CHAPTER 11

CRITICAL EVALUATION OF SELECTED PROJECTIONS

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The purpose of this chapter is to summarize in a coherent manner the different views embodied in the projections concerning possible futures for world food and agriculture to 2050. The preparation of this chapter started when syntheses of the expert meeting (EM) papers of June 2009 were being prepared for the High-Level Expert Forum on "How to feed to the world in 2050". It soon become apparent that not only views were diverse, but also that it was difficult to understand why they differed. To illustrate this problem, it suffices to take as an example some results on the climate change impacts on world market prices reported in the EM papers, whose revised versions have become chapters of this volume. Percentage differences over baselines without climate change in 2050 are as follows.

Chapter 3, price index for all cereals:

- climate model Hadley without CO_2 fertilization: + 10 percent;
- climate model Hadley with CO_2 fertilization: -1 percent;
- climate model Commonwealth Science and Industrial Organization (CSIRO) with;
- CO_2 fertilization: + 2 percent.

Chapter 2, Table 2.3[1]; models National Center for Atmospheric Research (NCAR) and CSIRO:

- wheat: NCAR + 111 percent; CSIRO + 94 percent;
- maize: NCAR + 52 percent; CSIRO + 55 percent;
- rice: NCAR + 37 percent; CSIRO + 32 percent.

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[1] Chapter 2 reports results which are also found in a recent paper of the International Food Policy Research Institute (IFPRI) (Nelson *et al.*, 2009).

A similar degree of diversity is observed also in the projection of other key variables. It is therefore important to compare the main results reported on different themes, and, as far as possible, to understand the origin and the reasons for such differences.

The rest of the chapter is organized along five topics: projections on world prices and consumption volumes; impact of climate change; impact of biofuels; economic growth, global inequality and poverty; and expected developments in sub-Saharan Africa. For each of these themes projections are analyzed and compared, and reference is made to the associated food and nutrition outcomes. Focus is mostly on the results offered by Alexandratos in Chapter 1, by Msangi and Rosegrant in Chapter 2, by Fischer in Chapter 3, by Hillebrand in Chapter 4, and by van der Mensbrugghe, I. Osorio-Rodarte, A. Burns and J. Baffes in Chapter 5. Both Chapter 2 and this chapter draw also on more recent IFPRI work (Nelson *et al.*, 2009)[2].

Prices and quantities in the baseline scenarios

Prices

A frequently asked question is whether the price surges of recent years were a harbinger of things to come or, as in the past, a temporary occurrence (Alexandratos, 2008; Mitchell, 2008). Do the price projections reported in previous chapters provide answers? When the first versions of these chapters were prepared, in June 2009, cereal prices had fallen by 30 percent from their peaks of spring 2008. Nevertheless, they were still well above averages for the pre-surge period.

Chapter 5 reports price projections only for total agriculture to 2030. They show that with a productivity growth of 2.1 percent per annum in agriculture there is a small negative trend over the long term (Figure 5.10).[3] Chapter 3, shows detailed price projections to 2050 for several commodity groups and total agriculture (Table 3.4). Chapter 2 reports percentage price changes from 2000 to 2050 for the three major cereals, drawing on Nelson *et al.* (2009) (Table 2.3). Chapter 1 does not provide price projections.

For comparisons, the different price projections need to be rebased on a common base-year denominator. Figure 11.1 shows that, at least for cereal and in terms of annual averages, the price surge started in 2006. Therefore, a good base for comparing projections vis-à-vis "the present" is the three-year average

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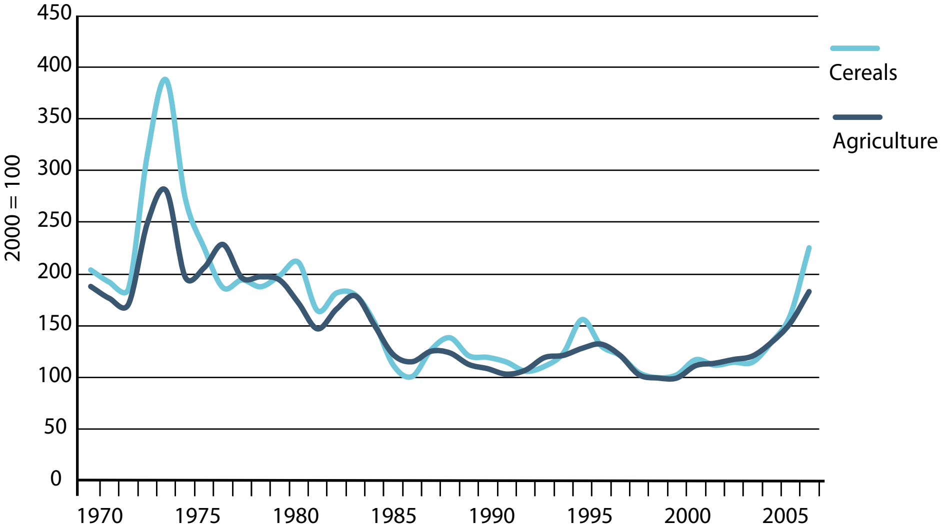
[2] Clarifications were received from the authors of Chapter 2, 4 and 5. The author of this chapter thanks all the authors for their help, and particularly Siwa Msangi who provided detailed background material.

[3] Presumably "overall agriculture" corresponds to "total agriculture" used in construction of the price indices in the World Bank's commodity price data.

2006/2008. For comparing future prices with those of the pre-surge period, instead, the three-year average 2003/2005 is used. If the 2006/2008 average were used, it would be concluded that prices will fall. If a pre-surge three-year average is used, the opposite general conclusion is reached. Figure 11.2 shows price projections of the 2009 OECD/FAO agricultural outlook to 2018 (OECD/FAO, 2009), after rebasing them on the two three-year averages: prices are higher in 2018 by 6 to 19 percent for the three cereals with respect to those of the pre-surge years, but much lower than those of 2006/2008.

Figure 11.1
Cereals and agriculture real price indices



Source: World Bank commodity price data. Indices are from price data at constant 2000 dollars.

Figure 11.3 compares price projections to 2030 from Chapters 3, 5 and from IFPRI[4], computed from both the 2003/2005 and the 2006/2008 bases. The main message seems to be that over the next two decades real prices will be much lower than the average of surge years 2006/2008. The picture is more mixed when viewing the price projections in relation to those of the pre-surge period.

Concerning total agriculture to 2030, Chapters 3 and 5 suggest that the average price level in 2030 will be not very different from that of the pre-surge period 2003/2005. The same applies to the IFPRI projections of wheat and maize

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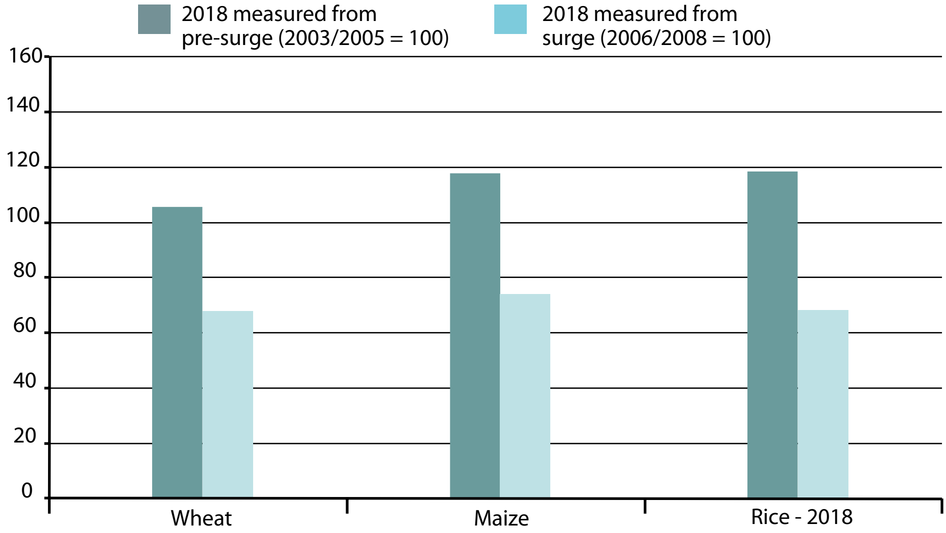
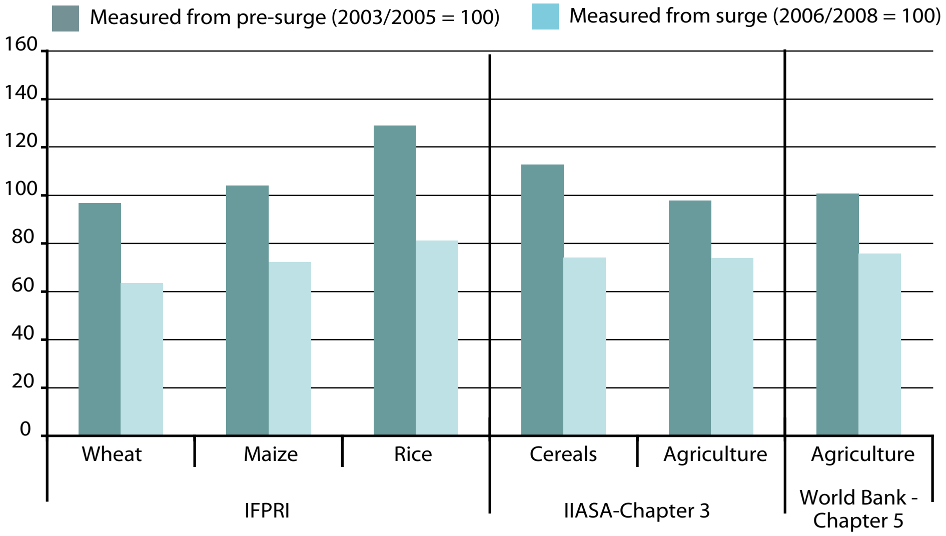
[4] Chapter 2 only reports projections to 2050. The background data for Figure 11.3 was supplied separately by the authors of Chapter 2.

Figure 11.2
OECD-FAO 2009 projections: cereals price indices to 2018



Source: OECD/FAO, 2009: Figures 6.8 to 6.10.

Figure 11.3
Price indices to 2030: projections from chapters 2, 3 and 5

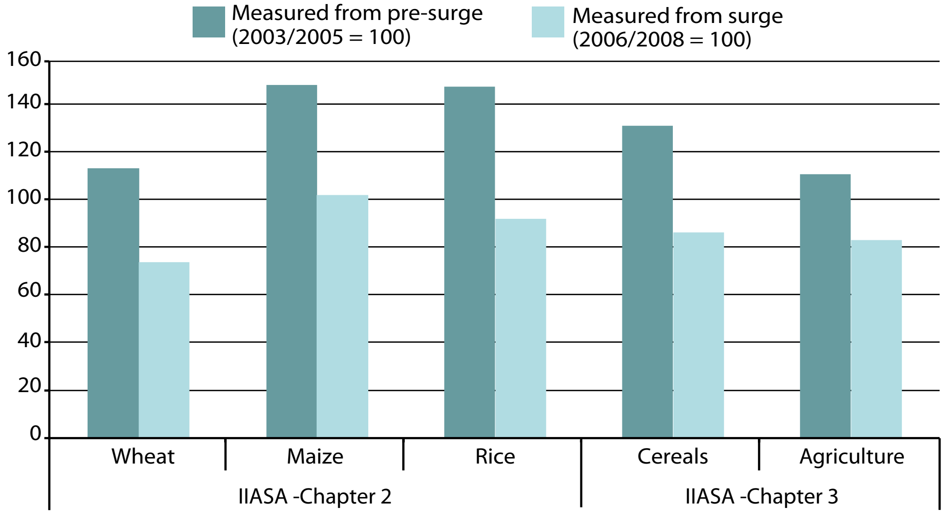


Sources: IFPRI: detailed tables for Chapter 2 (supplied separately by the authors), Chapters 3, 4 and 5.

prices. The only significant differences are in rice prices, which could be 29 percent higher than the pre-surge 2003/2005 average according to IFPRI; and the average cereals price index, which may be 13 percent higher than the pre-surge 2003/2005 average, according to Chapter 3.

Figure 11.4 reports baseline price projections to 2050 from Chapters 2 and 3. The average level of agricultural prices according to the IIASA projection (Chapter 3) may be just 10 percent higher than in the pre-surge period, and well below "present levels". However, Chapter 3 projects that cereal prices will rise faster than the average for all agriculture. Prices of the other agricultural products increase by less than those of cereals (Table 3.4). The cereals price index implied for wheat, maize and rice in Chapter 2 drawing on Nelson *et al.*, 2009 is broadly in line or somewhat higher than that projected by IIASA in Chapter 3 (Figure 11.4).

Figure 11.4
Price indices to 2050: baseline projections from chapters 2 and 3



Sources: Chapters 2 and 3.

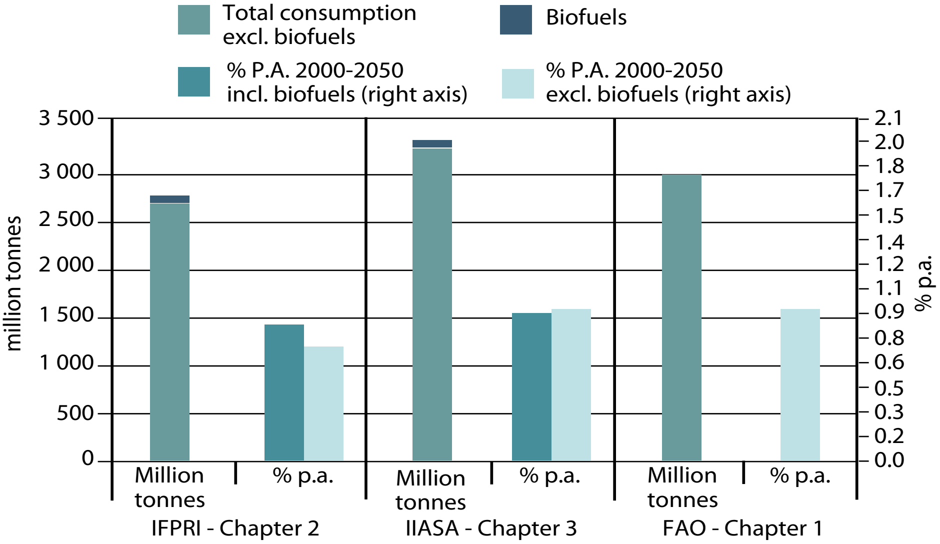
To sum up, 2050 cereal prices projected in the baseline are higher than those of the pre-surge period, but much lower than those of the period of price surges. Projections to 2030 of Chapters 3 and 5 generally suggest that real world agricultural prices will tend to revert to levels near those of the pre-surge period. For 2050, all projections broadly indicate that prices will be higher than those of the pre-surge years but lower than those reached in the years of price surges.

They will not revert to the long-term trend of decline, but this is not really a novel element: the path of decline had already been largely halted from about the mid-1980s.

Consumption volumes

Projected world cereals consumption in 2050 differs widely among the different authors (Figure 11.5). Chapter 3 projects 3 388 million tonnes in 2050[5]; and Chapter 2 has 2 739 million tonnes. As noted earlier, the price projections for individual cereals in Chapter 2 are only slightly higher than those implied by Chapter 3 for all cereals. This raises the question regarding why, if their price projections are similar, the papers' projections of cereals consumption are so different from each other?

Figure 11.5
Cereals projections: world consumption in 2050 and growth rates – Chapters 1, 2 and 3



Sources: Chapter 1; Chapter 2, Table 2.1 (biofuels are from the detailed files); Chapter 3, Table 3.3.

The answer is to be found partly in the wide differences in the historical data used in the two analyses. Chapter 2 (Table 2.1) starts with 2000 world consumption

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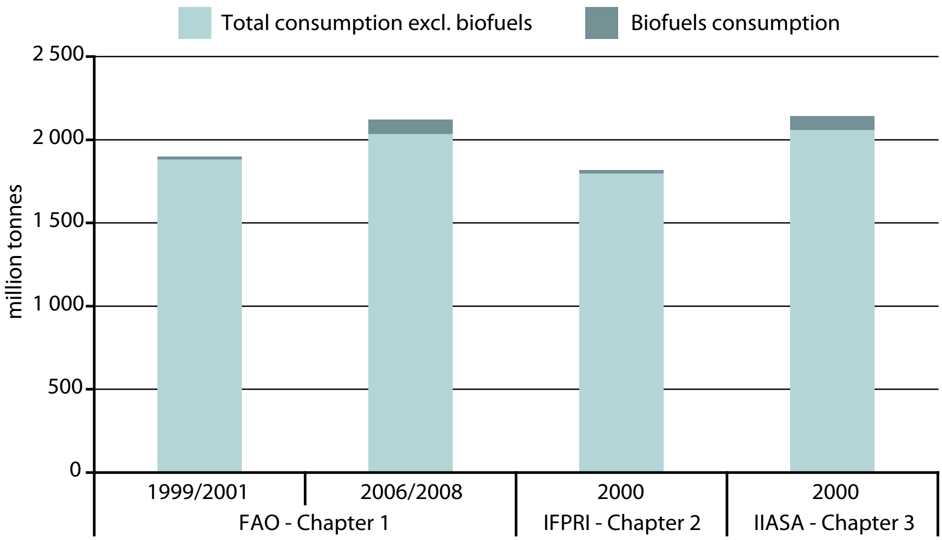
[5] Use of cereals for biofuels is maintained at the 2008 level throughout the projection years in this IIASA scenario (Scenario WEO-01 in Chapter 3).

of 1 818 million tonnes, while Chapter 3 has 2 144 million tonnes for the same year (Table 3.3). Both are different from the FAO historical data (1 900 million tonnes average for 1999/2001). The figure for 2000 in Chapter 3 is even higher than the increased world consumption of recent years, i.e. the 2006/2008 average. These discrepancies are depicted in Figure 11.6. They prevent a comparison of the absolute values of projected world cereals consumption. A better idea of the differences in projected world cereals consumption can be obtained by observing growth rates of consumption, which are also shown in Figure 11.5. The growth rate in Chapter 3 is higher than that of Chapter 2, and the difference is even more pronounced if biofuels are excluded from total cereals consumption.

Figure 11.6
World cereals consumption historical data versus data for 2000 used in chapters 2 and 3



Sources: OECD/FAO.

Differences in historical data bedevil the attempt to form an idea concerning the volume of world cereals production that would be required to meet the growth of consumption in 2050. Figure 11.5 also shows the FAO projection to 2050 (FAO, 2006). The 3 billion tonnes projected for 2050 is based on historical data for up to 2001, which does not include biofuels. On this benchmark, the IFPRI projection in Chapter 2 looks too low, mainly because of the lower starting data for 2000 and to a lesser extent because of the lower growth rate; and the one of IIASA in Chapter 3 definitely too high, again because of the starting 2000 figure.

However, is the FAO projection any better? It certainly has two advantages. Firstly, it is grounded on reliable historical data; and, secondly, it is subjected to a reality check in Chapter 1, where the trajectory of world production/consumption for 2000 to 2050 was compared with outcomes to 2008 and medium-term projections to 2018 from OECD/FAO (2009) (Table 1.1 and Figure 1.1). The FAO projection trajectory was close enough to both actual outcomes to 2008 and the subsequent ten-year OECD/FAO projection, both not including cereals use for biofuels.

Of primary interest for the issue at hand are the food and nutrition outcomes associated with the different prices and quantities projected. FAO, and Chapter 1 in this volume, estimate changes in the incidence of undernourishment based on per capita food consumption expressed in kcal/person/day (FAO, 2006: Box 2.2). In Chapter 3, IIASA provides projections of population at risk of hunger, which presupposes the availability of projections in terms of kilocalories per person per day for all commodities, not only cereals. The IIASA World Food System model used in that chapter computes the population at risk of hunger based on the correlation between the share of undernourished in total population and the ratio of average per capita food supply to the average per capita food requirements. However, it is doubtful whether this is a statistically valid correlation, given that the numbers undernourished in the FAO statistics are not independent data, but are derived as a function of the average per capita dietary food supply, the average national per capita food requirements and an index of inequality.

Chapter 2 contains projections of child malnutrition (Table 2.4), for which a key explanatory variable is per capita calorie availability. The IFPRI model "computes changes in the prevalence of malnutrition in the population aged zero to five years as a function of per capita calorie availability (generated endogenously by the model), as well as exogenous projections of schooling rates among females of secondary school age, the share of population with access to clean water, and the ratio of female-to-male life expectancies" (Chapter 2). The projections of this variable are not given in Chapter 2, but are in Nelson *et al.* (2009: Table 5). Comparisons on food security outcomes are in the next sections of this chapter, and especially in the last one, that discusses prospects for Sub-saharan Africa.

Climate change impact on agriculture

This issue is analyzed in most detail in Chapter 3. Chapter 2, drawing on Nelson *et al.* (2009), presents results for scenarios incorporating climate change effects and Chapter 5 addresses the issue of climate change and agriculture, but only for the sector as a whole[6]. The FAO projections in Chapter 1 do not address climate change.

Conclusions of the different chapters about climate change impacts are disparate. Differences are not primarily due to the many uncertainties regarding what climate changes are in store; they persist even after controlling for such uncertainties. It is therefore worth starting by outlining what is involved in building scenarios of possible agricultural and food security outcomes under climate change. The following steps may be distinguished:

1. Define future levels of greenhouse gas (GHG) concentrations in the atmosphere from some concept of the future rate and pattern of socio-economic development, demographics, energy use, etc. for the globe. These are called "development pathways" in the terminology of the Intergovernmental Panel on Climate Change (IPCC).
2. Use climate models – general circulation models (GCMs) – to translate these GHG concentrations into deviations of key climate variables of relevance to agriculture, such as temperature, precipitation, etc., from those assumed in 2050 in the baseline scenario. The baseline usually assumes prevalence of present climate in the future, although this may be an impossibility.
3. Superimpose deviations in climate variables on biophysical data and models (e.g., agro-ecological attributes, crop growth models) to portray how resource characteristics may be altered (e.g., changes in the length of growing periods, soil moisture, incidence of pests/diseases), and how plants may respond to the changed conditions. Resulting estimates refer to the impact of climate change on the potential productive capacity of resources, not on projected production.
4. From this interface, derive information to modify the model of agriculture used to project production, consumption, trade and prices. This means changing the way in which models recognize the altered biophysical base of agricultural production. Revised estimates of land/water constraints should be included, along with assumptions of alternative paths to adaptation, i.e., how people may respond by changing crop calendars or introducing crop varieties better suited to the altered climate.

Steps 1 and 2 need not be an integral part of the agricultural modeller's task: changes in climate variables necessary for estimating impacts can be taken

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[6] This section is also based on personal communication from the authors of Chapter 5, and evidence reported in Nelson *et al.* (2009).

from the work of others specializing in GCMs. However, caution is required: the socio-economic pathway generating the GHGs that will affect the climate, and especially assumptions on GDP and population growth, must not be too different from those assumed in the baseline. This is necessary if the projected results of the scenarios with and without climate change are to be compared. Moreover, the definition of a scenario without climate change is not unambiguous: assuming that present climate will prevail in the future is almost tantamount to assuming that present GHG concentrations will remain constant. But could such a situation exist? Even ignoring the possibility that climate variables can continue to change even if current GHG concentrations do not change, there is no possible development and demographic path that will not increase GHG concentrations. The debate is entirely about how much emissions could be reduced, and there is no option of reducing them to zero. GHG concentrations will increase anyway, bringing climate change; so there seems to be no point in estimating a scenario with present climate that, by definition, cannot exist.

Step 3 requires that the modeller has access to, and can manipulate, detailed biophysical data describing land resources and the physiology of crops in relation to climate variables. For this purpose, IIASA uses the Global Agroecological Zones Study (GAEZ) that it produced with FAO and is reflected in Chapter 3. IFPRI uses "a hydrology model and links to the Decision Support System for Agrotechnology Transfer (DSSAT) crop-simulation model, with yield effects of climate change at 0.5-degree intervals aggregated up to the food-production-unit level" (Nelson *et al.*, 2009: 1); this is reflected in Chapter 2.

Step 4 is the crucial one. It can be speculated that in previous chapters this is mostly carried out by modifying the values of exogenous variables of models, most likely intercepts and rates of productivity growth. IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) "simulates growth in crop production, determined by crop and input prices, externally determined rates of productivity growth and area expansion, investment in irrigation, and water availability" (Nelson *et al.*, 2009: 1). Similar observations may apply to the IIASA model[7].

Climate change effect on prices and quantities

The results described in Chapter 5 include climate change effects, but only for agriculture. In the model, climate change influences agriculture by lowering the growth rate of agricultural productivity. In the case of no climate change,

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[7] "Results of [Agro-Ecological Zone] agricultural production potential assessments, under various climate change/CO_2 emission scenarios and obtained for different GCM-based climate experiments, were input to IIASA's system of national agricultural models to further assess world food system and trade implications" (Fischer, Shah and van Velthuizen, 2002: 22).

productivity growth is exogenously assumed to be 2.1 percent per annum. The extent to which climate change affects this growth rate is derived from Cline (2007), assuming that the 2.5 oC temperature increase is reached in 2050, rather than in 2080 as in Cline's work.[8] The impact on the rate of productivity growth is the average of Cline's scenarios with and without CO_2 fertilization effects. In this scenario, temperature rises by 1.7 oC in 2030, which translates into a reduction in the rate of productivity growth from 2.1 percent per annum to 1.76 percent per annum. The result is that the baseline projects the price index of agriculture in 2030 to be a little below that of the base year 2005. As noted (Figure 11.3), this translates into 2030 prices nearly equal to those of the pre-surge period (average 2003/2005) and well below those reached in the surge years (average 2006/2008). There is no scenario without climate change, so price outcomes with and without climate change cannot be compared. However, it is reasonable to assume that without the reduction in agricultural productivity growth brought about by climate change, projected prices would be lower, at least up to 2030. This is an interesting finding, which is in sharp contrast to the predictions of other analyses, particularly that of Chapter 2.

Chapter 3 estimates a number of climate change scenarios. The analysis assumes that climate change is driven by GHG emissions generated by the socio-economic development/demography path of the IPCC Special Report on Emissions Scenarios (SRES) A2.[9] These projected concentrations are combined with the GCMs of the Hadley Centre for Climate Prediction and Research (United Kingdom) and CSIRO (Australia) to generate the projected changes in temperature, precipitation, etc. As noted, changes in climatic variables are defined for each individual grid point of the GAEZ, and the implied changes in the biophysical base of the analysis are derived.[10]

Estimates of impacts on potential production are derived from such changes in the biophysical base, and adaptation options are restricted to currently existing varieties. Such restriction is justified when estimating changes in production

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[8] Note that Cline's estimates refer to climate change effects on "agricultural capacity" in the 2080s, not on projected production.

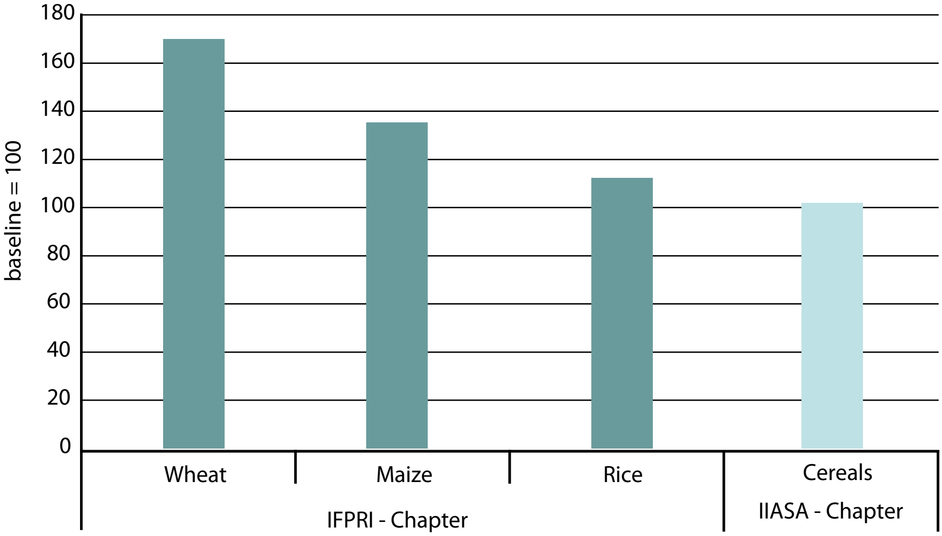
[9] This scenario implies that GHG concentrations in the atmosphere will rise from their current 354 parts per million (ppm) to 536 ppm in 2050 (IPCC, 2007b: Table 1). A more recent IPCC report indicates that "Atmospheric CO_2 concentrations were 379 ppm in 2005. The best estimate of total CO_2-eq[uivalent] concentration in 2005 for all long-lived GHGs is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375 ppm CO_2-eq" (IPCC, 2007a: 67).

[10] The author of Chapter 3 computes implications only for the impacts on potential production of rainfed agriculture for any particular crop, and only for land currently under cultivation. He does not provide estimates of the implications for irrigated and total land, whether currently under cultivation or not.

potentials under the assumption that climate change was occurring today. But estimates of future impacts of climate change should include the option that novel varieties may be developed that can better withstand the new climatic stresses. This is an important issue, especially when considering options for responding to climate change, such as optimal combination of mitigation and adaptation actions.

Impacts estimated in Chapter 3 refer to changes in production potentials. Climate change would have only a minimal impact on global quantities, lowering them by between 0.2 percent to 1.4 percent (Table 3.16). Effects on projected cereal prices would also be small, ranging from -1 percent to + 10 percent at worst, under the Hadley A2 scenario without CO_2 fertilization. These projected changes would occur with cereal prices in 2050 being 31 percent above pre-surge levels as per baseline (Figure 11.4, see also Figure 11.7).

Figure 11.7
Effects of climate change on cereal prices in 2050: Chapter 2 versus Chapter 3



Sources: Nelson *et al.*, 2009: Table 2; Chapter 3, Table 3.15.

Findings on climate change impacts reported in Chapter 2 are those reported in Nelson *et al.* (2009). They are based on the IPCC SRES A2 scenario, which is combined with GCMs from NCAR (United States of America) and CSIRO to derive changes in the climate variables that affect production potentials. One of IFPRI's scenarios is "CSIRO with CO_2 fertilization" and "autonomous adaptation as farmers respond to changing prices with changes in crop mix and input use"

(Nelson *et al.*, 2009: 6).[11] Therefore, the results can be compared with those of Chapter 3 for the same scenario: prices in 2050 are projected to be 70 percent higher than the baseline for wheat, 35 percent higher for maize, and 12 percent higher for rice (Figure 11.7) (Nelson *et al.*, 2009: Table 2). This is far more than the 2 percent projected in Chapter 3; hence some structural fundamentals differ widely in the approaches of IFPRI and IIASA. One of these differences may be that in Chapter 2 the most severe declines in potential yields occur in irrigated wheat and rice, while Chapter 3 reports effects for rainfed production potentials only.

Impacts of climate change by region

Climate change impacts can differ widely among latitudes, regions, countries and agro-ecological zones. Outcomes for the world as a whole are made up of pluses and minuses from different regions, countries and country groups. Increased production potentials in the parts of the world benefiting from climate change are not necessarily available to make up losses suffered in other parts.

Findings of Chapters 3 and 5 indicate small global impacts, at least up to 2050. Figure 11.8 shows that the two most food-insecure regions, sub-Saharan Africa and South Asia, suffer declines in cereal production potentials of 7 and 6 percent respectively, with a peak of -32 percent in Southern Africa. With CO_2 fertilization and adaptation most countries/groups become net gainers, including sub-Saharan Africa and South Asia. Such gains disappear in later decades, but do not turn negative globally (Table 3.12). Full gains from CO_2 fertilization and adaptation are uncertain, hence the outcome could be less rosy than it appears. Moreover, as recalled these estimates refer to cereals production potentials only, and not on projected production; and they refer to rainfed land currently cultivated.

The possibility of a net gain in production potentials at the world level, at least for rainfed cereals, raises the interesting and provocative question regarding whether the world could be better-off with climate change and the associated CO_2 fertilization and adaptation, at least from the standpoint of agricultural potentials. In theory, gainers could compensate losers and still leave a net gain. In practice, however, this looks unlikely. Losers could only gain if the improvement in global potential could be translated into increases in their consumption. The most food-insecure region, sub-Saharan Africa, is projected to suffer a marginal decline in 2050 cereals consumption compared with the baseline, despite the finding that

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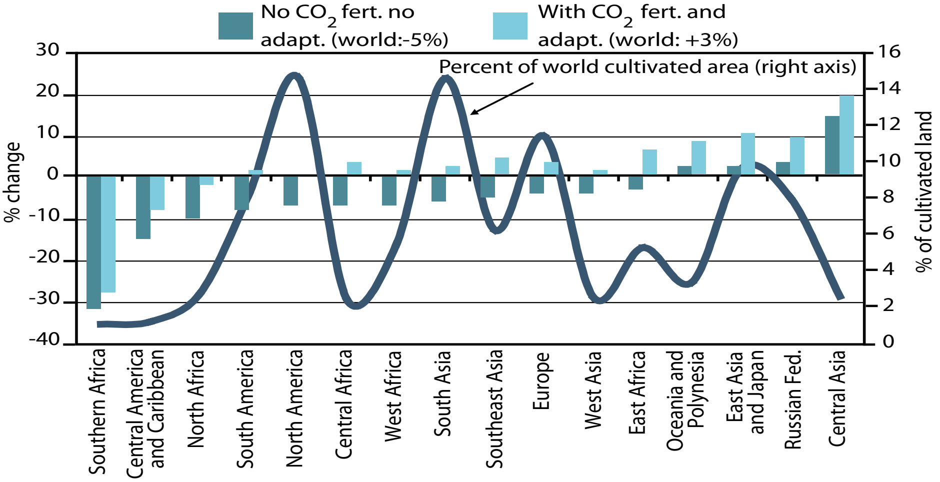
[11] This seems to be similar to the adaptation concept used in Chapter 3, but may not be. As noted, Chapter 3 speaks of farmers shifting to crop types that are better able to withstand the new climatic stresses. Chapter 2 speaks of farmers adapting their crop mixes and input use in response to changing prices.

its cereals production capacity could increase by 1 percent under this scenario (Hadley A2 with CO_2 fertilization and adaptation). A stronger negative impact is projected for the other food-insecure region, South and Southeast Asia (Tables 3.16 and 3.17), with production down by 3.7 percent and consumption by 1.0 percent.[12]

Figure 11.8
Chapter 3: effects of climate change on rainfed cereals production potential from currently cultivated land in 2050



Source: Chapter 3, Table 3.11.

Projections in Chapter 2 indicate that global cereal production in 2050 could be 15 to 17 percent lower than in the baseline (Nelson *et al.*, 2009: Table 3). This implies substantial declines in some regions. For example, in Europe and Central Asia production is expected to decline up to 51 percent for wheat and 38 percent

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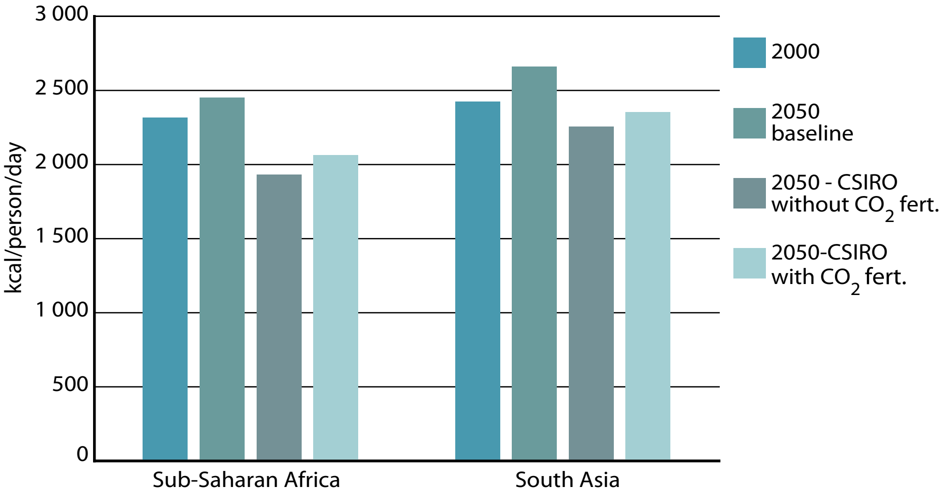
[12] Impacts on rainfed production potentials (Table 3.12) are given in greater detail (by country/ country group) than the economic model projections (Tables 3.16 and 3.17). It is therefore not clear how changes in potentials are related to changes in projected production and consumption. The evaluation of impacts on production potentials refers only to rainfed production on currently cultivated land, so there need not be a close relationship between such potentials and the production projected by the economic model. In the latter, production also comes from irrigated land , that is particularly important in South Asia; and from expansion on to currently uncultivated land, that could be important in sub-Saharan Africa.

for maize.[13] This finding requires further investigation, as this region includes areas like the Russian Federation and Central Asia that in the estimates of Chapter 3 are shown to benefit the most from climate change, with increases of 3 and 14 percent, respectively, for rainfed cereals production potential (Table 3.11).

Figure 11.9
IFPRI: effects of climate change on per capita food availability in 2050



Source: Nelson *et al.*, 2009: Table 5.

Findings of Chapter 2 for the two most food-insecure regions are dire. Negative impacts on crop production are pronounced in sub-Saharan Africa and South Asia. In sub-Saharan Africa rice, wheat, and maize yield may decline compared to the baseline by 15 percent, 34 percent and 10 percent, respectively. And in South Asia climate results in a 14-percent decline in rice production, a 44- to 49-percent reduction in wheat production, and a 9- to 19-percent reduction in maize. (Nelson *et al.*, 2009: 6 and Table 3). For both regions, the modest gains projected in the baseline are more than reversed in the scenarios with climate change (Figure 11.9): food availability would be lower not only compared to the baseline, but also compared to the starting point in year 2000.[14] This is a

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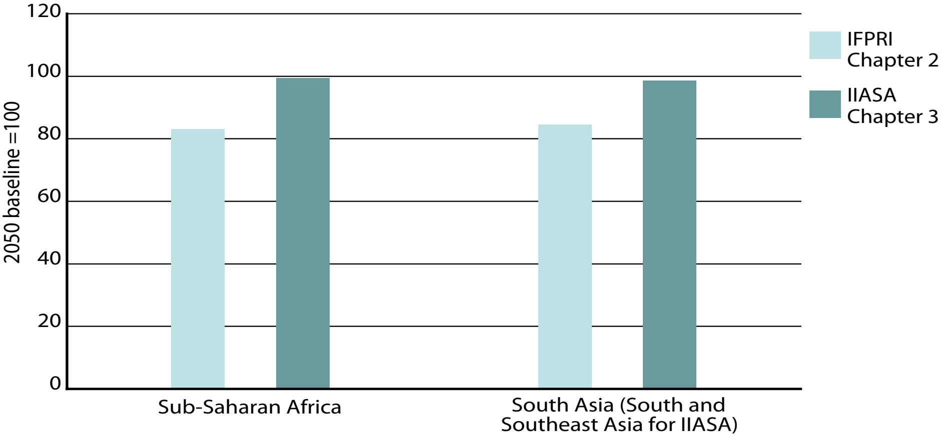
13. These findings refer to the NCAR and CSIRO scenarios without CO_2 fertilization but with adaptation in Chapter 2, as defined earlier.

14. "Calorie availability in 2050 will not only be lower than in the no-climate-change scenario – it will actually decline relative to 2000 levels throughout the developing world" (Nelson *et al.*, 2009: vii and Figure 5).

really catastrophic impact, given that in 2000 these regions had very low food availability in terms of calories per person per day. It raises the question as to how credible it is that India's star economic performance, which dominates that of South Asia, will go into reverse because of climate change impacts on its agriculture, as implied by the finding that South Asia may have lower per capita food consumption in 2050 than in 2000.

As seen, IIASA projections in Chapter 3 are less pessimistic. The only feasible direct comparison with Chapter 2 is between impacts on consumption for cereals under the CSIRO with CO_2 fertilization scenario for sub-Saharan Africa and South Asia (Figure 11.10). Impacts in sub-Saharan Africa are minimal in estimates from Chapter 3, but quite large in Chapter 2.

Figure 11.10
Effects of climate change on cereals consumption in 2050, sub-Saharan Africa and South Asia (baselines = 100)



Effects are from scenarios with GHG from SRES A2 and climate from CSIRO with CO_2 fertilization. IFPRI data are for food consumption; IIASA data are for all uses. Non-food use of cereals is small in both regions, so the difference in definitions should not distort comparisons unduly.

Sources: Nelson *et al.*, 2009: Table 4; Chapter 3, Table 3.17.

Discussion of climate change impact

The reasons why climate change impact evaluations vary so much need to be better understood. The large differences among models suggest that much work is still needed before well-grounded views can be formed on the significance of climate change for agriculture and food security. The reasons for these differences lie in a combination of the data, coefficients, exogenous assumptions, databases and models. Differences in the representation of biophysical environments could play a role in explaining why results are so different. They affect the production potentials that are used as inputs into the economic models and therefore play a key role in the projections of production, consumption, prices.[15]

Easterling *et al.* (2007: Table 5.6) give an idea of the relative importance of biophysical versus economic models in determining the differences. They present projected climate change impacts from the application of the same economic model employed in Chapter 3 to two crop modeling systems: one application by Fischer, using the GAEZ and one by Parry using the DSSAT, which is the same crop model employed by IFPRI in the analysis reported in Chapter 2. Impacts are given only for the projected numbers of people "at risk of hunger" under alternative SRES scenarios and the Hadley climate (GCM) model with CO_2 fertilization. The impacts on the numbers at risk of hunger for 2050 are minuscule compared to the baseline, and nearly identical whether the IIASA economic model is coupled with the GAEZ or the DSSAT crop-modelling system. This suggests that the reasons why impacts of climate change differ so much between Chapters 2 and 3 are more likely to be found in the economic models. However, more needs to be understood about both economic and biophysical models before any firm conclusions can be drawn. It is noted that much of the decline in yield potentials in the IFPRI analysis of Chapter 2 occurs in irrigated wheat and rice, for which Chapter 3 reports no specific information.

There may be a bias in the comparisons of projections with and without climate change. Both Chapters 2 and 3 estimate scenarios assuming future GHG concentrations generated by the IPCC SRES A2 scenario which has world population of 11.3 billion in 2050[16]. Impacts are then derived by comparing results of such scenarios with those of the baselines which use a much lower world population in 2050 - 9.1 billion. This means that climate impacts originating in GHG concentrations of 536 ppm in 2050 are compared with baselines that, due to lower population, would generate GHG concentrations of less than 500 ppm.[17]

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[15] "The simulated crop-price changes in response to climate change are quite moderate due to the relatively small net global impact on crop-production potential" (italics added; Fischer, Shah and van Velthuizen, 2002: 108).

[16] The identity commonly used to convey the relationship is: impact = population × affluence × technology (Nakicenovic and Swart, 2000: Chapter 3). SRES A2 assumes high population growth and slow technological change: both tend to magnify the climate impact.

[17] An IPCC scenario with 2050 population of 9.3 billion (scenario SRES B2) generates GHG concentrations of 478 ppm (IPCC, 2007b: Table 1). Naturally, the lower GHG concentrations in SRES B2 are due not only to the lower projected population but also to differences in other scenario variables, such as developments in the energy efficiency and carbon intensity of growth, more equitable development, and a more environment-conscious policy context. (See scenario storylines in Nakicenovic and Swart, 2000: Chapter 4.).

Analyses may thus tend to overstate the impact of climate change because, if the baselines had been projected with the higher population, the demand would have been higher and so would the projected prices. As a consequence the difference in projected prices between the with- and the without climate change scenarios would have been smaller.

Indeed, in another IIASA study using a projected 2050 population of 11.1 million, the difference in cereal prices results as 14.4 percent for 2080 (Fischer, Shah and van Velthuizen, 2002: Tables 4.1, 4.10; it has projected prices only for 2080), i.e. smaller than the 23 percent estimated for the same year in the present IIASA paper (Table 3.15). In both cases, the climate change effects are those of the Hadley GCM with CO_2 fertilization. Fischer, Shah and van Velthuizen (2002: Tables 4.1,4.10) estimated also scenarios with a 2050 population of 9.3 billion and GHG of 478 ppm originating from the same 9.3 billion population of scenario SRES B2: they project 2080 prices with climate change to be 2.1 percent higher than the baseline without climate change. In conclusion, the discrepancy in the population assumptions between the baseline projections and the scenarios that generate GHG concentrations can be at the origin of an upward bias in the estimation of climate change effects in Chapter 3. Mutatis mutandis, the same may apply to the analyses of Chapter 2.

Concerning food security, the analyses presented in previous chapters analyze the effects of climate change mainly via its impact on potential production in agriculture, and the related changes in food consumption. This would be acceptable if changes in food consumption depended only upon changes in production potentials. But climate change may affect food consumption and food security through several channels. First, impacts on production may have implications for incomes generated both in agriculture and other sectors. Poverty, and hence consumption and food security can be affected by climate change via this feedback link, especially in countries where agriculture accounts for significant shares of GDP and employment. Such feedback effects may be accounted for in the projection generated with general equilibrium models, such as IIASA's economic model described in Chapter 3 and the World Bank model described in Chapter 5. IFPRI's IMPACT model, employed in Chapter 2, is partial equilibrium, and the consumption projections probably do not account for such feedback effects. If they did, projected climate change impacts on consumption may have probably been lower than reported (Figure 11.9).

Second, climate change may affect economic growth, incomes, poverty and food security via other phenomena, such as sea-level rise, population dislocations, destruction of infrastructure, natural catastrophes from extreme events, altered biodiversity, and growing incidence of disease.[18] These impacts may be particularly relevant for developing countries. Many of these countries are located in latitudes with temperatures close to thresholds beyond which even small increases can have large effects (Cline, 2007: 41). They are less equipped to respond, and their high dependence on agriculture enhances their vulnerability.[19] This suggests that projections of consumption and food security outcomes under climate change scenarios should account for the lower GDP growth, along with reductions in agricultural production potentials. Among those employed in previous chapter, only the World Bank model (Chapter 5) seems to have the potential for doing so. The GDP and poverty projections reported in Chapter 5 account for climate change damages, but only those operating via lower agricultural productivity. Should other damages be considered in the simulations, the macroeconomic and poverty projections for developing countries may become somewhat less optimistic.

In general, two visions of world futures with climate change seem to emerge from the preceding discussion. The first is one of a significantly more prosperous world in 2050, with reduced poverty and food insecurity, in which climate change affects the rate of development by reducing the growth of agricultural productivity. This position of Chapter 5 is also echoed in contributions such as Easterling *et al.* (2007) and Schmidhuber and Tubiello (2007). The second vision is of a world of falling per capita food consumption and growing food insecurity, as depicted in Chapter 2, in which climate change makes the world poorer than today, as implied by falling food consumption caused by sharp declines in crop yield potentials, and assuming no corrective action is taken.

FAO's long-term assessments and projections have not so far addressed climate change impacts. This is a gap that must be filled. Based on the above discussion, the following preliminary indications can be put forward to orient future work.

Firstly, the new GAEZ should provide a sound basis for estimating climate change impacts on production potentials. More efficient way should be sought, however, of using them in economic models.

Secondly, if the objective of FAO long term scenario work is to generate a depiction of the likely future, assuming that present climate will prevail in the baseline might not be a realistic approach, since this might well be an impossibility, given that the consensus is that temperatures are going to rise anyway.

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18. On issues concerning total costs of climate change see Mendelsohn, 2007; Weitzman, 2007; Economist, 2009.

19. "Estimates are that they would bear some 75 to 80 percent of the costs of damages caused by the changing climate. Even 2 °C warming above preindustrial temperatures – the minimum the world is likely to experience – could result in permanent reductions in GDP of 4 to 5 percent for Africa and South Asia" (World Bank, 2010: 6, Box 1).

Thirdly, scenarios with climate change must be based on values for the exogenous variables (e.g. population growth) similar to those used in the baseline. Perhaps the main difference from the baseline could be specified in terms of volumes of emissions and the associated GHG concentrations in the future. The latter could be related to assumptions about mitigation policies.

Finally, given that climate change affects not only agricultural potentials but also the overall development prospects, income growth rates used to project food demand should not be maintained as exogenous variables. Feedbacks from climate change via effects on agriculture must be brought to bear on the GDP growth assumptions.

Impact of biofuels

In this volume, only Chapter 3 proposes detailed projections on biofuels. Chapter 2 makes references to biofuels, and shows projections of crops used for biofuels as part of IFPRI's baseline scenario, but does not indicate what difference biofuels can make to projected levels of other variables, such as prices and per capita food consumption. Chapter 5 underlines the potential impact biofuels development on agricultural prices, but the agricultural variables in the baseline projection, such as the productivity growth and prices, do not account for biofuels (van der Mensbrugghe *et al.* personal communication). FAO's long-term agricultural projections proposed in Chapter 1 do not include biofuel use of crops (FAO, 2006)[20] because the projections were prepared from 2003 to 2005 using historical data up to 2001, when such use was not a major issue. However, Chapter 1 does show biofuels projections to 2018 from FAO's more recent work (OECD/FAO, 2009).

Several scenarios of possible biofuels outcomes are analyzed in Chapter 3. These seems to be based on IIASA's work for the Organization of the Petroleum Exporting Countries Fund for International Development (OPEC/OFID) (Fischer *et al.*, 2009), and constitute variants around the reference projection of the International Energy Agency's (IEA's) 2008 World Energy Outlook (WEO) (IEA, 2008) (Box 11.1, based on Table 3.26).[21]

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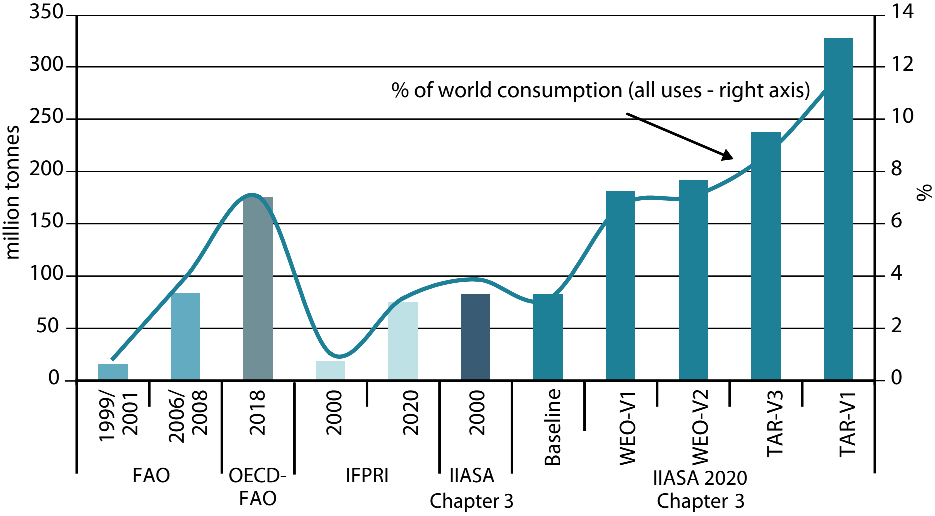
[20] Unknown amounts of cereals, sugar cane and vegetable oils used for biofuels were included as part of the more general non-food industrial use category of these products (there were no separate biofuels use statistics at the time).

[21] There is some confusion as to which scenario is the baseline. Chapter 3 indicates that it reports "a baseline projection without any use of agricultural feedstocks for biofuel production, as portrayed in the FAO-REF-00 scenario ..."; but in Table 3.3 it presents cereals projections based on scenario FAO-REF-00 while describing the projections as being from "baseline simulation without climate change and biofuel expansion" (scenario FAO-REF-01). As there is no cereals projection with zero biofuels, the comparisons in this chapter use as baseline the FAO-REF-01 scenario, which assumes that cereals use for biofuels remains constant at the 2008 level of 83 million tonnes.

In order to examine what previous chapters project for biofuels and what consequences this has for production, consumption and prices of agricultural products, we start from the projections to 2020, and compare them with those for 2018 reported in OECD/FAO (2009) (Figure 11.11). Cereals use for biofuels was 15 to 20 million tonnes in 1999/2001 and grew rapidly to 105 million tonnes in 2008, or 4.8 percent of world consumption of cereals. The OECD/FAO projections use these data in their starting years. Chapter 3 assumes that cereals use for biofuels in 2000 was 83 million tonnes, a level achieved only later.

Figure 11.11
World cereals use for biofuels, 2018 (OECD/FAO) and 2020 (Chapters 2 and 3)



Sources: OECD/FAO, 2009; IFPRI: detailed tables for Chapter 2 (supplied separately by the authors); Chapter 3.

The OECD/FAO projection foresees further rapid growth in cereals-based ethanol production, although slower than in the recent past. This is driven mostly by policies, especially the United States Energy Independence and Security Act, and the European Union (EU) Renewable Energy Directive, which together account for the bulk of the projected cereals use for ethanol. Chapter 2 projects a much lower biofuel use in 2020, at 75 million tonnes, which is less than the actual quantities of 2008.[22] In the five scenarios of Chapter 3 (Box 11.1) biofuel use in 2020 ranges from 83 million tonnes to 327 million tonnes in scenario TAR-V1,

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[22] Quantities for biofuels are included in IFPRI's Baseline in the total demand for cereals shown in Table 2.1.

assuming full achievement of the mandates and targets and slow penetration of second-generation biofuels. The bulk of ethanol production in this scenario comes from cereals and sugar cane. OECD/FAO projection for 2018 is similar to those of two Chapter 3 scenarios for 2020. This probably reflects both studies' reliance on IEA's (2008) energy sector projections.

Figure 11.12 compares projections from Chapters 2 and 3. The projected share of biofuel in cereal use peaks in 2030 under the high-biofuel scenario of Chapter 2 (TAR-V1); but there is little further growth after 2030 even in this scenario, given that second-generation biofuels are assumed to kick in after 2030.

Box 11.1 - IIASA biofuels scenarios

There are five scenarios:

1. Baseline scenario: Cereals use for biofuels is kept constant in all projection years at the level used in 2008 (83 million tonnes). This level is assumed to have existed also in 2000, when actual use was only 15 to 20 million tonnes. So this is a problem when seeking to compare projections with historical data.

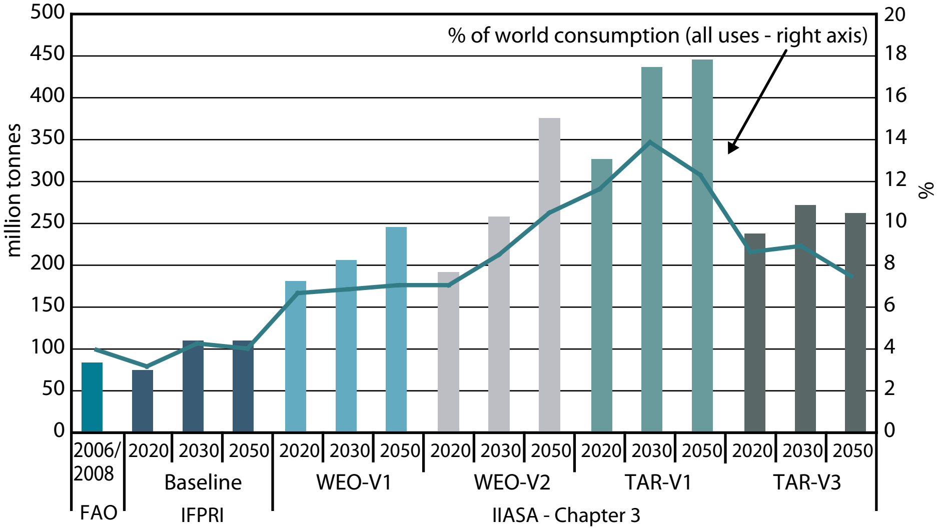
In the other four scenarios, the basis is the reference scenario projection of total demand for transport fuel of WEO 2008: demand for transport fuel is projected to increase by 40 percent from 2006 to 2030. IIASA extends the projection to 2050, implying a further rise of 18 percent from 2030 to 2050. From this WEO scenario, the other IIASA scenarios are generated by assuming alternative rates of: i) achievement of the biofuels mandates (mandatory, voluntary or indicative) in different countries; and ii) progress in second-generation biofuels (Chapter 3, Tables 3.26 and 3.33).

2. Scenario WEO-V1: Same as WEO reference scenario with extension of transport fuel to 2050 (as above). Biofuels mandates in the different countries are partly achieved (as in the WEO reference scenario) and the share of biofuels in total transport fuel rises from 1 percent in 2006 to 3.5 percent in 2020, 4.2 percent in 2030, and 6.0 percent in 2050 (total transport fuel is 2 830, 3 171 and 3 750 million tonnes of oil equivalent [TOE] in the three years; Chapter 3, Table 3.21). Second-generation biofuels have a slow start: they contribute 3 percent of total biofuels in 2020, 13 percent in 2030 and 30 percent in 2050. This scenario generates the lowest projection of cereals use for biofuels. This chapter uses the term "low-biofuels" scenario for easy reference in further discussions.

Impact on prices and quantities

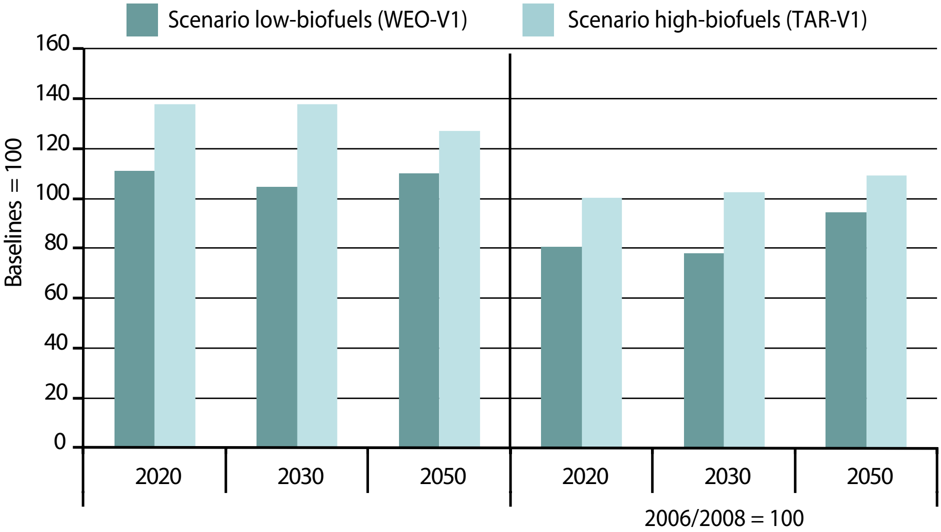
The very rapid growth of cereals use for biofuels in recent years is thought to have been a key demand-side factor that contributed to the price surges (Alexandratos, 2008; Mitchell, 2008). It is therefore interesting to consider what the analyses in Chapters 2 and 3 imply in terms of prices. Figure 11.13 shows price effects of the high- and low-biofuels scenarios. The left side of Figure 11.13 shows that projected 2050 prices could be from 10 percent to 27 percent higher under the low-biofuels and high-biofuel scenarios respectively, compared to a baseline in

Figure 11.12
IFPRI and Chapter 3 projections of cereals use for biofuels, all years



Sources: IFPRI: detailed tables for Chapter 2 (supplied separately by the authors), Chapter 3.

Figure 11.13
Effects of biofuels on cereal prices – Scenarios in Chapter 3



Source: Chapter 3, Tables 3.4 and 3.27.

which biofuels use of cereals is constant at the 83 million tonnes of 2008. The right side of Figure 11.13 rebases these price projections to the levels reached in the surge years (2006/2008 = 100). It shows that the high-biofuel scenario implies that prices in 2050 could be 9 percent above those reached in the surge years. Altogether, the impact of biofuels on cereal prices could be substantial, according to projections of Chapter 3.

Chapter 2 refers to what the growth rate of prices would have been if cereals use for biofuel had not accelerated from 2000 to 2007, and had grown at the same rate as between 1990 and 2000. The authors conclude that the growth rate of average grain prices would have been 30 percent lower than the actual ones. Based on data available today, this conclusion implies the following.

1. The actual growth rates of cereals use for biofuels were 6.0 percent per annum for 1990 to 2000, leading to 18 million tonnes of such use in 2000 (of which 16 million tonnes was maize in the United States of America); and 24.7 percent per annum for 2000 to 2007, leading to 85 million tonnes in 2007 (of which 77 million tonnes was maize in the United States).[23] If cereals use for biofuels from 2000 to 2007 had grown at 6.0 percent per annum as in the 1990s, as implied by IFPRI' s counterfactual scenario, biofuel use in 2007 would have been 27 million tonnes, i.e., 58 million tonnes less than the actual 85 million tonnes.
2. If prices grew 30 percent less than the actual 7.0 percent from 2000 to 2007 per annum, they would have grown at 4.9 percent per annum. The World Bank cereals price index in 2007 would have been 140 instead of the actual 160, i.e., prices would have been 13 percent lower in 2007. The reduction of cereals use for biofuels by 58 million tonnes in this counterfactual scenario would have led to a reduction of aggregate demand for cereals of less than 58 million tonnes, as the lower prices would have stimulated demand for food and feed. Based on findings in Chapter 3, however, it can be surmised that about one-third of the 58 million tonnes would have appeared as increased demand for food and feed, and the balance as reduced production.

Chapter 2 also refers to another biofuels scenario, that assumes the United States target of producing 15 billion gallons of first-generation biofuels by 2022 is met.[24] No indications are given regarding what this would imply for cereal

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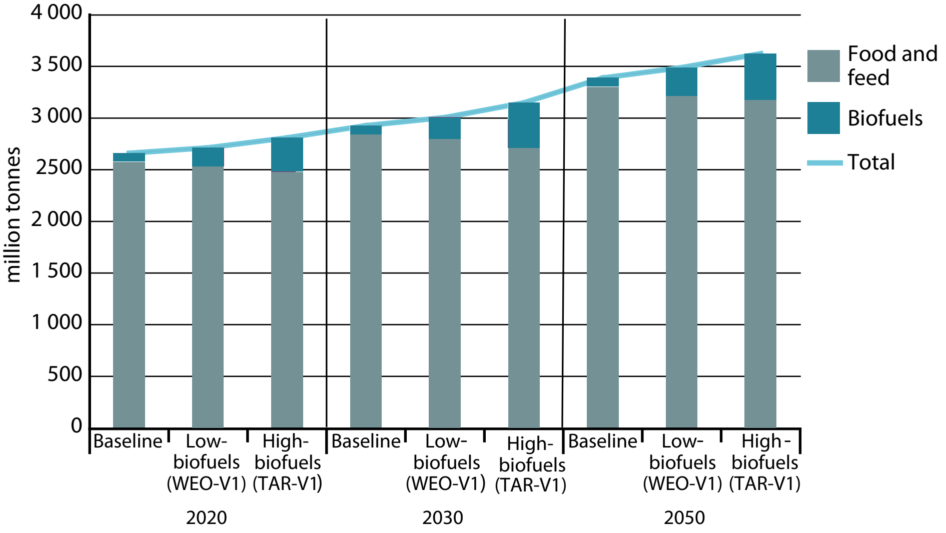
[23] The growth rate of the 1990s is for United States use of maize for ethanol, as there was little cereals use for biofuels outside the United States. Data from 2000 to 2007 are from the OECD/FAO (2009) files.

[24] The 15 billion gallons is the target for 2015, which continues at same level until 2022.

quantities used for biofuels, and for prices. The authors argue that the additional quantity of maize going to biofuels would be considerable and the effects on food security would be negative. If such effects were to be offset by additional production through accelerated yield growth, they estimate that average world cereal yields would have to grow at 1.8 percent per annum from 2000 to 2030, up from the 1.3 percent per annum of the baseline.

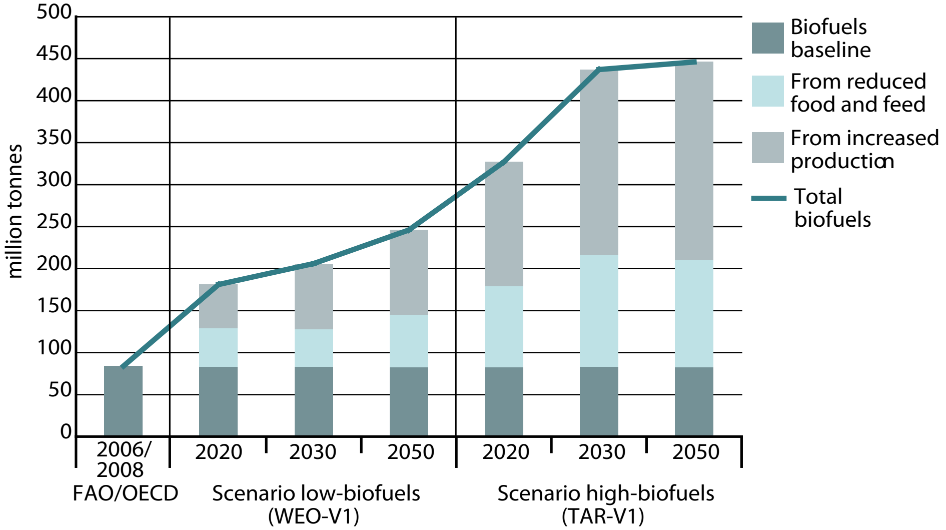
The projected higher prices following increased use of cereal in biofuel production have the potential for depressing demand for food and feed. It is interesting to consider what previous chapters indicate on this matter. Chapter 3 shows projected levels of food, feed and biofuel use of cereals under different scenarios (Figure 11.14). In 2030, for instance, food/feed consumption would fall from 2 845 million tonnes in the baseline scenario (when biofuels use was assumed to be only 83 million tonnes) to 2 712 million tonnes in the high-biofuels scenario, or to 2 800 million tonnes in the low-biofuels scenario. The high-biofuels scenario implies that of the total increase in cereals use for biofuels in 2030, 38 percent will come from reduced food/feed consumption and 62 percent from increased production. Figure 11.15 illustrates these outcomes in more detail. Overall, more of the incremental use of cereals for biofuels would come from increased production.

Figure 11.14
Cereals consumption: biofuels scenarios in Chapter 3



Source: Chapter 3.

Figure 11.15
Increments of cereals use for biofuels: scenarios in Chapter 3



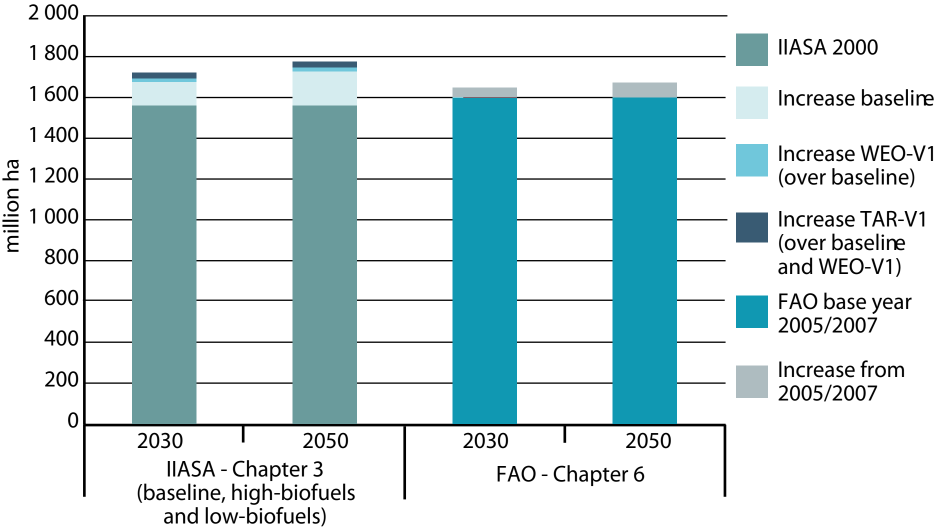
Source: Chapter 3.

It would be interesting to further analyze the implications of this scenario in terms of per capita food consumption and nutrition. Figures 3.6 and 3.7 imply that about 30 percent of the total decline in combined food/feed use comes from food, mostly in developing countries, and the rest from feed, mostly in developed countries. Chapter 3 implies but does not show an estimated effects on per capita food consumption in terms of kcal/person/day from all food, not only cereals, because it shows impacts on the numbers of people at "risk of hunger", which depend on the values of the kcal/person/day.

Biofuels and land use

Scenarios discussed in Chapter 3 provide estimates of the extent to which cultivated land – that is "arable land" and "land in permanent crops" in FAOSTAT terminology would need to expand beyond what is envisaged in the baseline to produce the crop feedstocks required by the biofuels industry. Figure 11.16 shows this under different scenarios, along with land-use projections from FAO (Chapter 6, Table 6.7). At first glance, biofuels seem to add little to total projected land use. However, increases in land for biofuels do not seem to include land required for the production of lignocellulosic biomass for second-generation biofuels embodied in projections. The author estimates that some 50 million ha of land would be required in 2030 for the production of second-generation feedstocks under scenario TAR-V1.

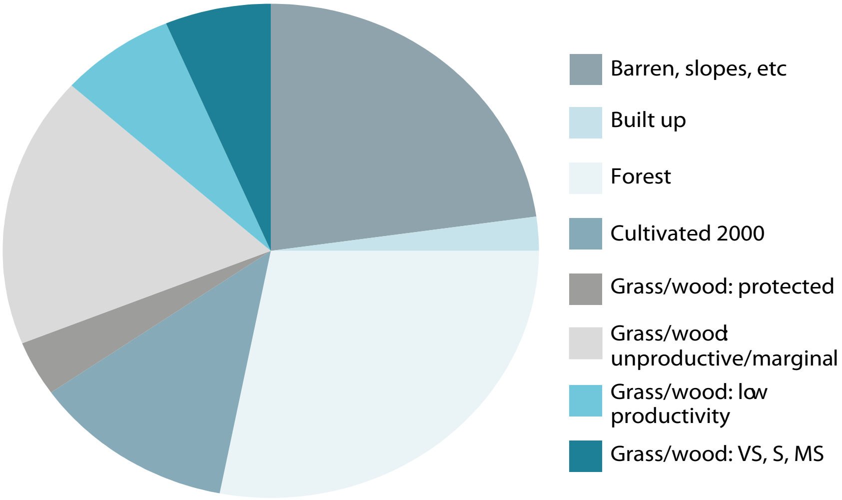
Figure 11.16
Cultivated land



Sources: Chapter 3, Tables 3.7 and 3.31; Chapter 6, Table 6.6.

Are the projected land expansions in the baseline or for increased biofuels feasible? Chapter 3 does not address this issue directly by providing estimates of land with crop production potential into which the expansion could be made. In Chapter 6, the assessment of land with rainfed crop production potential in various agro-ecological suitability classes suggests that this may amount to 4.2 billion ha for the world as a whole (Table 6.6). This information comes from the old IIASA GAEZ, and includes all types of potentially cultivable land, including land under forest, in protected areas and in human settlements. The part that is really available for expansion without deforestation and disturbance of protected areas is much smaller. About 1.6 billion ha are currently used for crop production. This is approximately the same figure that IIASA uses for 2000 in Chapter 3. Projections in Chapter 6 show a small increase in land used for crop production by 2050, of 70 million ha. This contrasts sharply with the projection reported in Chapter 3, which points to a 166 million ha increase in the baseline scenario, implying smaller increases in yields and/or cropping intensities than Chapter 6.[25] Figure 11.17 shows the classification of all land surface globally according to Chapter 3.

Figure 11.17
Land areas by use and suitability for lignocellulosic feedstock crops (billion hectares)



Suitability classes for lignocellulosic feedstock production: VS = very suitable; S = suitable; MS = moderately suitable.

Sources: Chapter 3, Table 3.37; Fischer *et al.*, 2009: Table 2.7-3e.

The same Chapter 3 does provide an estimate of land "potentially usable" for production of lignocellulosic biofuel feedstocks (Table 3.37). This is apparently based on the OFID work in Fischer *et al.* (2009: Table 3.6-7), using the updated 2009 GAEZ. The authors derive a figure of 1.75 billion ha of grassland and woodland with potential for lignocellulosic feedstocks; however, the OFID report (Fischer *et al.*, 2009: Table 2.7-3e) classifies only 860 million ha of this land as very suitable, suitable or moderately suitable for such feedstocks. Fischer *et al.* (2009) point out that much of this grass- and woodland may be used for livestock grazing, and only some 700 to 800 million ha may currently be available

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[25] Figures on cultivated land in Chapter 3 are similar to those of FAO and other studies, as they all come from FAOSTAT data for arable land and land under permanent crops; However cereals production in year 2000 looks higher in Chapter 3. This implies that the yields and/or cropping intensities derived from the interface between land and production may not provide a good basis for the projections on yield growth versus area expansion.

for lignocellulosic feedstock production. However, this is less comforting than it appears, as this same grass- and woodland may be the only area into which agriculture in general, and not only bio-fuel feedstocks, can expand in the future.

Finally, Chapter 3 suggests that competition for land may be limited, as production of feedstocks for second-generation biofuels are expected to be grown mainly outside cultivated land, and that some 100 million ha would be sufficient to achieve the target biofuel share in world transport fuels in 2050.

Discussion on biofuels

In analyzing biofuel development scenarios, increased attention should be devoted to the implications for food consumption and nutrition of a faster growth of agriculture generated by the expansion of biofuels. The potential negative impacts on food consumption, and by implication on nutrition, are not always discussed in sufficient detail. It is not always clear whether potential positive effects are accounted for, such as those associated with raising rural incomes and food consumption for the population groups who may benefit from higher prices arising from biofuel development. As noted also in the section on climate change, the general equilibrium approach may be more suitable than the partial equilibrium for capturing feedbacks from agricultural production to GDP and to food demand and nutrition. Future work on the impact of biofuels on food security cannot be limited to the negative effects of higher prices on the demand for food. Positive developmental impacts are an important aspect of the biofuels issue (ODI, 2009).

In terms of land resources, as seen Chapter 3 only addresses land-use and the suitability of an expansion to a limited extent. Even if there were plenty of land with production potential for lignocellulosic feedstocks, however, there can be no assurance that the cultivation of such feedstocks would expand only on to that land: it could also invade the land suitable for food crops, if economic realities so dictated. This means that the question as to whether the advent of second-generation biofuels will remove food versus fuel competition remains open.

Energy markets seem not to play a large role in the analyses of biofuels proposed in this volume; for example, the sensitivity of projections to oil prices is not addressed. The only link to energy markets is the one implied by adoption of the WEO 2008 reference scenario projection of total transport fuel to 2030, and the part of it to come from biofuels in IIASA's WEO-V1 scenario (Chapter 3). All other biofuels projections are derived from exogenous assumptions concerning the implementation of mandates and the shares of second-generation biofuels in total biofuels, with total transport fuel remaining constant[26].

If the future of biofuels is assumed to continue to depend predominantly on mandates, a gradual easing of competition with food and feed, and of the associated concerns about food security impacts, can be expected. This is because the role of mandates as the major driving force in biofuel development will tend to be gradually exhausted/weakened in the future: in the United States of America, the demand for ethanol created by the 10 percent blend mandate may soon be filled, and act as a constraint on further growth[27]; and with falling demand for transport fuel in the United States during the current crisis, the 10 percent mandate may not allow the absorption of the full 15 billion gallons of ethanol target for 2015 to 2022. Of more interest to long-term issues is the possible strengthening of links between the energy and agriculture markets, which may come about if the oil crunch that some foresee for the not-too-distant future were to materialize (Stevens, 2008; IEA, 2008).

Such an event would alter the economic fundamentals driving the biofuels sector, making it less dependent on mandates and other support policies, and more on market forces. In such circumstances, intensified competition for feedstock crops would tend to siphon off supplies and resources from the food sector, to the detriment of the food security of weaker population groups. Trade policies also have an important role, as they can help spread pressures on resources to countries with more resource endowments, such as in South America or sub-Saharan Africa. The eventual advent of second-generation biofuels may ease the impact, but will not eliminate it, because the production of lignocellulosic feedstocks may not be confined to land with no food crop production potential. In conclusion, analysis of the longer-term aspects of the food versus fuel issue requires that biofuel outcomes be explored in the context of alternative energy futures, and not only of alternative mandates and other support policies within a single energy future.

Demography, growth, inequality and poverty

Population data

Authors who use population projections in their quantitative analyses generally state that they are using those of the United Nations (UN), not always specifying which version. The UN has conducted four assessments over the last five years

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[26] There is no reference to the oil prices that are associated with such assumptions. Implicitly, the oil prices underlying the IIASA basic scenario (WEO-V1) are those of IEA's reference scenario: an average of USD 100/barrel over the period 2008 to 2015, rising to US 120/barrel by 2030 (in 2007 dollars; in nominal terms, 2030 prices are assumed to reach USD 200/barrel [IEA, 2008: 59]).

[27] In jargon, it is about to hit the "blend wall".

between the one for 2002, published in 2004, and the latest of 2008. The world projected population, according to the medium variant projection, has changed in successive assessments, moving from 8.9 billion in the 2002 assessment, to 9.2 billion in the 2008 assessment.

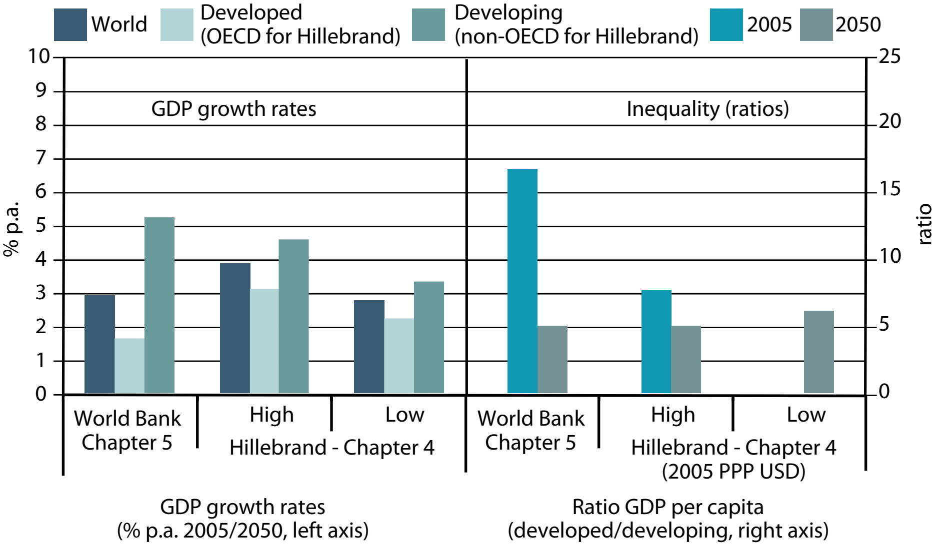
At the global level, the differences in the projected 2050 population are not large enough to affect significantly the issues addressed in this chapter. However, it is important to note that the differences in the world totals reflect predominantly higher projected populations in sub-Saharan Africa (1 557 million in the 2002 assessment and 1 753 million in that of 2008). This is the region with the most severe problems of poverty and hunger. Obviously, 200 million more people in the region's population could have a significant impact on the prospects for improving food security. For example, the 2050 projected incidence of undernourishment of 5.8 percent (FAO, 2006: Table 2.3), when applied to a population that includes an additional 200 million people, would add nearly 12 million to the region's projected numbers of undernourished. Other factors also change when the demographic situation changes and the projected numbers of undernourished increase by more than the 12 million people, including changes resulting from revisions of the historical data and the parameters used in the estimation (Table 11.1).

Income growth and distribution

Economic growth can play different roles in projections exercises. Generally it enters the analyses in two distinct ways: i) as a result in economy-wide models; and ii) as exogenous assumption in partial equilibrium analyses. Two chapters in this volume adopt the first approach: these are Chapters 4 and 5; Chapter 2 adopts the second approach, and Chapter 3 is based on a general equilibrium model, hence in principle GDP is modified by feedbacks received from changes in the solution for the agriculture sector.

Chapters 4 and 5 specifically address the issue of how the world economy may grow to 2050, and how income differentials between developed and developing countries may evolve. The common theme is "convergence": per capita incomes in developing countries are projected to grow faster than those in developed ones, so by 2050 the income divide will have narrowed compared to the present, at least in relative terms, and at the level of the two large aggregates. The magnitude of the income divide, and how much it narrows, depends on how the starting situation is measured, as well as on the differential growth rates assumed for the two country groups (Figure 11.18).

Figure 11.18
GDP growth rates and ratios of per capita incomes between different country groups, 2005 to 2050



Sources: Chapter 4, Table 4.1; author's calculations from World Bank, 2009 and UN population data.

Chapter 5 uses market exchange rates to measure GDP. The low and middle-income countries (LMYs)[28] account for 21 percent of global GDP,[29] but for 84 percent of world population. The ratio of per capita GDP of the high-income countries (HICs) to that of the LMYs is 1:20. This is a huge divide, which has been narrowing, but very slowly: it was 1:22 in 1990. The working hypothesis in the World Bank baseline scenario is for GDP to grow at rates of 1.6 percent per annum in HICs, 5.2 percent for LMYs and 2.9 percent for the world. The ratio of

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[28] In the GDP scenarios, neither of the two chapters use the term "developed and developing countries". However, the authors of Chapter 5 use the term "developing" in its poverty estimates. The large country groups used in the GDP scenarios are largely overlapping but not identical. The World Bank classifies countries into "high-income" (accounting for 16 percent of world population) and "low and middle-income" groups (84 percent). (Country lists available from the World Bank's World Development Indicators website: http://data.worldbank.org/data-catalog/world-development-indicators). In Chapter 4, Hillebrand divides countries into OECD (14 percent) and non-OECD (86 percent) groups. (Hillebrand's OECD group comprises only those countries that were OECD members in 1981.) The UN uses the terms "more developed" (19 percent of world population in 2005 according to the 2006 UN population assessment) and "less developed" (81 percent). FAO (2006) uses the terms "developed" (22 percent) and "developing" (78 percent).

[29] GDP data in constant 2000 dollars are from World Bank, 2010.

per capita GDP in LMYs'to that of HICs improves drastically: from 1:20 in 2005 to nearly 1:5 in 2050.

Chapter 4 addresses the same issue of economic growth to 2050, and presents two scenarios: a high one, called "market first", with world GDP growing by 3.8 percent per annum; and a low one, called "trend", with GDP growth of 2.8 percent. GDP is measured in purchasing power parity (PPP) dollars of 2005, which give higher weight to developing countries. With GDP thus measured, non-OECD countries account for 46 percent of world GDP in 2005, a huge difference from the 21 percent when GDP is measured at market exchange rates. As a consequence, the starting per capita GDP divide is much narrower: the ratio of non-OECD to OECD per capita GDP is 1:7.3 in 2005, falling to 1:5.3 or 1:6.1 by 2050.

Despite starting with huge differences in their global inequality measures, the two Chapters come to nearly identical conclusions: in 2050 the ratio of per capita GDP in rich to poor countries would be in the range of 1:5 or 6. This result reflects mainly the views embodied in the scenario hypotheses. The authors of Chapter 5 are upbeat regarding LMYs' prospects and rather conservative regarding those of HICs. The author of Chapter 4 are in the opposite direction, although both project faster growth in non-OECD than OECD countries.[30]

In both projections, declines in relative inequality imply widening gaps in absolute per capita incomes. People who are concerned about absolute gaps may see this as deterioration, but for those concerned with raising the income levels of low-income countries and fighting absolute poverty, the projections imply significant improvement, even if absolute gaps increase. In practice, achieving rising incomes for the poor often depends on the incomes of the rich growing in tandem, a point made by Hillebrand in Chapter 4. However, the link may be weaker in the future, following the emergence of growth poles in the non-OECD area.

As for poverty, in Chapter 5 this is measured as the number of people living on less than USD 1.25 per day in 2005 PPP dollars. Poverty is projected to virtually disappear in developing countries. Only sub-Saharan Africa and Latin America are projected to have measurable poverty rates in 2050, at 2.8 and 1.0 percent respectively. Hillebrand (Chapter 4) is less optimistic, but still projects significant declines in the high scenario. However, under his low scenario the poverty rate actually increases in sub-Saharan Africa, from the already very high 52 percent in 2005 (Figure 11.19).

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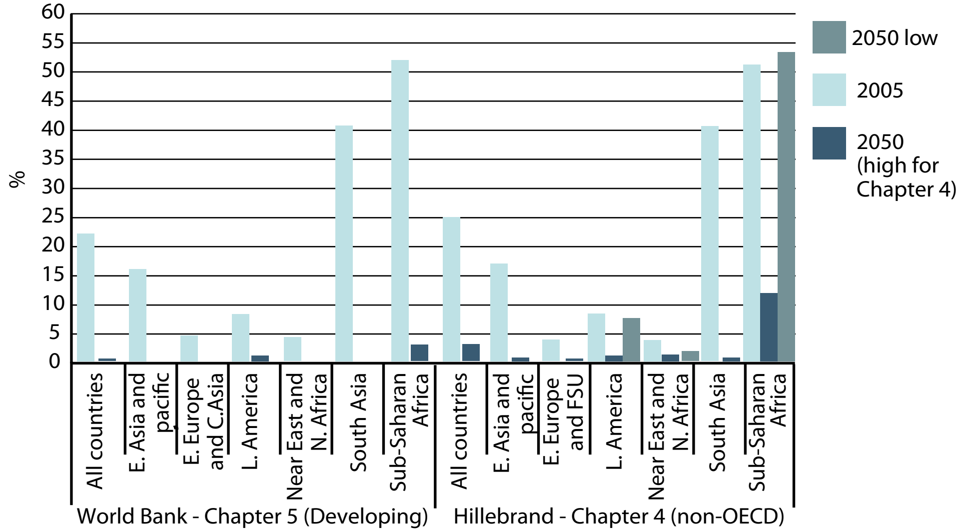
[30] Using market exchange rates rather than PPP to value and compare GDPs exaggerates the initial income gaps and can lead to erroneous conclusions regarding the implications of moving towards any given degree of convergence over the projection period. See "Hot potato" (Economist, 15 February 2003) and "Hot potato revisited" (Economist, 8 November 2003).

Figure 11.19
Poverty rates, population on less than USD 1.25/day



FSU = former Soviet Union.

Sources: Chapter 5, Table 5.8; Chapter 4, Tables 4.1 and 4.10.

Discussion on demography, growth and distribution

For the specific concern regarding food, agriculture and nutrition, the projected narrowing of the relative income divide should lead to an even sharper narrowing in the food consumption divide, because the latter, in contrast to income, is a bounded variable.[31] Chapter 4 explores the food and nutrition consequences of the projections of income, implied poverty and global inequality. In its "high" scenario, the non-OECD-to-OECD ratio of per capita food consumption (kcal/person/day) falls from 1:1.29 in 2005 to 1:1.16 (Table 4.9). This relatively modest change does not tell much in terms of food welfare and nutrition. Absolute levels of food consumption are the important factor. As reflected in Hillebrand's market first scenario, the outlook for 2050 is for food consumption in non-OECD countries to increase from an inadequate 2 662 kcal/person/day in 2005 to 3 135 kcal/person/day. This would be compatible with a significant reduction in undernourishment, but an adequate average across this large group of countries does not mean that every country, or even region, will be in the same happy position. Next section

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[31] A poor person must consume a minimum amount of food, while physiology limits the amount of food a rich person can consume.

points out that Hillebrand's food consumption projections for sub-Saharan Africa are probably too pessimistic.

This leads into the issue of likely rising inequalities within low-income countries. Chapter 5 states that the process of convergence between HICs and LMYs and declining inequality at the global level will be accompanied by higher within-country and within-region inequality. For example, the per capita GDP ratio of East Asia and the Pacific LMYs to that of sub-Saharan Africa will rise from about 1:2.5 at present to 1:5.7 in 2050.[32] Chapter 4 shows projected growth rates of per capita GDP, with that of sub-Saharan Africa being the lowest of all regions (Table 4.8). Moreover, its projected poverty rates and food consumption levels make it clear that there will be increasing differentiation, with sub-Saharan Africa making far less progress in these variables than the other regions in the non-OECD group.

A final point worth mentioning is the view, implicit in scenario projections, that world economic activity can continue to grow unimpeded by constraints imposed by natural resources and the environment. In Chapters 4 and 5 the world economy in 2050 is a multiple of that in 2005.[33] Authors do not explicitly address these constraints and the possible impacts on global growth. Chapter 4 refers briefly to the Club of Rome's Limits to Growth. Chapter 5 reports possible impacts of climate change on agriculture, and also speaks of exploring the impacts of rising energy prices on agriculture, without pursuing the matter. This can mean either that such constraints will not prove binding in the 45-year projection period, or – more likely – that in time-honoured fashion, a more prosperous world will be finding ways around such constraints, as and when they arise, reflecting a Julian Simon concept of economic progress (Simon, 1996). Hillebrand, in Chapter 4 explicitly recognizes that "Resource constraints, if not met by technological solutions, will surely make the poverty estimates shown here worse".

These broader issues cannot be addressed here, but it is worth considering the possibility of binding constraints emerging in the sphere of natural resources and the environment, when dealing with long-term processes involving huge increases in economic activity. The main binding constraints to solving the hunger problem may not be agricultural resources, but rather those that can stand in the way of ever-expanding global economic activity at rates sufficient to raise incomes and eliminate poverty in countries with food insecurity problems. This possibility was already being raised 15 years ago in FAO's 1995 edition of World agriculture: Towards 2010 (Alexandratos, 1995: 136 –137).

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[32] "This ratio drops to six by 2050, but varies highly across regions, with a low of 3.5 in East Asia and the Pacific and a high of 20 in sub-Saharan Africa" (Chapter 5). Therefore, if YHIC/YSSA = 20 and YHIC/YEAP = 3.5, then YEAP/YSSA = 20/3.5 = 5.7.

[33] Both chapters emphasize that their long-term projections are scenarios rather than forecasts.

Sub-Saharan Africa

The future of agriculture and food security of this region was the topic of separate sessions at the 2009 Expert Meeting on "How to feed to the world in 2050". Not all expert contributions provided quantitative projections on this region. Those that did had often disparate variables -- income growth rates, poverty rates, food consumption, numbers undernourished ¬ hence results cannot always be easily compared. The main variables on which results are available are shown in Table 11.1.

In Chapters 1 and 2 growth rates are exogenous, and Chapter 5 does not show GDP projections by region. Per capita growth rates reported in other chapters are shown in Table 11.1. Three are in the range 2.3 to 2.5 percent per annum for 2005 to 2050, and only Chapter 2 has a significantly lower rate, at 1.9 percent. Chapters 4 and 5 shows projections of poverty rates by region. Chapter 5 is upbeat, with absolute poverty virtually disappearing by 2050 in sub-Saharan Africa (Table 11.1). This implies that whatever GDP growth rate underlies the World Bank's poverty projections, must be fairly robust; moreover, these drastic poverty reductions occur despite the assumption that within-country income distribution becomes somewhat more unequal. Chapter 4 is less optimistic: the region's poverty rate is projected to decline to 11.7 percent by 2050 in the high GDP growth scenario when per capita GDP grows at 2.5 percent per annum. This assumes no changes in within-country income distribution and in the part of GDP devoted to private consumption, so here too it is economic growth that drives declines in the poverty rates, rather than internal redistribution. The lower-growth scenario of Chapter 4 is outright pessimistic: poverty actually increases slightly, to 53.1 percent of a much larger population, so the implied absolute numbers in poverty are huge.

Two main questions arise from these results. Firstly: does evidence support the proposition that sustained economic growth leads to declines in the poverty rates? The latest World Development Indicators data, reporting figures up to 2005 show negative correlation between the two variables (Figure 11.20).[34] The poverty rate started falling from 1999, when growth of per capita GDP accelerated. Macroeconomic projections assume a continuation of the GDP per capita growth of recent years, so the significant further reductions in the poverty rates do not seem out of reach, provided these high growth rates actually materialize. Secondly: is it realistic to expect that the relatively high growth rates of per capita incomes achieved in the decade to 2008 can be sustained for several decades? One reason for scepticism is the region's initial poverty conditions: starting with 52 percent

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[34] Assuming that the two data sets are independent, i.e., the poverty rate is not estimated as a function of income.

of the population below this very low poverty line USD 1.25/day -- means that poverty rates will continue to be high for long periods in the intervening years. Would such a situation provide the social and political environment necessary for sustaining high economic growth rates for several decades?

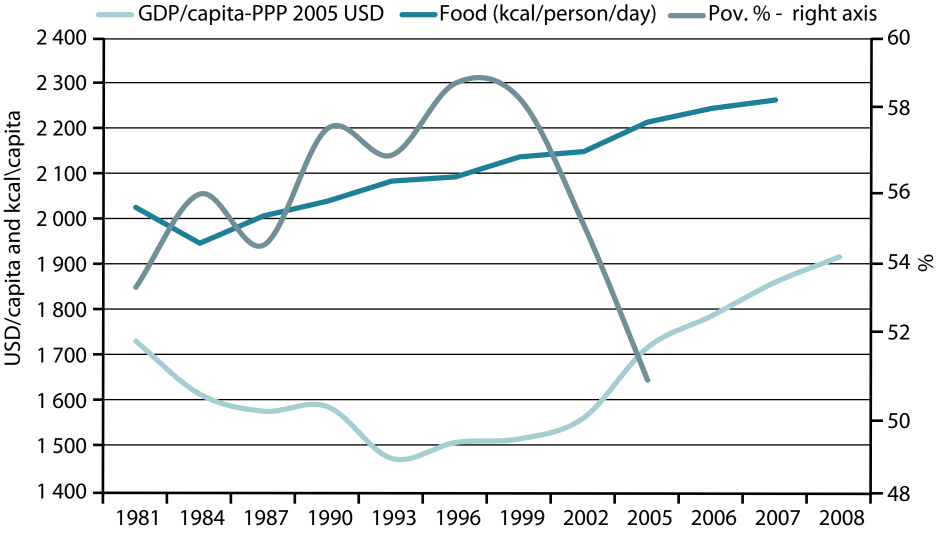
Table 11.1
Key figures for sub-Saharan Africa

	Actual		Projection
GDP/capita (% per annum)	2000–2005	2000–2050	2005–2050[a]
Hillebrand (Chapter 4, Table 4.8, high scenario)	1.9		2.5
FAO (2006: Table 2.5)	1.9	2.3	2.4
IFPRI (personal communication)	1.9	1.9	1.9
IIASA (Chapter 3, Tables 3.1 and 3.2)	1.9	2.2	2.3
B. Poverty (% population with < USD 1.25/day in 2005 PPP dollars)	2005		2050
Hillebrand (Chapter 4, Table 4.10, high scenario)	51.2		11.7
Hillebrand (Chapter 4, Table 4.10, low scenario)			53.1
World Bank (Chapter 5, Table 5.8)	51.7		2.8
	Data used in projections		Projection
C. Food consumption (kcal/person/day)	2000	2005	2050
Hillebrand (Chapter 4, Table 4.9, high scenario)		2 256	2 588
FAO (2006: Table 2.1)	2 194		2 830
FAO (Chapter 1, Table 1.4)	2 128	2 167	2 708
IFPRI (Nelson *et al.*, 2009: Table 5, baseline)	2 316		2 452
IFPRI (Nelson *et al*, 2009: Table 5, climate change-CSIRO with CO$_2$ fertilization)			2 064
D. Undernourished (% population)[b]			
FAO (2006: Table 2.3)	33.3		5.8
FAO (Chapter 1, Table 1.3, actual and revised)	32	30.5	7
IIASA (Chapter 3, Tables 3.1 and 3.5, on risk of hunger)	29.9		12.6
E. Undernourished (million people)			
FAO (2006: Table 2.3)	201		88
FAO (Chapter 1, Table 1.3, actual and revised)	202	213	118
IFPRI (Nelson *et al.*, 2009: Table 6, baseline, children only)	33		42
IFPRI (Nelson *et al.*, 2009: Table 6, CSIRO with CO$_2$ fertilization, children only)			48
IIASA (Chapter 3, Table 3.5, at risk of hunger)	196		239

[a] Except for Chapter 4, the projected growth rates for 2005 to 2050 are derived from those for 2000 to 2050 and the actual rates for 2000 to 2005.

[b] Hillebrand's EM paper gave estimates for this variable (percentage of population malnourished), which have been removed in the version for this volume (Chapter 4).

Figure 11.20
Sub-Saharan Africa: per capita GDP, per capita food consumption and poverty rate



Sources: World Bank, World Development Indicators; FAOSTAT.

These questions cannot be answered, but it is worth considering them. It must also be kept in mind that reducing or even eliminating this kind of poverty does not imply a region free of deprivation for significant parts of the population: the poverty line used is very low, and 45 years is a long time to wait for such an outcome.

Food security in Sub-saharan Africa

Of prime interest here is what may happen to the food situation in Sub-saharan Africa, and particularly whether the projected reductions in poverty rates will be accompanied by commensurate declines in the rates of undernourishment. In principle this should be so, given that "almost all the national poverty lines use a food bundle based on prevailing diets that attains predetermined nutritional requirements for good health and normal activity levels, plus an allowance for non-food spending" (World Bank, 2009). In turn, the international poverty line of USD 1.25/person/day is based "on the mean of the poverty lines in the poorest 15 countries" in the sample of countries surveyed. Other countries have higher poverty lines (Haughton and Khandker, 2009: 185; Ravallion, Chen and Sangraula, 2009). Assuming the latter are also based on the "bundle of food" principle, the

USD 1.25 level will not be sufficient to ensure that “nutritional requirements for good health and normal activity levels” are met in all countries. Therefore, it is not surprising that studies using similar assumptions of per capita income growth find that undernourishment rates in 2050 are projected to be higher than the USD 1.25 poverty rates.

As mentioned, kcal/person/day is the main variable used by FAO to estimate the incidence of undernourishment (FAO, 2006: Box 2.2). The projection in Chapter 1 is the most optimistic among those reported in this volume: food consumption is projected to rise from 2 167 kcal/person/day in 2003/2005 to 2 708 kcal in 2050, and the percentage of population undernourished falls from 32 to 7 percent. The absolute numbers undernourished remain high, with 118 million in 2050, down from 212 million in 2003/2005. The target of the 1996 World Food Summit of halving the numbers undernourished by 2015 is not achieved, even by 2050, assuming the global halving target is applied to the region.[35] These developments in the absolute numbers undernourished, despite the significant decline in the percentage of population, reflect the very rapid population growth in sub-Saharan Africa, at 142 percent from 2005 to 2050, compared with 38 percent for the other developing countries. This raises the issue of how to compare the relative performances of different countries/groups regarding progress towards the target. Defining the target in absolute numbers rather than as a percentage of population tends to penalize countries with high demographic growth, by making progress look less than it would be in percentage terms.

In Chapter 4, Hillebrand’s 2.5 percent per capita income growth rate in the “high” scenario is associated with an increase in food consumption, from 2 256 kcal/person/day in 2005 to 2 588 kcal in 2050. The implicit income elasticity is unrealistically low (at 0.12), given the very low starting level, even when food is expressed in calories.[36] How is this result derived? The model represents the crop sector in terms of physical quantities with all crops lumped together as one variable plus meat, dairy and fish, but “Calories consumed per capita are estimated as a function of GDP per capita and relative prices” (personal communication).[37]

Chapter 2, as recalled, provides projections in terms of kcal/person/day, and numbers of malnourished children in millions, but not as percentages of the population in the zero to five years age group. In these projections, sub-Saharan

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[35] Progress towards the target is measured from the 169 million people undernourished in 1990/1992 (FAO, 2008: Table 1), the base year used at the 1996 World Food Summit.

[36] Estimates of calorie-income elasticities are provided by Skoufias (2002) and Ohri-Vachaspati *et al.*, (1998).

[37] implicit income elasticity may be so low because projected food prices rise significantly. The author does not address this issue.

Africa's per capita food consumption increases only marginally in the baseline from 2000-2050 (Nelson *et al.*, 2009: Table 5) and suffers a sharp decline (to 2 064 kcal/person/day) in the climate change scenario. This is a very pessimistic outlook, given that it considers a 50-year horizon. As a consequence, the numbers of malnourished children in the baseline are projected to increase from 33 million in 2000 to 42 million in 2050 (Nelson *et al.*, 2009: Table 6). This may be the outcome of the small improvement in per capita food consumption projected by IFPRI, and the projected price increases (Figure 11.4). As in the case of cereals (Figure 11.6), part of the reason may be the historical data. Food consumption in the region is given as 2 316 kcal/capita/day in year 2000, while FAO records 2 128 kcal (Table 11.1).

In general, statements about food security in the future require a credible projection of per capita food consumption, which is generally derived as a function of GDP per capita and prices. However, at least for the regional average for sub-Saharan Africa, evidence suggests that per capita food consumption is more closely related to the evolution of domestic food production than to anything else. This was observed in FAO (2006: Figure 2.2, example of Nigeria) where the evolution of per capita food consumption seemed to bear little relation to per capita incomes. In most sub-Saharan African countries with limited shares of imported food in total supplies, high economic dependence on agriculture and little non-food use of food commodities, food consumption seems to follow the evolution of production and, to a lesser extent, food imports.[38] As explained in the methodology of the earlier FAO projections (Alexandratos, 1995), in such cases, the growth of food consumption is derived iteratively in the process of evaluating the scope for increasing production and trade. Much of the credibility of the food consumption projections therefore depends on the credibility of the food production projections.

Looking at cereal projections for Sub-saharan Africa, Chapter 2 has the smallest increase in per capita food consumption, and also the lowest growth rate for cereals production in its baseline projection, at 1.7 percent per annum from 2000 to 2050 (Nelson *et al.*, 2009: Table 3). Chapter 3 shows a higher growth rate for cereals production, at 2.5 percent per annum for the same period (Table 3.3). Projections in Chapter 1 are in between, at 2.1 percent per annum (FAO, 2006: Table 3). It is to be noted that sub-Saharan Africa's cereals production increased by 4.5 percent per annum between 2000 and 2008, and production grew by more

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[38] In the food balance sheets, food consumption is derived as part of the utilization of total supplies of each food product (production + net imports + net changes in stocks). It is therefore natural to expect a close correlation between production and consumption in countries with little net trade in food, and limited non-food uses (e.g., feed) of food commodities.

than 4 percent per annum in several major producers in the region, including Ethiopia, Nigeria and the Sudan (Chapter 1, Annex 1.1). Such high growth rates were partly due to recoveries and favorable weather; however, there is no reason to believe that the region's cereals production cannot grow at a somewhat higher rate than that of the population. This may not apply to all countries, given that, for example, the Niger has annual population growth of more than 3 percent to 2050.

At the same time, it is useful to note that cereals are a relatively small component of food production in sub-Saharan Africa, accounting for 17 percent of total food production. Potential links between production and consumption may be even stronger for the other major food groups in the regions, such as roots, tubers and plantains.

Discussion on Sub-saharan Africa

The chapters of this volume present contrasting views on the prospects for sub-Saharan Africa. At one extreme, Chapter 5 foresees a much improved future, judging from its projection of drastic falls in poverty, despite the assumption of no improvement or even deterioration of income distribution, and after accounting for climate change damage to agriculture. This view seems to reflect confidence in continuation of the upturn in the region's performance of the last decade, after a long history of stagnation and decline. The most recent World Bank assessment (World Bank, 2011: Table R6.3) foresees continuation of robust GDP performance to 2012. It must be kept in mind that the region now has ten oil-exporting countries and receives growing amounts of foreign private investment (World Bank, 2011: Table R6.1). A recent article in the Economist highlights sub-Saharan Africa's good economic growth record of the current decade, and its future prospects.[39] As already noted, agriculture has also improved its performance in the current decade.

At the other extreme, Chapter 2 paints a pessimistic future for the region, as deduced from the limited progress in raising per capita food consumption by 2050 in its baseline projection. The future is projected to be dismal, as a consequence of climate change effects on agriculture: in the best climate change outcome, per capita food consumption is projected to suffer a drastic fall from its already very low level. As noted in Figure 11.10, this is at great variance also with the findings of Chapter 3. However, catastrophic predictions are common, and the latest foresees doom already by 2025: "about two-thirds of arable land in Africa is expected to be lost by 2025" (Hisas, 2011). Climate change futures that seem to

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[39] "A more hopeful continent: The lion kings? Africa is now one of the world's fastest-growing regions", Economist, 8 January 2011.

imply such huge divergences in views about the region's long-term prospects are clearly in great need of further analysis.

References

Alexandratos, N., ed. 1995. *World agriculture: Towards 2010, an FAO study*. Chichester, UK, J. Wiley and Sons, and Rome, FAO.

Alexandratos, N. 2008. Food price surges: Possible causes, past experience, and longer-term relevance. *Population and Development Review*, 34(4): 663–697. www.fao.org/es/esd/foodpricesurges-alexandratos.pdf.

Cline, W.R. 2007. *Global warming and agriculture: Impact estimates by country*. Washington, DC, Center for Global Development and Peterson Institute for International Economics.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J. & Tubiello, F.N. 2007. Food, fibre and forest products. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, chapter 5, pp. 273–313. Cambridge, UK, Cambridge University Press.

Economist. 2009. Is it worth it? 3 December 2009.

FAO. 2006. *World agriculture: towards 2030/2050, interim report*. Rome. www.fao.org/es/esd/gstudies.htm.

FAO. 2008. *The State of Food Insecurity in the World 2008*. Rome.

Fischer, G. 2000. Simulating global agricultural development according to IPCC SRES scenario paradigms. Paper prepared for the Global Modelling Forum, New York, 2 to 4 February 2000.

Fischer, G., Shah, M. & van Velhuizen, H. 2002. *Climate change and agricultural vulnerability*. Special report for the World Summit on Sustainable Development. Laxenburg, Austria, IIASA.

Fischer, G., Shah, M., Tubiello, F.N. & van Velhuizen, H. 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Phil. Trans. R. Soc. B*, 360: 2067–2083.

Fischer, G., Hizsnyik, E., Prieler, S., Shah, M. & van Velthuizen, H. 2009. *Biofuels and food security*. Study prepared by IIASA for the OPEC Fund for International Development (OFID). Laxenburg, Austria, IIASA.

Haughton, J. & Khandker, S. 2009. *Handbook on poverty and inequality*. Washington, DC, World Bank.

Hisas, L. 2001. The food gap: The impacts of climate change on food production: A 2020 perspective. Alexandria, Virginia, USA, Universal Ecological Fund.

IEA. 2008. *World energy outlook 2008*. Paris, OECD/IEA.

IPCC. 2007a. *Climate change 2007: Synthesis report*. Nairobi.

IPCC. 2007b. *General guidelines on the use of scenario data for climate impact and adaptation assessment*. Nairobi.

Mendelsohn, R. 2007. A critique of the Stern Report. *Regulation*, Winter 2006–2007.

Mitchell, D. 2008. *A note on rising food prices*. Policy Research Working Paper No. 4682. Washington, DC, World Bank.

Msangi, S. & Rosegrant, M. 2009. World agriculture in a dynamically-changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints. Paper presented at the FAO Expert Meeting on How to Feed the World in 2050, 24 to 26 June 2009, Rome, FAO. www.fao.org/wsfs/forum2050/background-documents/expert-papers/en/.

Nakicenovic, N. & Swart, R., eds. 2000. *Special report on emissions scenarios*. Cambridge, UK, IPCC and Cambridge University Press. 570 pp.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M. & Lee, D. 2009. *Climate change: Impact on agriculture and costs of adaptation*. Washington, DC, IFPRI.

ODI. 2009. *Biofuels: Could the South benefit?* Briefing Paper No. 48. London, Overseas Development Institute (ODI).

OECD/FAO. 2009. *Agricultural outlook, 2009–2018*. Paris.

Ohri-Vachaspati, P., Rogers, B.L., Kennedy, E. & Goldberg, J.P. 1998. The effects of data collection methods on calorie–expenditure elasticity estimates: a study from the Dominican Republic. *Food Policy*, 23(3/4): 295–304.

Ravallion, M., Chen, S. & Sangraula, P. 2009. Dollar a day revisited. *World Bank Economic Review*, 23(2): 163–184.

Rosegrant, M. 2008. Biofuels and grain prices: Impacts and policy responses. Testimony for the United States Senate Committee on Homeland Security and Governmental Affairs, 7 May 2008. Washington, DC, IFPRI.

Schmidhuber, J. & Tubiello, F. 2007. Global food security under climate change. *Proceedings of the National Academy Science*, 104(50).

Simon, J. 1996. *The ultimate resource II*, second edition. Princeton, New Jersey, USA, Princeton University Press.

Skoufias, E. 2002. *The sensitivity of calorie-income demand elasticity to price changes: Evidence from Indonesia*. FCND Discussion Paper No. 141. Washington, DC, IFPRI.

Stevens, P. 2008. *The coming oil supply crunch*. London, Chatham House.

Weitzman, M. 2007. The Stern Review of the economics of climate change.

Journal of Economic Literature, 45: 703–724.

World Bank. 2009. *World Development Indicators 2009*. http://data.worldbank.org/data-catalog/world-development-indicators.

World Bank. 2010. *World Development Report 2010: Development and climate change*. Washington, DC.

World Bank. 2011. *Global economic prospects 2011*. Washington, DC.