, yield improvements of the three most important cereals (rice, wheat and maize) rather than area expansion have been the basis for production increases over the last 50 years (World Bank, 2012a). Similarly, Bruinsma (2011) decomposes the historical growth in world crop production over the 1961-2005 period and finds that 77% of this growth came through yield growth and 9% from increased cropping intensity, with just 14% due to expansion in arable land area, although these components differed by crop.

There is some lack of consensus on whether agricultural productivity growth has been increasing or decreasing. According to USDA-ERS estimates, total factor productivity (TFP) growth in the past two decades has exceeded 2% per year in both developed and developing countries, comfortably outpacing world population growth, which is currently running at around 1.1% per year (Fuglie, 2012). Output growth rates have fallen, but input growth rates have fallen by even more (Figure 2.4.). In developed countries, resources were being withdrawn from agriculture at an increasing rate. TFP continued to rise but the rate of growth in 2000-07 was under 0.9% per year, the slowest of any decade since 1961. In developing regions, input growth slowed but was still positive, while productivity growth accelerated in the 1980s and following decades. Two large developing countries in particular, China and Brazil, have sustained exceptionally high TFP growth rates since the 1980s. Performance has been less encouraging in some countries and sub-regions. In particular, sub-Saharan Africa as a whole lags behind, with TFP growth rates of less than one per cent. Also, Asia's performance has been modest if one nets out the strong performance of China (Fuglie, 2012). In the 1990s, factor inputs contracted sharply in the countries of the former Soviet Union and output fell significantly. However, by 2000, agricultural resources had stabilised and growth resumed, led entirely by productivity gains in the sector.

Figure 2.4. Trends in total factor productivity growth for world agriculture



Source: Fuglie (2012) from FAOSTAT.

On the other hand, crop yields, used as an indicator of land productivity, show declining average global rates of growth for most of the major cereals (FAO, OECD et al. [for G20], 2012 and Alston, 2010). In many countries and regions yields are well below both their genetic potential and their potential in an economic sense, i.e. in terms of exploiting differences between the benefits and cost of attaining a given increase in output. Crop yields in Sub-Saharan Africa and South Asia remain, in most cases, much lower than in other regions, with cereal yields in Central and West Africa of l-2 tonnes per hectare, contrasting with average yields of 7 MT/ha for wheat and 9 MT/ha for maize in Western European countries. There is also a wide divergence in rice yields across Asia, with yields of less than 4 MT/ha in Southern and Central Asia, and only 2 MT/ha in India, contrasting with yields of over 6 MT/ha in East and West Asia. In aggregate terms, developing countries are closing yield gaps with the most productive OECD countries, but this convergence does not extend to many of the world's poorest economies.

At the global level, a greater share of future productivity improvements is expected to come from improvements in technical efficiency (moving closer to the boundary of the production possibility frontier) rather than through technological change (moving the frontier forward), with the latter slowed by diminishing returns in plant and livestock breeding, and by climate change. However, a recent OECD study suggests that biotechnology offers important scope for sustainable intensification (Box 2.2).

There is great scope for developing countries to close the "yield gap" with developed countries. The gap can be divided into two components: agro-environmental and other non-transferrable factors, which create gaps that cannot be narrowed, and crop management practices, such as sub-optimal use of inputs, which may occur for a variety of reasons. The second component can be narrowed, if it makes economic sense to do so, and is therefore termed the "bridgeable" yield gap (Bruinsma, 2011). There is scope to close yield gaps by changes in these factors: more efficient farm sizes, improved management capacity, access to markets, other legislative and institutional factors, and better use of inputs.

The best places to improve crop yields may be on underperforming land, where yields are currently below average. Improved nutrient and water supplies and other production strategies can lead to significant improvements in crop yields. Foley et al. (2011), in a recent analysis of 16 major staple food and feed crops, estimated that increasing yields to within 95% of their potential would add 2.3 billion tonnes to crop production, representing a 58% increase over current production.

Mueller et al. (2012) find that closing yield gaps to 100% of attainable yields could increase worldwide crop production by 45% to70% for most major crops (with 64%, 71% and 47% increases for maize, wheat and rice, respectively). Eastern Europe and Sub-Saharan Africa show considerable "low-hanging" intensification opportunities for major cereals; these areas could have large production gains if yields were increased to only 50% of attainable yields. Looking forward, the OECD and FAO *Agricultural Outlook* anticipates lower yield growth over the coming decade due to increased pressure on natural resources. At the same time, Ludena et al. (2007) project that TFP growth will accelerate over the coming decades. The latter assumes faster land productivity growth in the livestock sector, and more rapid improvements in technical efficiency (i.e. factors being combined more efficiently).

The key to wider total factor productivity improvements is innovation, which the *Oslo Manual* defines as "the introduction of new or significantly improved goods or services, or the use of new inputs, processes, organisational or marketing methods" (OECD and Eurostat, 2005). The concept of an "innovation system" takes account of the interactions of individuals and organisations processing different types of knowledge within particular social, political, policy, economic and institutional constraints. Innovation systems are increasingly linked to the adoption of more sustainable, as well as more productive, practices, such as no-till farming, the development of insect resistant crops, more efficient irrigation and better water management systems.

Shortcomings in crop management practices may be overcome by agricultural education and wider investments in human capital, together with more effective use of inputs. Wider constraints to yield growth include a lack of access to output and input markets, due to trade barriers, monopoly power or weak infrastructure. Institutional and legislative factors may also be important, for example in facilitating or thwarting the emergence of efficient farm structures (including efficient farm sizes).

Investment in the agricultural sector is strongly correlated with TFP performance. Evenson and Fuglie (2012) found TFP performance in developing-country agriculture to be specifically correlated with national investments in agricultural research and technological improvement, and the country's ability to develop and extend improved agricultural technology to farmers ("technology capital"). Countries that had failed to establish adequate agricultural research and extension institutions and extend basic education to rural areas were stuck in low-productive agriculture and behind the rest of the world.

Box 2.2. The use of biotechnology in agriculture

Biotechnology offers technological solutions to the challenge of increasing agricultural production subject to finite resources (notably land and water) that are likely to be further constrained by climate change. It includes not only genetic modification (GM) but also intragenics, gene shuffling and marker assisted selection. These techniques can increase the supply and environmental sustainability of food, feed and fibre production, improve the nutritional content of food staples and help to maintain biodiversity (OECD, 2009). In conserving scarce natural resources they are a potentially important complement to improved agronomic practices (Rosegrant et al*.,* 2012).

OECD work estimates that by 2030 approximately 50% of agricultural output could come from plant varieties developed using one or more types of biotechnology – even without accounting for use in biofuels or as biomass for industrial feedstock. Many challenges of using crops for biofuel and other non-food uses could be addressed through biotechnology, allowing crops to be adapted for growth in different environments, raising productivity or increasing the efficiency of processing (Rosegrant et al.*,* 2012). The OECD study notes that approximately 75% of the future economic contribution of biotechnology and large environmental benefits are likely to come from agriculture and industry, yet over 80% of research investments in biotechnology by the private and public sectors go to health applications.

The OECD report recommends that member countries: (i) boost research in agricultural and industrial biotechnologies by increasing public research investment, reducing regulatory burdens and encouraging private-public partnerships; and (ii) encourage the use of biotechnology to address global environmental issues (e.g. climate change) by supporting international agreements to create and sustain markets for environmentally sustainable biotechnology products.

Gene modification technology has created economies of scope and scale that have driven rapid corporate concentration. However, there is greater scope for the development of collaborative networks, and small dedicated biotechnology firms – as are common in the health sector. On the production side, the use of biotechnology can disrupt existing business models, implying a need to manage structural change away from existing production methods.

Some of the challenges for agriculture are social and institutional, including public opposition. Social attitudes to biotechnology can influence market opportunities, driving firms to alter the type of biotechnology used. Public opinion can also change if there is effective regulation and biotechnology products are seen to provide benefits for consumers and the environment. The OECD study stresses the importance of creating an active and sustained dialogue with society and industry on the socio-economic and ethical implications and requirements of biotechnologies.

Source: OECD (2009).

Box 2.3. Agricultural research for development (AR4D)

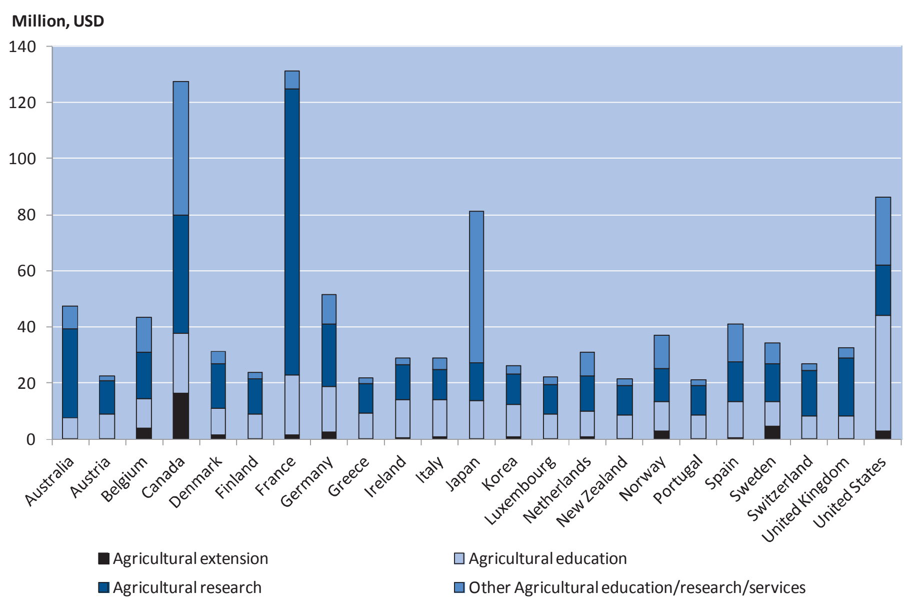
The 2009 L'Aquila statement on global food security called for strengthened investment in access to education, research, science and technology, as analyses of the impact of AR4D show that such investments have a very high rate of return.

Applying a narrow definition of AR4D (i.e. only Creditor Reporting System category 31182 – agricultural research), total Official Development Assistance (ODA) expenditures averaged USD 471 million per annum over 2009-10. About 20% of the overall total came from the multilateral sector, while France is by far the major bilateral donor, accounting for just under half of the bilateral total.

Actual support for AR4D is, however, expected to be much higher as some DAC donors may be reporting ODA for AR4D under other sector codes. Therefore, taking a broader definition of AR4D that covers the wider "agricultural education/research/services grouping," total ODA expenditures averaged USD 1.3 billion per annum in 2009-10, representing 11% of total ODA for Food and Nutrition Security (FNS). France is again the main donor and its ODA is dedicated primarily to agricultural research. Other important donors such as Canada, Denmark, Japan and the United States focus much more of their ODA on AR4D on agricultural, livestock and financial services (Figure 2.5).

AR4D can make an important contribution to FNS, but only relatively small amounts of aid presently support these activities. The Aquila Food Security Initiative (AFSI) group has therefore decided to monitor progress on the commitment to increase investment in this area and to align it better with partner countries' identified priorities.

Figure 2.5. Bilateral ODA for AR4D: 2009-10 average (million, USD)



Source: OECD DAC/CRS, disbursements, current prices.

Moreover, there is specific evidence of high returns to spending on agricultural R&D, implying under-spending, especially in developing countries. Annual internal rates of return of investments on agricultural R&D estimated in the literature range between 20% and 80% (Alston, 2010). In developing countries, the dollar-for-dollar impact of R&D investments on the value of agricultural production is generally within the range of 6% to 12% (Fan et al., 2008, Fan and Zhang, 2008; FAO, 2012b). Those countries which have invested heavily in R&D while simultaneously investing in extension have had the strongest productivity growth (Fuglie, 2012). Given long time lags, it is likely that the high returns to R&D are also associated with the progressive adoption of innovation in the wider sense.

Government expenditures on agricultural R&D in developing countries are generally lower as a percentage of agricultural GDP than in OECD countries, but there is a wide diversity across countries in terms of percentage shares and growth rates (OECD, 2011b). China accounted for about two-thirds of total public agricultural R&D spending in low- and middle-income countries in 2002. China's agricultural research spending accelerated rapidly during the 1981–2007 period, especially after the turn of the millennium (FAO, 2012b). In Sub-Saharan Africa, after a decade of stagnation in the 1990s, investment in agricultural research rose more than 20% between 2001 and 2008. However, most of this growth occurred in only a handful of countries (Beintema and Stads, 2011). In developing countries, funding is often dependent on foreign aid and granted for time-limited projects; this may hamper the development of national R&D institutions and capacity building. However, research in some developed and emerging economies will have spill-over effects to other developing countries. An important challenge is to make research results better adapted to local conditions and to foster the adoption of technologies able to improve productivity growth sustainably in diverse conditions (FAO, OECD et al. [for G20], 2012). Recognising the importance of investment in agricultural research, Development Assistance Committee (DAC) donors called for increased support as part of the L'Aquila Food Security Initiative. Box 2.3 provides information on Official Development Assistance provided for agricultural research for development.

Increasing agricultural land use sustainably

There is less scope for increasing land use than there is for increasing yields. FAO projections to 2050 foresee just 10% of future crop output growth (21% in developing countries) coming from area expansion. This reflects, in part, tightening constraints on global land and water availability; as well as greater optimism about the strong potential for yield growth in some of the poorest regions of the world.

FAO estimates that total arable land will increase, but only by 0.1% per year (less than 4% over 35 years), implying a steady decline in the amount of arable land per person. The Agrimonde Foresight study (Paillard et al., 2011) estimates higher increases, with the amount of crop land expansion by 2050 between 19% and 39% depending on the scenario. Higher yields are expected as a result of technological progress, and investments in agricultural research and irrigation systems.

The analysis of Global Agro-Ecological Zones (GAEZ) (Fischer et al., 2009) suggests that there is little or no room for expansion of arable land in South Asia, the Near East and North Africa. Where land is available, in sub-Saharan Africa, Latin America and Central Asia, more than 70% suffers from soil and terrain constraints (Alexandratos and Bruinsma, 2012). That land is also subject to competition from other uses (urban growth, industrial development, environmental reserves and recreational uses). The competition for competing land use will be resolved according to economic incentives, but those incentives may need to be regulated to ensure sustainable resource use and to address concerns about the social implications of land use changes (e.g. "land grabs").

Land quality is as important as total area. Considerable areas of productive land have been lost through degradation of soil, abandonment or different types of pollution, and restoring this land for cultivation or grazing is a way of increasing food production. The UK Foresight study suggests that land degradation costs an estimated USD 40 billion annually worldwide.

Policies are also important. Improving land tenure systems can have an important effect on famers incentives to look after their land (OECD, 2011a), and is central in ensuring that any change in farm structures occurs fairly. Foresight (2011) and Hertel (2010) stress that public investments in global databases about land use patterns and land quality would help in the design of a rational land use policy. The FAO's *Voluntary Guidelines on responsible governance of tenure of land, fisheries and forests in the context of national food security* (FAO, 2012c), endorsed by the Committee on World Food Security (CFS) in May 2012, outline the basic principles which should govern land tenure reforms designed to ensure sustainable and inclusive land use.

Making more efficient use of scarce water resources

Water is an essential input for agricultural production. At the global level, agriculture accounts for about 70% of total water withdrawal. In some countries, over 90% of withdrawals are for agricultural purposes. Cities and industries are competing intensely with agriculture for use of water, and an increasing number of countries, or regions within countries, are reaching alarming levels of water stress and pollution. Global freshwater resources will be further strained in the future in many regions, with over 40% of the world's population projected to be living in river basins experiencing severe water stress by 2050 (OECD, 2012a).

While the majority of cropland cover is rainfed, irrigated areas are considerably more productive and cover some 16% of the arable land in use, accounting for 44% of all crop production and 42% of cereal production in the world. The shares for developing countries are somewhat higher with 21% of arable land irrigated, accounting for 49% of all crop production and 60% of cereal production (Alexandratos and Bruinsma, 2012). Yet a large proportion of the world's food production is based on unsustainable exploitation of groundwater that at the same time is threatened by increasing pollution by agro-chemicals (OECD, 2010). Climate change will also affect the area and productivity of both irrigated and rainfed agriculture across the globe. Thus, measures to deal with climate variability and improve land and water management practices will be necessary to create resilience to climate change and to enhance water security.

The quality of surface and groundwater outside the OECD area is expected to deteriorate in the coming decades (FAO, OECD et al. [for G20], 2012). Water pollution also stems from inappropriate agricultural practices including poor waste management, such as excess nutrient flows due to overuse of inorganic fertilisers and livestock manure. The increase of agricultural production to meet increased demand for food will further exert pressure on water systems.

People who have better access to water tend to have lower levels of undernourishment. In areas that depend on local agriculture, lack of water can be a major cause of famine and undernourishment. Yet by 2025, it is estimated that 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions (FAO, 2012d). In vulnerable areas, investment in water management techniques should be considered when promoting agricultural productivity growth (OECD and FAO, 2012).

The priority is to use water as efficiently and sustainably as possible. Ways of improving water management practices include drip-feed irrigation, micro sprinklers and the use of no-till agriculture. It will also be important to invest in water infrastructure, in particular by expanding water supply capacity for irrigated agriculture, building water storage capacities, recycling water, improving irrigation infrastructure and taking measures to limit the impacts of drought and flood disasters. Factors that can encourage private investment in irrigation include defining titles to water rights, which encourage infrastructure maintenance and renewal (OECD, 2010).

In order for water to be used efficiently, it is important to create incentives for farmers and other users that reflect the value of water and the costs of pollution so that water users will tend to use less water (by increasing water use efficiency) and diminish pollution. Market incentives range from water charges to formal or informal trading of water user rights. Some OECD and developing countries (such as China) are now moving towards imposing charges that reflect the costs of supply and scarcity of water. The experience in OECD countries shows that the introduction of water charges has helped lower the quantity of water applied per hectare irrigated, but without leading to an overall reduction in agricultural output or incomes (OECD, 2010; FAO, OECD et al. [for G20], 2012). OECD research also shows that removing policies which intensify production, such as subsidies for inorganic fertilisers and pesticides, can reduce water pressure from agricultural activities.

To address water pollution there are also innovative policy tools, such as water quality trading and agreements between water supply utilities and farmers, which can reduce pollution and water treatment costs. Policies to improve water quality need to take into account the changing behaviour of farmers, the agro-food chain and other stakeholders (OECD, 2012b).

Reducing supply chain losses

There are numerous sources of loss and waste in the food system. On the producer side, those losses can occur during production, post-harvest (in storage or distribution) or while processing. The issue of consumer waste is discussed separately in Section 2.4 on the demand side determinants of food availability, although quantitative studies often combine assessments of producer and consumer losses.

There are considerable food losses in developing countries due to inadequate infrastructure, poor storage facilities, weak technical capacity and under-developed markets. A study undertaken for FAO suggests that these losses (without taking into account waste by consumers) range from 26% to 37% of all production or 114 to 159 kg per person year per capita in South Asian and Sub-Saharan African countries (Gustavsson et al., 2011). That figure compares with a figure of 20% or 185 kg per year capita in Europe and North America. Kummu et al. (2012)[5] estimate that globally about 25% of food produced, corresponding to 614 kcal per person per day is lost. Of that total, just over half is lost on the production side – in the field, post-harvest or during processing. The remainder is lost at the distribution and consumption stage. In terms of natural resources used for food production those losses account for 23% of land, 24% of freshwater resources and 23% of fertiliser. According to this estimate, a 50% reduction in global food losses would produce enough food to feed 1 billion people (Kummu et al., 2012). While there are few studies, and – as the studies' authors note – the findings need to be interpreted with caution, the losses are clearly important.

Waste on the production side can be reduced by improvements in harvest techniques, farmer education, storage facilities and cooling chains, and the development of infrastructure (roads, energy sources and markets). The UK Foresight report suggest that public and donor financing should be directed to locally relevant infrastructure improvements (Foresight, 2011). Better links between smallholders and regional and international food chains (for example by using mobile phones to access information) can improve the consistency and quality of food supply, providing in turn better returns on investment and allowing for reductions in seasonal oversupply and wastage.

Renewable energy and biofuel policies

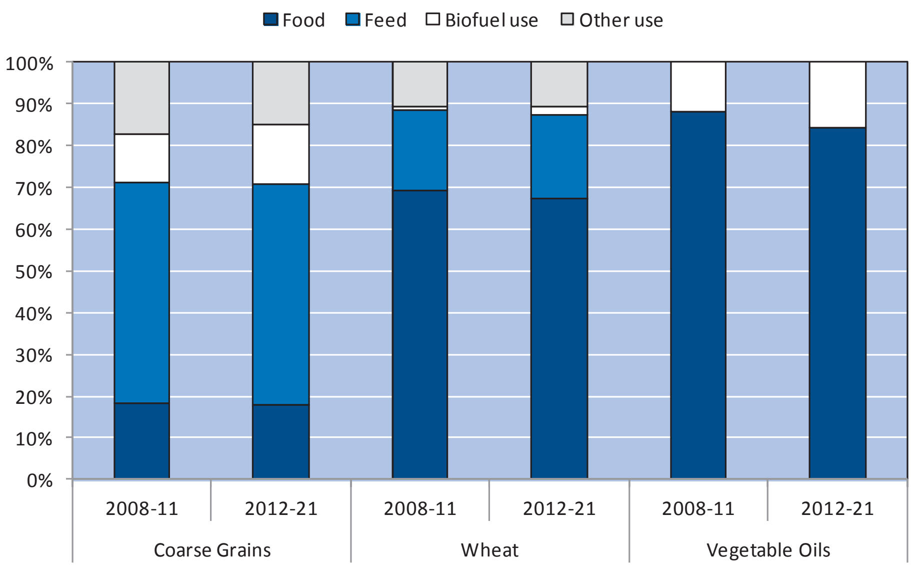
The use of agricultural crops for ethanol and biodiesel production is having a significant effect on world food markets.[6] The OECD and FAO *Outlook* anticipates that global ethanol and biodiesel production will continue to expand over the coming decade, supported by high crude oil prices and a continuation of policies promoting biofuel use (OECD and FAO, 2012), although the rate of increase will slow. In the longer term, Hertel et al. (Hertel et al., 2012) suggest that if oil prices continue to grow strongly, then biofuel production will continue to expand, even without subsidies or GHG targets. However, there are huge uncertainties about the scale of impact on overall land use, largely because technological developments in biofuels and the availability of fossil fuels are difficult to predict.

At present, the United States, Brazil and the European Union dominate the ethanol and biodiesel markets, while Argentina is also significant in the biodiesel market. Production and use of biofuels in United States and the European Union are driven predominantly by the policies in place. While policies have had an impact in Brazil, the growing use of ethanol is linked to the development of a flex-fuel vehicle industry and, more recently, to policy induced import demand from the United States.

By 2021 the OECD-FAO *Outlook* (OECD and FAO, 2012) projects that 14% of global coarse grains production and 34% of global sugarcane production will be used for ethanol production. About 16% of global vegetable oil production will be devoted to biodiesel production. US ethanol accounted for half the global increase in cereals consumption between

2005/06 and 2007/08 (Westhoff, 2010). Between 2008-11 and 2012-21, the average share of biofuel use in total demand is projected to increase modestly, by 2.6% for coarse grains, 0.8% for wheat and 3.6% for vegetable oils (Figure 2.6). Scenario analysis in the OECD and FAO *Outlook* suggests that narrowing the productivity gap between developed and developing countries could lead to a significant increase in the share of crops that goes into biofuel production (OECD and FAO, 2012).

Figure 2.6. Changes in share of demand increases of several crops 2008-11 and 2012-21



Source: Own elaboration based on OECD and FAO (2012).

Expansion of biofuels would push up prices for many food staples, but there is huge uncertainty over the magnitude of impacts owing to uncertainties over energy prices and policies (Matthews, 2012a). FAO estimates that maize prices could be between 25% and 71% higher by 2050, depending on the scenario (Alexandratos and Bruinsma, 2012). On the other hand, Fischer finds higher cereal price changes of between 20% to 40% by 2020, but lower impacts in 2050 due to the rise of second generation biofuels (Fischer et al., 2009). The price impacts are sensitive to the share that first-generation biofuels are mandated to contribute to total transport fuel consumption.

This analysis supports the IO recommendation to the G20 to remove all policies that subsidise or mandate the production and consumption of biofuels made from raw materials that compete with food, and to open international markets so that renewable fuels can be produced where it is viable to do so. It also underlines the importance of encouraging research into fuels which use feedstocks that do not compete with food (FAO, OECD et al. [for G20], 2012).

Climate change

Agriculture is a major net contributor of GHGs, with nitrous oxide and methane emissions accounting for around 14% of total anthropogenic greenhouse gas emissions (IPCC, 2007) – making it the fourth largest sectoral contribution after energy, industry and forestry (including deforestation). Agricultural GHG emissions account for about 30% of total GHG emissions if fuel, fertiliser and land use change are included, the latter accounting for 6–17% of total emissions. Livestock production is responsible for 37% of global methane and 65% of global nitrous oxide emissions, and 18% of total GHG emissions, including effects through land use change and deforestation (not included in IPCC calculations for agriculture) (Foresight, 2011). About 75% of total agricultural GHG emissions, including those from land use change, now occur in low and middle income economies, and their share is increasing, especially in Africa and Latin America.

Methane and nitrous oxide emissions coming from agriculture and from the wider food supply chain are expected to increase to 2050. Although agricultural land is expected to expand only slowly, the intensification of agricultural practices (especially the use of fertilisers) and changes in dietary patterns (in particular increased consumption of meat) are projected to drive up these emissions. While crops can be adapted to changing environments, the need to reduce emissions will increasingly challenge conventional, resource-intensive agricultural systems (Royal Society, 2009 cited by Foresight, 2011).

In response, a wide range of GHG mitigation measures (for reducing or promoting active carbon sequestration) are likely to be adopted from now until 2050. Market mechanisms, such as carbon taxes, emissions trading and product certification (to incentive changes in consumer behaviour) have the potential to lower emissions, as do selective regulations. However, these measures need to be balanced against the wider challenges of ensuring food availability. Management of land and aquatic systems currently provide the only practical means to enhance the capture and storage of carbon. If water becomes scarcer with climate change, improving water quality by reducing farm emissions will be critical (OECD, 2011b).

Ways of reducing carbon emissions and stimulating carbon sequestration include restoring degraded lands, reforesting; optimising nutrient use by more precise dosage of inorganic fertilisers; improving productivity (output per unit of GHG); reutilising agricultural waste and finally reducing the carbon intensity of fuel and raw material inputs through improvements in energy efficiency and the use of alternative sources (Foresight, 2011). Reducing producer and consumer food losses also implies that less food needs to be produced and therefore less GHG emitting activities need take place.

OECD work on climate change has stressed that those responsible for climate change should bear the costs of mitigation. Governments can put that principle into practice by supporting efficient adaptation programmes that target local sources of climate change (OECD, 2011b). Effective adaptation should significantly reduce the damage resulting from climate change. For example, investment in research, irrigation, rural roads could offset the crop productivity losses driven by climate change (OECD, 2011b). Furthermore, the negative effects of climate change on food security can be counteracted by economic growth, higher agricultural productivity and open international trade in agricultural products to offset regional shortages (Nelson et al., 2009). However, production will ultimately need to migrate from areas where it becomes inherently unsustainable (for example due to chronic or recurring drought and desertification).

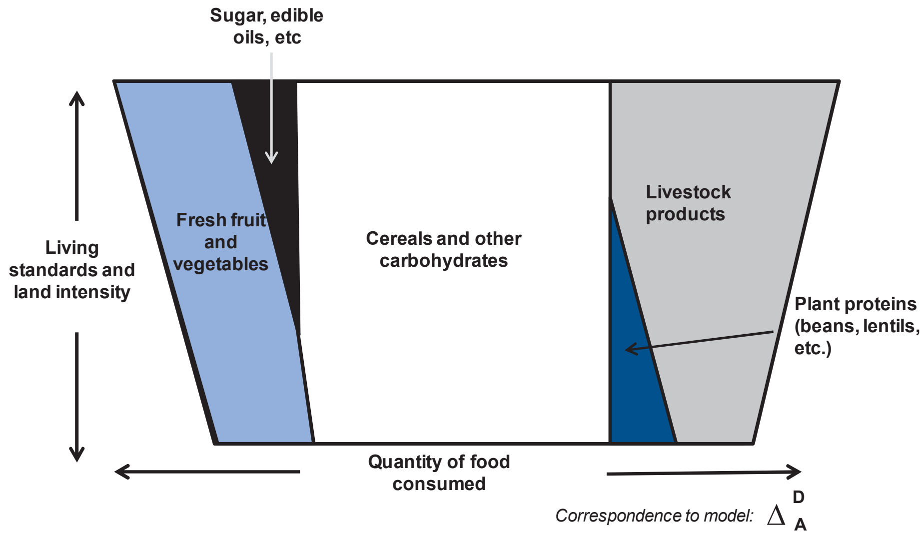
The primary role of governments in climate adaptation is to provide public policies that help the private sector adapt. One key area is in providing more accurate assessments of climate change, allowing farmers to make anticipatory changes. Another central role is in research, for example in supporting the development of new seed varieties. Water policies, as well as land use and land management policies, can also be important in providing farmers with incentives to adapt. Government subsidies to weather insurance have been proposed as a possible risk management tool, but induce moral hazard by reducing farmers' incentives to move away from high risk locations.

2.4. Reducing demands that are detrimental to food security

Modifying food preferences

Rising incomes lead to increased calorie consumption, while creating demands for more protein and greater diversity in consumption. Up to a certain point that leads to healthier diets; but beyond that, people tend to consume too many calories and more meat, sugar and vegetable oils than are required for a healthy diet (Figure 2.7).

Figure 2.7. Income growth and dietary changes

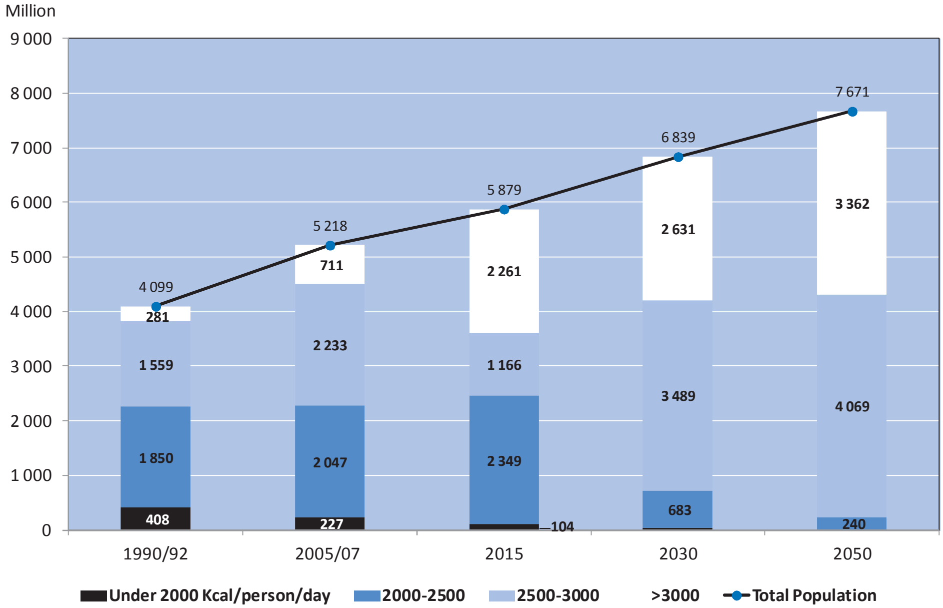


Source: Southgate et al. (2011).

In global terms, average calorie consumption is around 2 800 kcal per person today. This contrasts with a minimum daily energy requirement (MDER) that, taking into account age structure and activity levels, averages about 1 850 kcal per day across countries (the figure is about 2 100 per adult). However, inequality of access implies that about one in seven people are undernourished, even with this surplus of calorie availability. For most countries, existing income inequalities imply that about 2 800 kcal per day is in fact the average consumption level needed to ensure that no more than 1-2% of the population falls below the minimum daily energy requirement.

There are at least as many people over-nourished in the world as are under-nourished, and over-nourishment is an increasing health problem in developing countries. Physically redistributing food from the former to the latter is not a realistic proposition, but modifying dietary patterns so that people have healthier diets would reduce overall demand and prices, and associated pressure on land and water resources. The option of using food taxes to constrain excessive demand has to take account the regressive nature of such measures and the fact that most foodstuffs – unlike say tobacco – are good for health within limits. The most straightforward first step to reducing excessive consumption is through the provision of information and education which can change food consumption cultures.

Figure 2.8. Developing countries: Population with given kcal per person per day



Source: Alexandratos and Bruinsma (2012).

High levels of meat consumption are a particular contributor to excessive calorie consumption (and overall to excessive fat consumption too), with many developed countries consuming more meat than is recommended by nutritionists. Moreover, meat consumption exerts a strong demand on land and water resources. It takes 2 tonnes of grain to produce a tonne of poultry, four tonnes of grain to produce a tonne of pork, and between seven and ten tonnes to produce a tonne of beef. Lower meat consumption would enable more of that grain production to be allocated directly to food use. Lower consumption of sugar, which is weak in nutritional value, would similarly allow resources to shift into other crops.

FAO expects that whereas currently 53% of all the calories consumed in developing countries are provided by cereals and 20% by meat, dairy and vegetable oils, by 2050 the contribution of cereals will have dropped to 47% and that of meat, dairy and fats will have risen to 29% (Figure 2.8).

A major factor behind recent changes in demand has been rapid growth in the consumption of livestock products in countries like China and Brazil. As incomes rise, changes in meat consumption will have potentially important implications for food availability and land use (Paillard et al., 2011). However, there are many uncertainties over how meat demand will respond to income growth, with that response dependent on a range of factors, some cultural. India's meat consumption is low, at less than 4 kg per person per year. This compares with a figure of 48 kg per person per year in China, which already exceeds the 34 kg per person per year in Japan. These figures remain far below the consumption levels seen in Brazil (84 kg per person per year) or the United States (91 kg). Looking further ahead, meat accounts for only 6% of calories in Sub-Saharan Africa, compared with an average of 30% in OECD countries.

Reducing consumer waste

The same FAO study commissioned to investigate producer-side losses also considers consumer waste. In the industrialised world, food is wasted more on the consumer side, with waste per-capita amounting to 95-115 kg per year in Europe and North-America, or 11-13% of production. This compares with figures of 6-11 kg in Sub-Saharan Africa and South and Southeast Asia, which equates to just 1-2% of production (Gustavsson et al., 2011). Besides increasing food availability directly, reductions in waste would help to reduce water stress, soil degradation, and greenhouse gas emissions.

The UK Foresight report notes that there is a range of opportunities for reducing consumer and food service sector waste such as public campaigns, advertising, taxes, regulation, purchasing guidelines and improved labelling (Foresight, 2011). One suggestion is that commercial and charity organisations could arrange for the collection and sale or use of discarded "sub-standard" products that are still safe and of good taste and nutritional value (Gustavsson et al., 2011). A significant share of production is wasted because it does not meet standards for shape or appearance. Raising awareness among food industry, retailers and consumers is needed to reduce these and other forms of waste (OECD and FAO, 2012).

Notes

1. There would be an aggregate global impact resulting from the accumulated changes to food supply and food demand, with direct effects on domestic prices for countries that are not integrated with world markets.

2. www.agmip.org.

3. There is some ambiguity in comparing trends because output measures for different crops and livestock products can be aggregated using different units – mass-based, calorie-based and price-based. Tilman et al. use a calorie-based measure but confine themselves to crop demand, although growth in livestock consumption is implicitly accounted for by taking into account the use of crops for feed. Calorie consumption oversimplifies the challenge because of a trend towards greater diet complexity. Staple food consumption will increase more slowly than calories, but consumption of meat, sugar, oils, fruits and vegetables will grow more rapidly.

4. Climate change is leading to rising temperatures. The IPCC anticipates that global temperatures will rise by between 1.50 and 4.50 by 2100 (10 to 30 by 2050) (IPCC, 2007). It also involves other changes to nature that affect agricultural production potential, including to radiation, rainfall, and soil and water availability. In addition sea levels are expected to rise, leading to salt water inundation and intrusion along coastlines, while extreme weather events (e.g. droughts, floods, thunderstorms and heat waves) may become more frequent or intense, posing a significant challenge to food security.

5. Their calculation uses the loss and waste percentages of Gustavsson et al. 2011

6. Analysis of indirect land use change has fundamentally altered assessment of the impacts that biofuels have on greenhouse gas (GHG) emissions. Previously, biofuels were considered as an instrument to reduce GHG emissions, but recent research suggests that over the decades to 2050 and perhaps beyond, GHG emissions could rise due to biofuel expansion, mainly because of destroyed pasture and forest areas. However, that analysis also finds cumulative GHG emissions turning negative later in the century as second generation biofuels come on-stream (Hertel et al., 2012).

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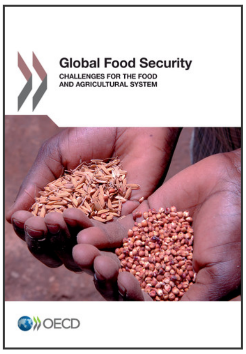

Global Food Security

Challenges for the Food and Agricultural System

Access the complete publication at:
https://doi.org/10.1787/9789264195363-en

Please cite this chapter as:

OECD (2013), “Ensuring global food availability”, in *Global Food Security: Challenges for the Food and Agricultural System*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264195363-5-en