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EXPERT MEETING ON "HOW TO FEED THE WORLD IN 2050"
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Critical Evaluation of Selected Projections

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Critical Evaluation of Selected Projections

1. INTRODUCTION

The preparation of this paper originated at the time summaries and syntheses of the Expert Meeting (EM) papers and discussions of June 2009 were being prepared for the forthcoming Forum and the Food Summit. It soon became apparent (at least to me) that no statements could be prepared that would synthesize in a coherent manner the different views embodied in the projections concerning possible futures of world food and agriculture to 2050. It was not so much a matter that views were diverse, which is natural. There is no harm in stating that paper *x* had one view and paper *y* had a different one. Rather, the problem was that we did not quite understand why views differed and, related to it, how they had been generated. No person can summarize/synthesize different views on several topics without a good understanding of what he/she is talking about. Some illustrations:

- One could not just lift and use in a summary/synthesis a phrase like: *"world grain prices will further increase 30-50% before 2050…. beyond current high levels"*. This statement is not very informative: speaking in 2009 when "current" prices were just past their peak of the surge years, this phrase conveys a message of ever growing scarcities in world markets – a definitely pessimistic prospect. If, on the other hand, the phrase referred to projected prices compared to those of the base year of the model (usually 2000) then the message would be quite different: much lower prices than those of the surge years. It follows that to use statements appearing in the EM papers on price prospects one would have to delve in some depth into the papers and related material in order to find out what they meant, then use additional information from other sources to re-base the projections on a common denominator. Only then could one generate and put in the synthesis a statement on the different views concerning future prices.
- Likewise, one cannot readily use a phrase referring to a *"more than doubling of the global market price for maize in 2050 due to climate change*": other estimates indicated minimal impacts, at least at the global level and up to 2050. Unless one had some knowledge how such statements were generated (e.g. what climate models and what biophysical data were used), one would be forced to limit to trivial generalities the discussion of the climate change issue in the summaries/syntheses. Elaborating a little on this point, I illustrate what I mean by showing here what is on offer in the EM papers regarding estimates of climate change impacts on world market prices (percent differences over their baselines without climate change in 2050, more details later):

    - IIASA, price index for all cereals
        - Climate Model Hadley without CO2Fertilization: +10%
        - Climate Model Hadley with CO2Fertilization: -1%
        - Climate Model CSIRO with CO2Fertilization: +2%

- IFPRI-EM paper (Climate Model and CO2 Fert. not reported)
    - Wheat: +80%
    - Maize: +96%
    - Rice: +28%

- IFPRI-New Estimates (Nelson *et al*, Oct. 2009, Climate Model CSIRO with CO2Fert)
    - Wheat: +70%
    - Maize: +35%
    - Rice: +12%

Given the above, the organizers asked me to take a closer look at the papers and produce a paper comparing what they had to say on the different issues and, as far as possible, explaining why. The objective was to see whether we could learn something useful for informing the development of FAO positions and planning of activities, particularly on topics on which FAO had not done, but was required to do, much work, e.g. long-term issues related to biofuels or to climate change and their possible significance for agriculture and food security. Taking a closer look is easier said than done, since the papers do not provide sufficient information to understand how their positions were generated. Some of the authors[2] responded to some of my queries for clarifications, but this was rarely sufficient for me to gain a full understanding why the projections were what they were.

In what follows I present what the papers[3] project on five topics: Prices, Climate Change Impacts, Biofuels, GDP/Global Inequality/Poverty, and sub-Saharan Africa.

[2] I received responses from IFPRI, the World Bank and Hillebrand. A thank you to all the authors for this help, particularly to Siwa Msangi who provided fairly detailed background material.

[3] I review projections of following papers: World Bank (van der Mensbrugghe *et al*, 2009), Hillebrand (2009), IIASA (Fischer, 2009), FAO (Alexandratos, 2009; FAO, 2006), and IFPRI (Msangi and Rosegrant, 2009). In addition, I draw on a more recent IFPRI paper (Nelson *et al*, 2009) which apparently reports revised projections for the baseline and climate change impacts. The present draft has been sent to the papers' authors for comments.

2. PRICES

2.1 Introduction

One of the frequently asked questions is whether the price surges of recent years were a harbinger of things to come or, like in the past, a temporary occurrence (on this, see Alexandratos, 2008; Mitchell, 2008). Do the price projections of the EM papers provide answers? We first note that at the time of the EM (June 2009) cereal prices had fallen by some 30% from their peaks of spring 2008. Nevertheless, they were still well above the average of the pre-surge period (the 2003/05 average: wheat and maize by some 70%, rice by 138% - all in current USD). Three EM papers (World Bank, IFPRI, IIASA) show, or refer to, projections of prices, either of specific commodities (e.g. maize), groups of commodities (e.g. cereals) or total agriculture. However, none of them measure price changes from the surge years and some draw on earlier work by the authors, as far as I can tell. So we shall have to bring price projections to a common base year denominator before we can compare/discuss them. In this task we shall also use the price projections of the latest OECD/FAO Agricultural Outlook of 2009 which does take into account the price surges of 2008. Thus:

The World Bank paper (van der Mensbrugghe *et al*, 2009) has only one statement on agricultural price projections, only for total agriculture and only to 2030 (they have no statements about price projections for 2050, nor for any commodity or group). It says: "The baseline scenario……yields a benign price pattern for overall agriculture, i.e. there is a small negative trend over the long-term…(Figure 4.4)". Their base year is 2005, so I presume "benign pattern" refers to a comparison of projected 2030 prices vis-à-vis those of 2005, i.e. a year before the price surges. By implication, this is saying that the price surges that started in 2006 were a temporary spike. It is not known which commodities the "overall agriculture" of the WB model includes, but I presume it should correspond to "total agriculture" used in the construction of the price indices in the WB Commodity Price Data. It is noted that the baseline includes effects of climate change (CC), but only those on agriculture (see below Section on Climate Change). There is no scenario with agricultural price projections without CC; therefore we cannot compare price outcomes with- and without CC. However, if the with-CC scenario generates such a benign path of prices, it is reasonable to assume that without the damages of climate change (reduction of assumed rate of agricultural productivity growth – see below) projected prices would be even lower, at least up to 2030.

The IIASA paper (Fischer, 2009) has more detailed projections of price indices to 2020, 30, 40 and 50 for several commodity groups: Crops (Cereals, Other Crops), Livestock and (total) Agriculture (their Table 3.4). The indices are based on 1990=100. Therefore, it is not possible to tell what they imply for future prices vis-à-vis present ones without further processing (see below).

The IFPRI EM paper (Msangi and Rosegrant, 2009) has three bar graphs with prices for wheat, maize and rice for 2000 and 2050. Prices are in 2000$. On request, they kindly provided more detailed values of projected prices and other variables from 2000-2050. They show for their baseline that prices should increase from 2000-50 by 17%, 6% and 61% for the three commodities, respectively. Apparently, the paper drew on work in progress and reported provisional findings.

A new IFPRI paper focusing on climate change (Nelson *et al*, October 2009) presents revised baseline (no-CC) projections: they indicate price increases from 2000-50 of 39%, 63% and 62% for wheat, maize and rice, respectively (note the large upward revisions for wheat and maize). Again, further processing is required before we can read what they imply vis-à-vis present.

Naturally, any statements on price developments have to be seen in the context of the scenario assumptions underlying such projections, model structures, parameters and data, as well as in relation to the quantities of production and consumption associated with such price projections. Moreover, as noted, statements about future price developments can differ widely depending on the base year from which changes are measured. It is, therefore, impossible to compare directly the different price projections. For example, IFPRI EM paper's statement that *"world grain prices will further increase 30-50% before 2050, and that, in the same period, meat prices will increase an additional 20-30% beyond current high levels"* is not very illuminating. If we interpreted "*current price levels*" to refer to the average of the years 2006-08 of the price surges, then the projected prices look quite different: they all decline from average 2006/08-2050 (Fig. 2.4, below). Obviously, it is difficult to interpret the above quotation.

2.2 Making Projections Comparable

For comparisons we need to re-base the different price projections on a common base-year denominator. But what common base year is appropriate for generating meaningful statements concerning future price prospects? Figure 2.1 shows the cereals and total agriculture price indices in real terms for the years 1970-2008 (Source: World Bank, *Commodity Price Data*). It is seen that, at least for the group cereals and in terms of annual values, the price surge started in 2006. Therefore, a good base for comparing future projections vis-à-vis "present" is the 3-year average 2006/08. For comparing future vis-à-vis the prices of the pre-surge period we use the 3-year average 2003/05[4].

If we used the most recent three year average 2006/08 we would conclude that prices will fall. If we used a pre-surge 3-year average, we arrive at the opposite general conclusion though there are cases when prices are projected to be lower in 2050 than in 2003/05 (IFPRI's wheat and maize, but only in the EM paper, not in the revised one – Fig. 2.4). In what follows I will use both options so that readers can judge for themselves what the price projections imply.

To grasp what these comparisons imply, I start by showing in Fig. 2.2 the most recent real price projections, i.e. those of the 2009 OECD-FAO Agricultural Outlook to 2018 (OECD-FAO, 2009) after rebasing them on these two 3-year averages. As noted, these projections were prepared in the first half of 2009 and account for developments in the years of the price surges. The graph speaks for itself: higher prices in 2018 (6%-19% for the three commodities) with respect to those of the pre-surge years, but much lower than "present levels", i.e. those of 2006/08.

[4] Data of real prices for 1990-2008 (needed to shift the base of the three projections to the two base years 2003/05 and 2006/08) are from the WB Commodity Price Data which have real price indices with 2000=100.

The price projection of IFPRI, IIASA and World Bank are sown in Figures 2.3 & 2.4. The projected prices are measured from both 2003/05=100 and 2006/08=100.

Fig. 2.1 Cereals & Agriculture: Real Price Indices - 2000=100

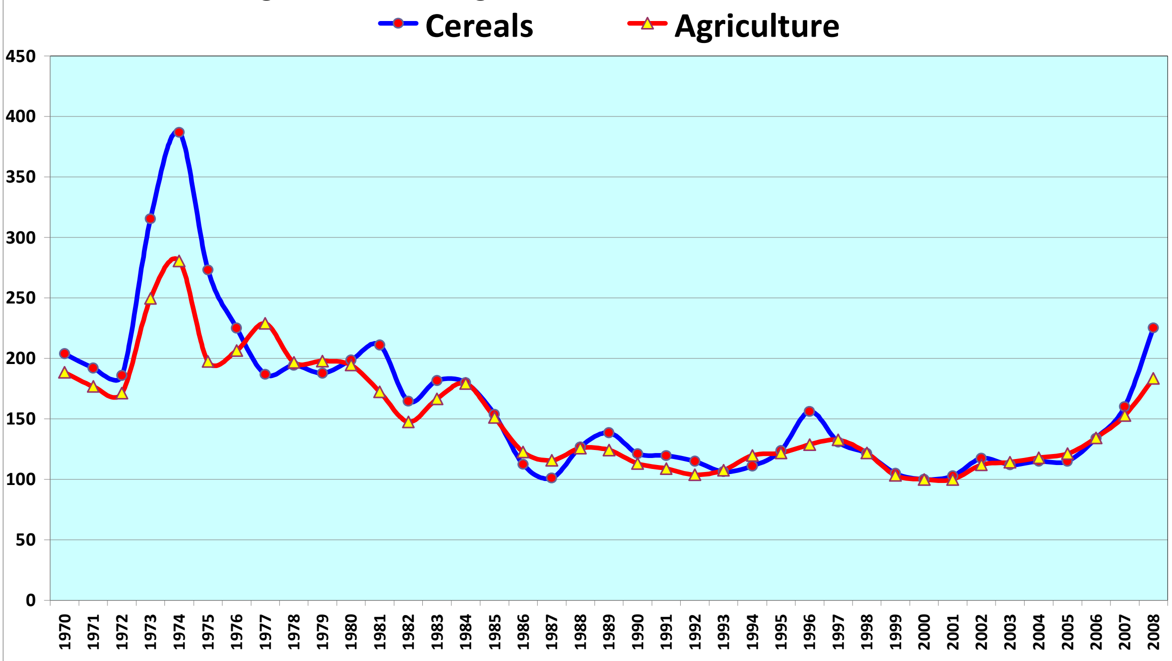
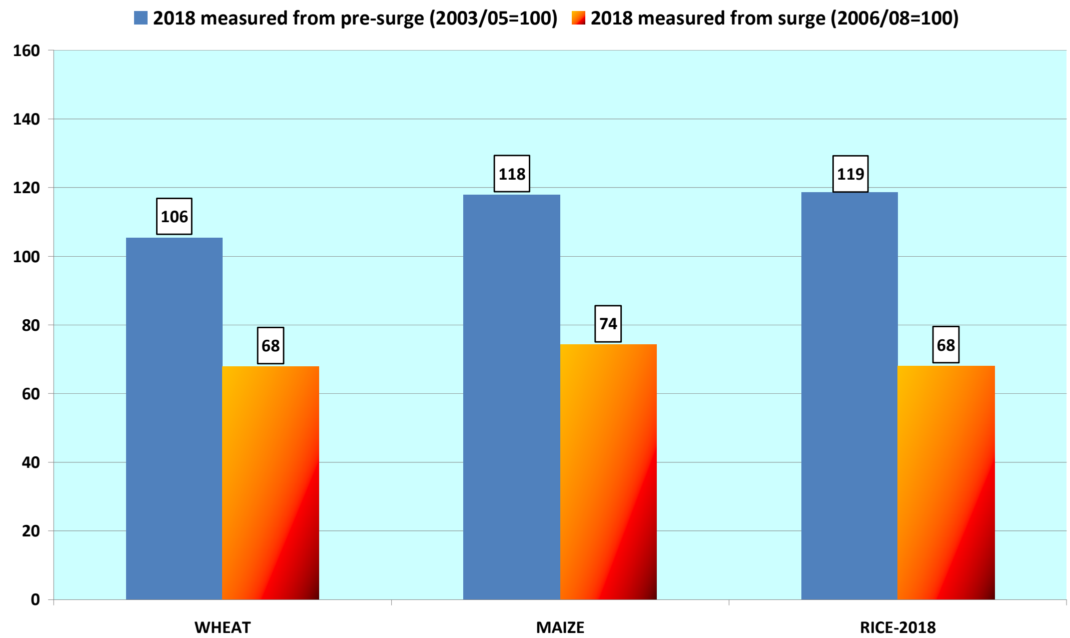


Fig. 2.2 Cereal Price Indexes to 2018 - OECD-FAO 2009 Projections

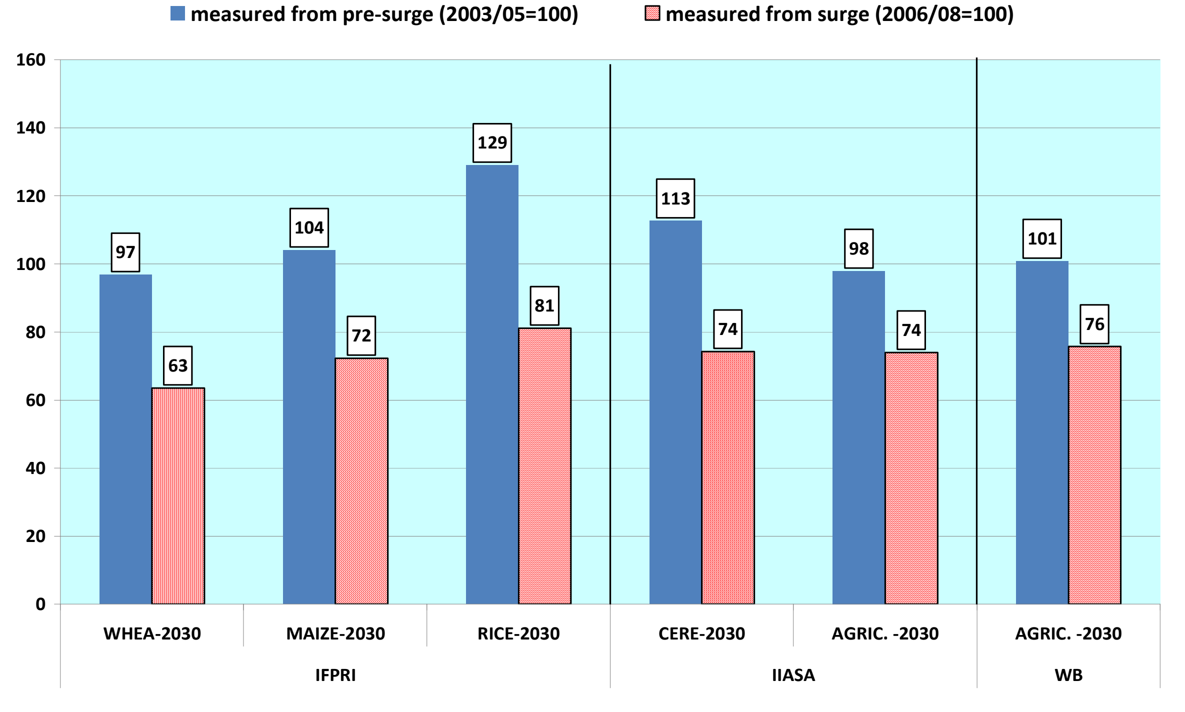


Source: OECD-FAO (2009), data for Figures 6.8-6.10

2.3 The outlook to 2030

All three EM papers have projections to 2030. They are shown in Fig. 2.3. The main message seems to be that over the next two decades real prices will be lower, indeed much lower, than the average of surge years 2006/08 (red bar in the Figure). The picture is more mixed when we view the price projections in relation to those of the pre-surge period (blue bar in the Figure). Concerning total agriculture to 2030, both the IIASA and World Bank projections suggest that the average price level of the sector will be in 2030 not very different from that of the pre-surge period 2003/05. The same goes for the IFPRI EM paper projections of wheat and maize prices. However, these 2030 prices have probably been raised in revisions for the work published (only for 2050) in the new IFPRI paper (see below). In the end, the only significant differences of prices in 2030 are (a) that rice could be 29% more expensive than in the pre-surge 2003/05 average (according to IFPRI) or, (b) that the average cereals price index will be 13% higher compared with pre-surge 2003/05 average (according to IIASA).

Fig. 2.3 Price Indices to 2030 - IFPRI, IIASA & WB Projections



2.4 The outlook to 2050

Only IFPRI and IIASA have 2050 projections. They are shown in Fig. 2.4. The IIASA index for total agriculture suggests that the average price level of the sector will be just ten percent higher than in the pre-surge period and well below "present levels". Cereal prices are, however, projected by IIASA to rise faster (by 31% compared with the pre-surge level) than the average for all agriculture. Prices of the other agricultural products (other crops and livestock in the IIASA model) increase by less than those of cereals (their Table 3.4).

IFPRI's EM paper is more sanguine, since 2050 prices for both wheat and maize are projected to be lower than those of the pre-surge years, indeed lower than those projected for 2030 and lower than the IIASA index for 2050. Only rice is projected by IFPRI to have ever rising prices, so that by 2050 they would be just 8% below the very high ones reached in the surge years[5]. This apparently contradicts the above mentioned statement that grain prices are to "*increase 30-50% before 2050*". However, the revisions of October 2009 change things: the projected prices of wheat and maize have been revised upwards and brought more in line with those of rice (Fig. 2.4). Differences from the projections of IIASA's cereals price index are now much less pronounced and indeed in the opposite direction.

Fig. 2.4 Price Indices to 2050 - IFPRI & IIASA Projections

2.5 Demand and Supply Quantities Associated with the Price Projections

Projected prices can be similar or differ widely among models for very many reasons. These we cannot detect without going into an in depth examination of the assumptions, data and parameters used, structure of each model and what "baseline" means in each case (the projections presented so far refer to what the different papers define as "baseline" scenarios; we

[5] Rice prices rise the most in spite of world consumption of rice having the lowest growth rate in the projections (0.2% p.a. from 2000-50, vs. 0.9% for wheat and 1.1 for maize). I suppose the projection model of IFPRI embodies much more stringent production constraints for rice than for wheat and maize, leading to rice prices in 2050 not falling much from the high levels of the surge years.

discuss price effects of biofuels and climate change in later sections). This would not be practical, even if we had complete access to all the model and data details, which we do not. However, of primary interest for the issue at hand (feeding the world in 2050) is what food and nutrition outcomes are associated with the different price projections. For example, if moderation in price rises is associated with demand growth that is less than what is needed to significantly reduce or eliminate hunger, the outcome cannot be considered optimistic.

What do the EM papers imply for future levels of per capita food consumption and associated nutritional outcomes? Unfortunately, they are not very informative on this matter. The IIASA paper implies that it projected such levels (since it provides projections of population at risk of hunger which presupposes the availability of projections of per capita food consumption in Kcal/person/day[6]) but does not show them. In similar vein, IFPRI's EM paper also contains projections of child malnutrition for which a key explanatory variable is per capita calorie availability[7]. The projections of this variable are not, however, given in the paper[8].

Both papers present cereals projections. We can examine the projected world consumption of cereals and juxtapose them with the projected prices in order to see whether a pattern emerges. However, comparing even simple variables like world quantities of cereals is less straightforward than it sounds. We first note that projected world cereals consumption in 2050 differ widely from each other (Fig. 5). Thus, IIASA projects 3,388 million tons (mt) in 2050, of which 83 for biofuels[9]. IFPRI's EM paper has 2,739 mt of which 110 mt for biofuels (no comparable figures are given in the revised IFPRI paper). One is tempted to say that the higher consumption of IIASA compared with that of IFPRI explains why IIASA projects higher cereal prices than IFPRI (EM paper – before revisions) for 2050 (Fig. 2.4).

However, this interpretation may not stand because the historical data, i.e. the tons of world cereals consumption (all uses) reported for 2000, also differ widely, both from each other and from the actual historical data. In turn, the differences in projected world demand may well be due as much to such differences in the base-year data used as in future visions embodied in the models and their structures and parameters. Thus, the IFPRI starts with 2000 world consumption of 1,982 mt (Msangi and Rosegrant, Table 1; the revised paper does not show total cereals, only cereals food per capita) while IIASA has 2,144 mt for the same year (their Table 3.3). Both are different from the actual historical data (1,900 mt, average 1999/01). The IIASA number for 2000 is even higher than the increased world consumption of recent years (2,121 mt, average

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[6] "The estimated number of people at risk of hunger used in the world food system model is based on FAO data (FAO, 2001; 2008b) and relies on a strong correlation between the share of undernourished in a country's total population and the ratio of average per capita dietary food supply relative to average national per capita food requirements" (Fischer, 2009, p. 29). It is doubtful whether this is a statistically valid correlation given that that the numbers undernourished in the FAO statistics are not independent data but are themselves derived as a function of the average per capita dietary food supply, the average national per capita food requirements and an index of inequality. No wonder that the implied correlation is, deceptively, strong.

[7] "The determinants of malnutrition are derived primarily from four key indicators – per capita calorie availability, access to clean drinking water, rates of secondary schooling among females, and the ratio of female-to-male life expectancy" (Msangi and Rosegrant, 2009).

[8] The more recent IFPRI paper has a Table with projected Kcal/person/day availabilities (Nelson et al, 2009, Table 5). We discuss them later (Sections 3.6.2, 6.2).

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

2006/08). IFPRI's number for 2000 is above the actual because it includes soybeans in the cereals total (error in making Table 1?). Removing soybeans does not remedy the situation: world consumption becomes 1,818 mt, well below actual one. As for IIASA, I can only guess that the numbers given for 2000 are not really data but projections[10] (including an assumption that the quantities used for biofuels in 2008, 83 mt, were also used in 2000, which is not correct). These discrepancies in the starting values of the model projections are depicted in Fig. 2.6. They make the absolute values of projected world cereals consumption non-comparable and certainly difficult to interpret. We can obtain a better idea of the relative importance of the differences in world consumption of cereals as one of the determinants of the differences in projected prices by observing the growth rates of consumption, rather than the increases in absolute volumes. These are also shown in Fig. 2.5. It is seen that the IIASA growth rate is somewhat higher than that of IFPRI (0.92% p.a. vs. 0.82%, 2000-50). The difference is even more pronounced if biofuels are excluded from the total cereals consumption. This may justify why IIASA has somewhat higher projected cereal prices than IFPRI's EM paper, but we cannot be sure for the reasons discussed above.

The differences in the historical data used by the two models bedevil any attempt to form an idea concerning the very important issue what could the volume of world cereals production required to meet the growth of consumption in 2050. In an attempt to shed some light on this matter, Fig. 2.5 also shows the FAO projection to 2050. It comes from the latest FAO long-term projections published in 2006 (FAO, 2006). The 3 billion tons projected for 2050 is based on the actual historical data for up to 2001, so this ensures it is not distorted by data inconsistencies. It does not include biofuels, so it should be compared with the IFPRI and IIASA projections without biofuels shown in Fig. 2.5. On this benchmark, the IFPRI projection looks too low (mainly because of the lower starting data for 2000 and to a smaller extent because of the lower growth rate) and the one of IIASA definitely too high (also because of the starting 2000 figure which is much higher than the actual world consumption in that year – see above).

But is the FAO projection of 3 billion tons (without biofuels) any better than the other two as an indication of how much more the world will have to produce by 2050, starting from the most recent 3-year average 2006/08 of 2.1 billion tons (Fig. 2.6)? It certainly has the advantage of being grounded on real historical data (the projections were made in the period 2003-05 with historical data up to 2001). In addition, it was subjected to a reality check on the occasion of the June 2009 EM. For this purpose the projections trajectory 2000-50 of world production/consumption was compared (in Alexandratos, 2009, Table 1 & Fig. 1) with (a) actual outcomes to 2008 and (b) the medium-term projections to 2018 of the latest OECD-FAO Agricultural Outlook 2009. On both counts, the projection trajectory was close enough to both actual outcomes to 2008 and the subsequent 10-year OECD-FAO projection, both not including cereals use for biofuels. However, the FAO projection needs to be supplemented with one or more alternatives for biofuels. This is a topic addressed in a later section.

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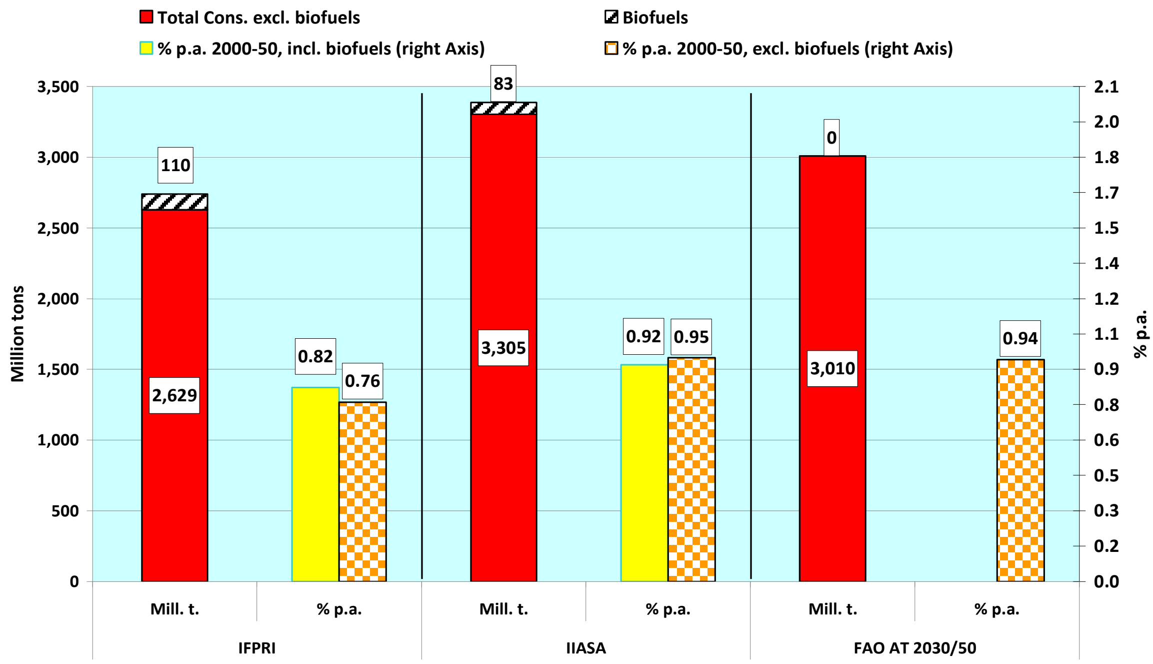
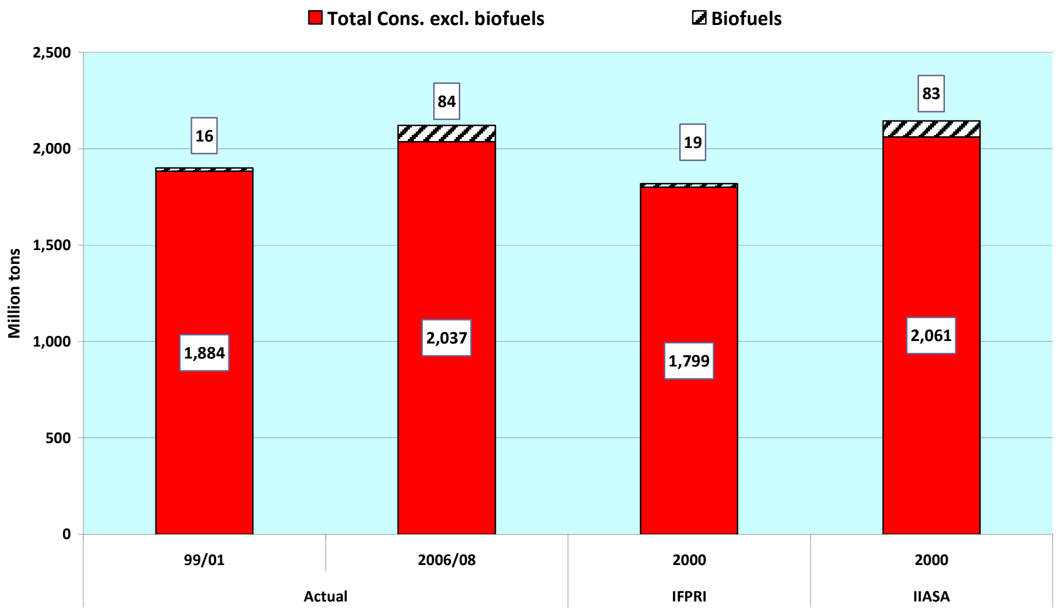
[10] I say this because the authors use 1990 as base year for reporting price projections and also because they say "The simulations were carried out on a yearly basis from 1990 to 2080". This implies that numbers for 2000 probably have nothing to do with the actual world situation as it was in that year. This happens despite the claim that: 'The IIASA world food system model has been calibrated and validated over past time windows and successfully reproduces regional consumption, production, and trade of major agricultural commodities in 2000" (Fischer, 2009, p. 49). We shall know for sure if and when the author responds to my queries.

Fig. 2.5 Cereals Projections: World Consumption in 2050 and Growth Rates



Sources: FAO AT2030/50, Alexandratos (2009, Table 1); IFPRI, Msangi & Rosegrant (2009, working files, Baseline, Cereals excl. soybeans); IIASA, Fischer (2009, Table 3.3 - Scenario WEO-01)

Fig. 2.6 World Cereals Consumption, Actual Historical Data vs. Year 2000 Data in models



Sources: Actual, Alexandratos (2009, Table 1, from FAO/CCBS data base); IFPRI, Msangi & Rosegrant (2009, working files, Baseline); IIASA, Fischer (2009, Table 3.3 - Scenario WEO-01)

2.6 Conclusions

The projections to 2030 of the World Bank and IIASA generally suggest that real world agricultural prices (index for the whole sector, no relevant information for 2030 is given in the revised IFPRI paper) will tend to revert to levels near those of the pre-surge period. We noted (Fig. 2.2) that the OECD/FAO projections (only for cereals) are not that optimistic for the next 10 years. However, they could be in accordance with those of IIASA which have the cereals price index for 2020 being 11% above the average of the pre-surge years.

Concerning 2050 we have only projections from IFPRI and IIASA. The revised projections of IFPRI for the individual cereals are probably compatible with the cereals price index of IIASA. In conclusion, all projections broadly indicate that prices in 2050 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-eighties (Fig. 2.1).

Two caveats: (a) the cereals demand-supply projections generated by the models (hence also the associated prices) are difficult to interpret because they are based on historical data at variance with what actually happened in the real world, and (b) as far as I can tell, the analytical work underpinning the price projections does not take into account, or not fully so, developments in the recent years of price surges. The OECD-FAO 10-year projections prepared in 2009 that do account for developments in the years of price surges conclude that prices significantly above those of the pre-surge years may prevail in the future, at least for the next 10 years. We shall re-visit the issue of price prospects when examining (in the next two sections) what the EM papers have to say on possible effects on prices and demand-supply balances of climate change and biofuels.

3. CLIMATE CHANGE IMPACTS

3.1. Introduction

Of the EM papers with quantitative projections, the one by IIASA (Fischer, 2009) explores the issue of climate change impacts on agriculture in most detail. The IFPRI paper (Msangi and Rosegrant, 2009) also addresses the issue but in less detail and their findings were provisional at the time of the EM meeting. The IFPRI have subsequently (October, 2009) published a report (Nelson *et al*, 2009) which appears to be a re-make of their EM paper. It focuses specifically on climate change impacts and presents revised results for both the baseline scenario and for scenarios incorporating climate change effects. In what follows I will utilize material from both IFPRI papers, since we are interested not only in what the EM papers contained but also, as far as possible, in what are the latest views of the authors. Finally, the World Bank paper (van der Mensbrugghe *et al*, 2009 and personal communication from the authors) addresses the issue of climate change and agriculture but only for the sector as a whole rather than in terms of commodities, yields, etc.

In what follows I review and compare key findings of, mainly, the IIASA and IFPRI analyses. Their conclusions about climate change impacts are so disparate that one despairs of forming any firm opinion about what climate change may imply for agriculture and food security. The differences are not primarily due to the uncertainties (which are many) of what climate changes are in store. They persist even after controlling for such uncertainties. It is worth, therefore, starting with stating my understanding (but I stand to be corrected) of 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 future rate and pattern of socioeconomic development, demographics, energy use, etc (development pathways in IPCC terminology) for the globe,
2. Use one or more climate models (General Circulation Models – GCMs) to translate these GHG concentrations into deviations of key climate variables of relevance to agriculture, e.g. temperature, precipitation, etc, from those assumed to exist in 2050 in the baseline scenario (usually present conditions, though this may well be an impossibility),
3. Superimpose these deviations in climate variables on data and models of biophysical nature (e.g. agroecological attributes, crop growth models, etc) which portray how resource characteristics (e.g. length of growing periods, soil moisture, incidence of pests/diseases, etc) may be altered and how plants may respond to the changed conditions. Resulting estimates refer to the impact of CC on the potential productive capacity of the resources, not on projected production. The latter can only be determined in the context of economic models accounting for other factors conditioning the evolution of demand and supply, e.g. population, incomes, etc. This is the task of the next step.
4. Derive from this interface information to modify the way the model of agriculture or the whole economic system (used to project production, consumption, trade, prices, etc) recognizes the underlying altered biophysical base of the sector. This should include revised estimates of land/water constraints and assumptions of alternative paths to adaptation, i.e.

how people may respond, by changing crop calendars, introducing crop varieties better suited to the altered climate, etc.

I guess that steps 1 and 2 need not be an integral part of the agricultural modeler's tasks: the changes in the climate variables necessary for estimating impacts can be taken from the work of others specializing in GCMs. But caution is required: the socioeconomic pathway which generates the GHGs that will affect the climate (e.g. the pathway's GDP and population growth assumptions) must not be too different from that 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 tantamount to assuming present GHG concentrations remain constant (correct?). But could such a situation exist? Even ignoring the possibility that, because of time lags, climate variables can continue to change even if present GHGs concentrations did not change, there is no possible development and demographic path that will not increase GHG concentrations: all the debate is by how much emissions could be reduced; there is no option of reducing them to zero. GHG concentrations will increase anyway and with it climate: what is the point of estimating a scenario with present climate which, by definition, cannot exist? This is a point worth keeping in mind when we undertake work for estimating future impacts of climate change (more on this later).

Step 3 requires that the modeler have access to, and can manipulate, fairly detailed data of biophysical nature depicting the attributes of land resources and the physiology of crops in relation to climate variables. For this purpose, the IIASA use the Global Agroecological Zones study (GAEZ)[11] of IIASA and FAO. IFPRI use "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, p.1).

Step 4 is the crucial one: how the findings of step 3 are used to modify the characteristics of the agriculture model (constraints, coefficients, parameters or whatever) used in the baseline in order to run scenarios incorporating climate change impacts. The papers do not provide sufficient information how such modification is done. However, one can speculate that one way of doing it is by modifying the values of some of the exogenous variables of the model, most likely intercepts and/or the assumed rates of productivity growth. IFPRI's model (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". The phrase "links to the DSSAT" indicates that influences from climate change to these exogenous variables may be transmitted through some formal mechanism, but I do not know if my hunch is

[11] "The agro-ecological zones method takes as input a climate scenario and estimates on a spatial grid of 5' by 5' latitude/longitude the likely agronomic impacts of climate change and identifies adaptation options" ….. "The evaluation of the potential impacts of climate change on production and trade of agricultural commodities, in particular on cereals, was carried out in two steps. First, simulations were undertaken where current climate and atmospheric conditions would prevail. Second, yield impacts due to temperature and CO2 changes, as derived from the agro-ecological assessment, were simulated with the world food system model and compared to the respective outcomes without climate change" (Fischer, 2009). See also Fischer *et al* (2005).

correct. Similar observations may apply to the model of IIASA[12], though one would need to delve in depth into the internals of the models to be sure.

We now proceed to examine what climate change effects are projected by the different models.

3.2. World Bank

The results of the Bank's baseline scenario are inclusive of climate change (CC) effects, but only for agriculture[13]. As noted, projections of agricultural variables reported in the paper are limited to essentially a projection of the price Index of total agriculture to 2030 (not 2050) - see Section 2, above. In the model, CC influences agriculture by lowering the growth rate of agricultural productivity assumed exogenously to be, in the case of no CC, 2.1% p.a. (I presume this is a world average figure). The extent to which climate change affects this growth rate has been derived from Cline's work (Cline, 2007), but assuming that the 2.5^{o} temperature increase is reached in 2050, rather than in 2080 as in Cline's work[14]. The impact on the rate of productivity growth is the average of the Cline's scenarios with- and without carbon fertilization (CO2Fert.) effects. In the scenario, temperature rises by 1.7^{o} in 2030 and it translates in the rate of productivity growth being reduced in the baseline from 2.1% p.a. to 1.76% p.a. over the projection period 2005-30.

The result is that the price index of agriculture is projected in the baseline, i.e. after the productivity-reducing impact of climate change, to be a little below that of their base year 2005. As noted (Fig. 2.3), this translates into 2030 prices nearly equal to those of the pre-surge period (average 2003/05) and well below those reached in the surge years (average 2006/08). There is no scenario without CC (but see below, section 3.7.4); therefore we cannot compare price outcomes with- and without CC. However, if the with-CC scenario generates such a benign path of prices, it is reasonable to assume that without the damages of climate change (reduction of assumed rate of agricultural productivity growth) projected prices would be even lower, at least up to 2030. This is an interesting finding which, if confirmed after further scrutiny, is in sharp contrast to the predictions of other analyses (particularly those of IFPRI, see below) that suggest a much more important role for climate change in creating scarcities and rising prices

3.3. IIASA

The IIASA paper estimates a number of scenarios with effects of climate change on the agricultural variables they project. To start with, they assume that climate change is driven by the

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[12] "*Linkage of AEZ Results with BLS:* Results of AEZ agricultural production potential assessments, under various climate change/CO2 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, p. 22).

[13] "The model also couples changes in global temperature to economic damages. Currently, damages are only incurred in agriculture through impacts on agricultural productivity" (van der Mensbrugghe *et al*, 2009).

[14] "our estimates of the impacts from climate change on agriculture occur much earlier than assumed in the Cline study as the 2.5 ^{0}C level is reached in 2050 and not in 2080" …."For the purposes of the baseline scenario, the damages have been assumed to be the average of the with- and without carbon fertilization effect" (van der Mensbrugghe *et al*, 2009). Note that Cline's estimates refer to climate change effects on "agricultural capacity" in the 2080s, not on projected production.

greenhouse gas (GHG) emissions generated by the socio-economic development/demography path of the IPCC scenario SRESA2[15]. This scenario implies that GHG concentrations in the atmosphere rise from current 354 ppm to 536 ppm in 2050 IPCC (2007a, Table 1)[16]. These projected concentrations are combined with the GCMs of the Hadley Centre and the CSIRO[17] to generate the projected climate changes in terms of temperature, precipitation, etc. The resulting CC scenarios are termed HadleyA2 and CSIROA2. As noted, these changes in temperature, etc are defined for each individual grid point of the GAEZ and the implied changes in the bio-physical base of the analysis are derived[18].

Estimates of impacts on potential production are derived. For example, the potential rainfed wheat production on presently cultivated land is reduced (from what it would have been without CC) from 5% to 11%, depending on whether CO2Fert and adaptation are taken into account (Fischer, 2009, Table 4.1). For maize, the changes range from +2% to +9%, i.e. CC increases rather than reduces potential production of maize. For all cereals together the changes range from -5% to +3.0%. As noted, the differences among scenarios reflect, in addition to differences in changes in the climate variables between Hadley and CSIRO, (a) the presence or absence of CO2Fert and (b) the extent to which farmers adapt[19]. Restriction of adaptation options through resort to presently existing varieties is justified when one estimates changes in production potentials as if climate change were occurring today. However, when one estimates future impacts of climate change adaptation should include the option that novel varieties that can better withstand the new climatic stresses (not presently existing but perhaps in the research pipeline), may be developed in the future. This is a rather important issue when one considers the options for responding to climate change, e.g. what is the optimal combination of actions aimed at mitigation (slowing down the rate of GHG accumulation in the atmosphere) and adaptation (e.g. investing in research to develop heat- and drought tolerant varieties).

The above impacts refer to changes in production potentials (results of step 3 above), not to the changes in projected quantities relative to those of the baseline. The latter assumed no climate change and had projected world cereals production of 3.4 billion tons in 2050 (Fig. 2.5). According to the IIASA analyses, CC would have only a minimal impact on this projection of global quantities, lowering it by from 0.2% (HadleyA2 with CO2Fert) to 1.4% (HadleyA2 without CO2Fert – Fischer, 2009, Table 5.2). Effects on projected cereal prices would also be small, ranging from -1% to, at worst, +10%, the latter under the HadleyA2 scenario without CO2Fert. These projected changes must be seen in context: as noted (Fig. 2.4), cereals prices in

[15] SRES= Special Report on Emissions Scenarios of the IPCC

[16] A more recent IPCC report says “Atmospheric CO2 concentrations were 379ppm in 2005. The best estimate of total CO2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO2-eq.” (IPCC, 2007b, p.67)

[17] Hadley: Hadley Centre for Climate Prediction and Research, UK; CSIRO: Commonwealth Scientific and Industrial Research Organization, Australia

[18] The paper gives only implications for the impacts on the potential production of rainfed agriculture for any particular crop and then only for the land presently in cultivation. It does not give estimates of the implications for irrigation and for total land, whether presently in cultivation or not.

[19] *With adaptation*: “best adapted plant types, e.g. available elsewhere and adapted to higher temperatures, would be available to maximize production potential”; No *adaptation:* “assumes that farmer’s would be able to change cropping dates and crop types but would be limited to local crop varieties, i.e. crop varieties with temperature characteristics and moisture requirements of LUT’s used in current climate” (Fischer, 2009).

2050 were projected in the baseline to be 31% above those of the pre-surge levels (see also Fig. 3.1 below).

3.4. IFPRI's EM paper

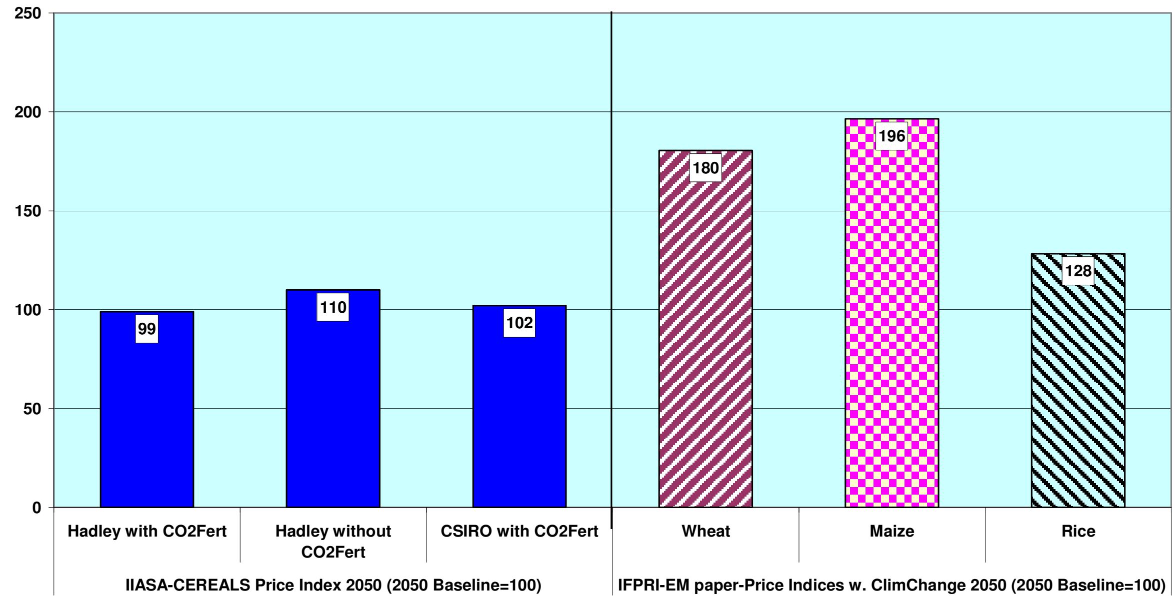
The IFPRI paper for the EM makes several references to CC scenarios and impacts on food and agriculture. Apparently, the report draws on work in progress and reported findings are provisional[20]. They use the same SRESA2 scenario as used by IIASA as the underlying socioeconomic development path and associated emissions that will determine the GHG concentrations in the atmosphere. However, they do not elaborate on the GCM used to translate these GHG concentrations into values of the climatic variables (temperature, precipitation, etc) that will impact agricultural production conditions and lead to the projected deviations from the baseline in production, prices, consumption, etc. In the more recent report (Nelson *et al*, 2009), IFPRI provides more complete information on the CC scenarios and impacts on food and agriculture. Therefore, rather than trying to explain what the EM paper says on CC impacts, it is best that we examine the more recent paper (see below).

Before doing so, however, it is worth noting that the IFPRI EM paper depicts a food and agriculture system in 2050 that is much more stressed because of CC than what the WB and IIASA findings suggest. Thus, maize prices are projected to be in 2050, because of CC, almost twice as high as in the Baseline (which assumed no CC), wheat prices 80% higher and rice prices 28% higher. These are potentially catastrophic outcomes, particularly because the reduced production potentials underlying these price rises are predominantly concentrated in the food-insecure areas of the world. Perhaps they reflect in part the assumption of no adaptation response and inadequate accounting for CO2Fert effects[21]. Still, the contrast with the findings of IIASA (shown in Fig. 3.1 below) is so stark that some significant differences in the fundamentals must be responsible, probably the depiction of land suitability changes and how crops respond to changes in temperature, rainfall, etc.

[20] "We must also report, at this juncture, that the methodology that we have used to account for climate change "shocks" within our modeling framework is still under revision and is subject to change in the near future".(Msangi and Rosegrant, 2009)

[21] "adaptive actions are not, actually, embedded in our results, as the endogenous technology choices of agents is not fully represented in our model. These types of adaptations and technology choices would have to be introduced by scenario, in order to account for the possibility of improved seed variety and other adaptive on-farm improvements, which are not endogenous within our framework" ….. "We have also not fully attributed the possible effects that carbon fertilization could have on future crop yields, due to the uncertainty that still exists in trying to quantify this result for various agronomic zones, where on-the-ground reality could differ significantly from carbon fertilization experiments in the laboratory". (Msangi and Rosegrant, 2009)

Fig. 3.1 Cereal Prices in 2050: Climate Change Scenarios, IIASA & IFPRI EM paper
(2050 Baselines=100)



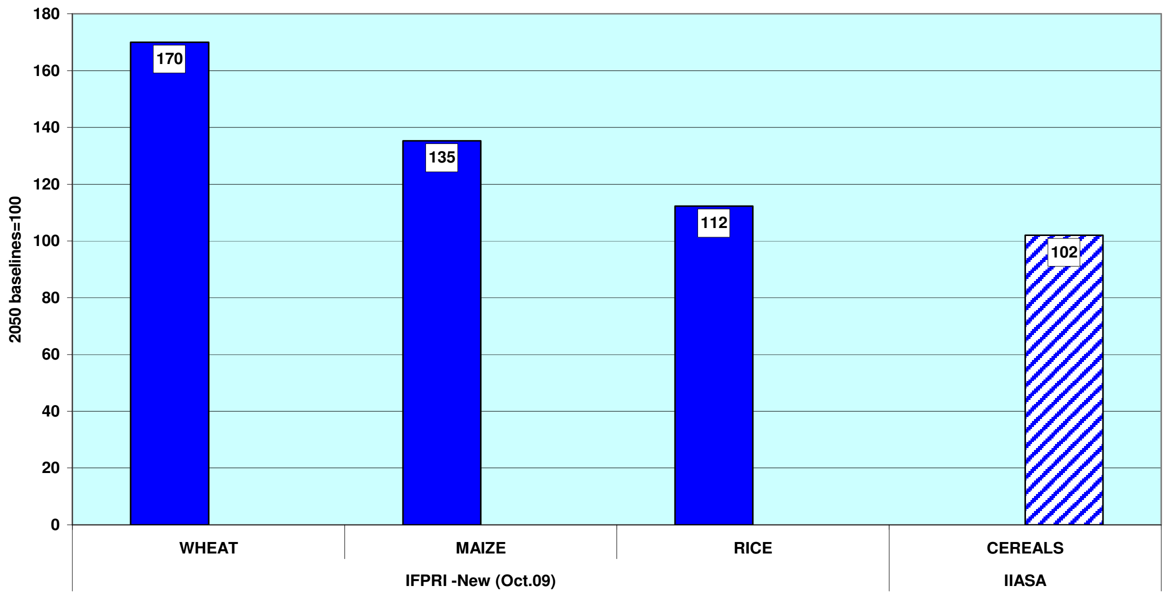
3.5. IFPRI's New Report

In this report, the CC scenarios are always based, for the underlying socio-economic developments and associated GHG emissions and concentrations in the atmosphere, on the IPCC SRESA2 scenario. The SRESA2 is combined with GCMs from NCAR[22] and CSIRO to derive the changes in the climate variables that affect production potentials. Interestingly, they have a scenario CSIRO with CO2Fert, so the results can be compared with those of IIASA for the same scenario. Figure 3.2 shows these comparisons. Again, the impacts of CC projected by IFPRI are way above those of IIASA. We noted that in the EM IFPRI paper the CO2Fert and adaptation effects were not, or inadequately, accounted for and suggested that this might explain a part of the large differences of CC impacts on projected prices between IIASA and IFPRI. The new IFPRI results now account (in the CSIRO scenario of Fig. 3.2) for CO2Fert effects and for "autonomous adaptation as farmers respond to changing prices with changes in crop mix and input use" (Nelson *et al*, p.6)[23]. But the estimated price impacts of CC continue to be large, though somewhat smaller than those in the EM paper: wheat prices are projected to be 70% higher than in the baseline (rather than the 80% of the EM paper), maize 35% rather than 96%, rice 12% rather than 28%. However, for wheat and maize this is largely the result of revised baseline projections: the new Report has higher projected 2050 baseline prices than the EM

[22] NCAR: National Center for Atmospheric Research, USA.
[23] This sounds similar to the adaptation concept used by IIASA, but I cannot be sure. As noted, IIASA speaks of farmers shifting to crop types (including those from outside their local environment) better able to withstand the new climatic stresses. IFPRI speaks of farmers adapting their crop mix and input use in response to changing prices.

paper (Fig. 2.4, above)[24]. Again, we must conclude that some structural fundamentals differ widely in the approaches of IFPRI and IIASA. One of them may be the fact that for IFPRI the most severe declines in potential yields occur in irrigated wheat and rice. As noted, IIASA reports effects only for rainfed production potentials. It does not report if and how effects on potential production from irrigated crops are accounted for.

Fig. 3.2 Cereals Price Effects of Climate Change 2050: IFPRI Oct09 vs. IIASA (both for CSIRO w. CO2Fert) (2050 baselines=100)



3.6. Climate Change Impacts differ widely among Regions

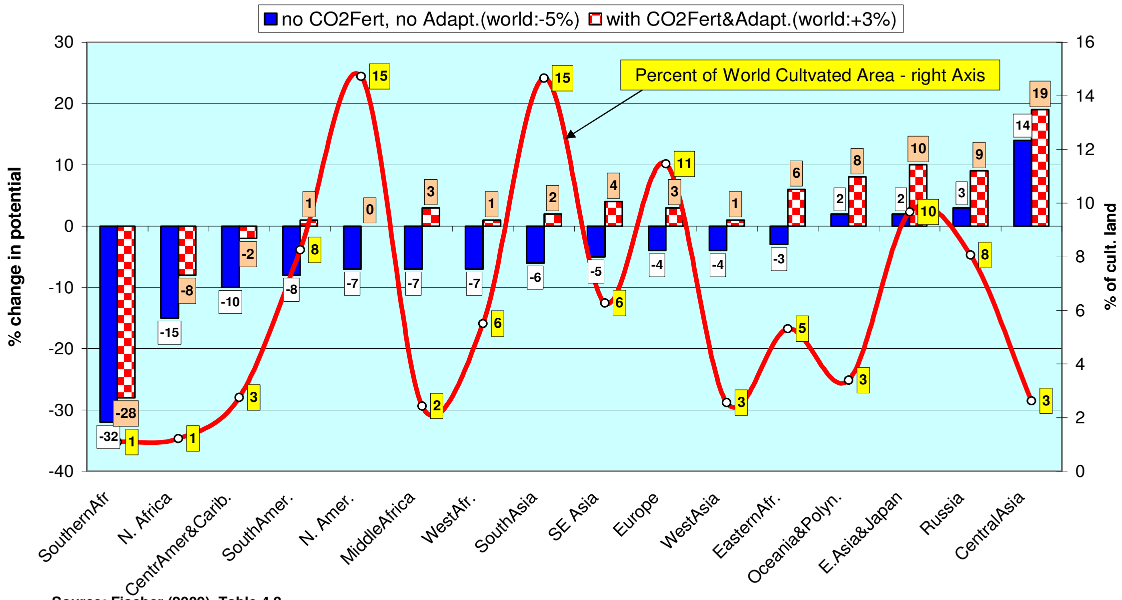
The preceding discussion focused on the findings of the on global impacts of CC, e.g. world production potentials and world market prices and production/consumption outcomes. However, when it comes to evaluating CC impact, particularly on food security rather than production alone, the devil is in the detail. It is well known from the literature on climate change that impacts can differ widely among latitudes, regions, countries and agroecological zones. Outcomes for the world as a whole are made up of pluses and minuses for different regions, countries and country groups. If the minuses occur predominantly in countries with food security problems currently, even a small impact of climate change on global production can easily translate into a large impact on food security. Increased production potentials in the parts of the world benefiting from CC are not necessarily available to make up losses suffered in other parts. Food security problems are predominantly local and will remain so for a long time to come even in a world with increased production potential as a result of CC.

3.6.1 IIASA EM Paper – Regional Effects

[24]Projected 2050 baseline prices were in the EM paper \$/ton 132 (wheat), 100 (maize) and 305 (rice). The revised ones used in the new Report are \$/ton 158, 155 and 307, respectively (all in \$ of 2000)

We noted that the IIASA findings, but also those of the World Bank, indicate only small global impacts on agriculture from Climate Change, at least up to 2050. A first glimpse of disaggregated outcomes can be seen in IIASA's estimates of impacts on the rainfed cereals production potentials in the 2050s of presently cultivated land of the different countries/groups distinguished in the analysis. They are shown in Fig. 3.3 for the scenario combining GHGs from SRESA2 and change in climate variables from Hadley. Without CO2Fert and adaptation the global potential suffers a decline of 5% and most countries/groups are losers. The two most food-insecure regions, sub-Saharan Africa and South Asia suffer declines of 7% and 6%, respectively, with a peak of -32% in Southern Africa. With CO2Fert and adaptation there is a net gain of 3% globally and most countries/groups turn around to be net gainers, including sub-Saharan Africa and South Asia (1% and 2%, respectively; Fischer, 2009, Table 4.3). Such gains disappear in later decades, but do not turn negative globally (Table 4.4 showing results into the 2080s). Of course, full gains from CO2Fert and adaptation (the latter as defined above) are uncertain, so the outcome could be less rosy than it appears. Moreover, these estimates refer to cereals production potentials and only on rainfed land currently cultivated, not production projected by the economic model (see below).

Fig. 3.3 IIASA EM Paper: Percent Changes in Rainfed Cereals Production Potential of presently cultivated land from Climate Change under SRESA2 GHG and Hadley GCM, 2050s



Source: Fischer (2009), Table 4.3

The possibility of a net gain in the production potentials at the world level, at least for rainfed cereals, raises the interesting and provocative question whether the world could be better-off globally with CC (plus CO2Fert and adaptation) than without, at least from the standpoint of agricultural potentials. In theory, gainers could compensate losers and still leave a net gain. In practice these things do not happen in the real world. Losers in production potential could only gain if the improvement in the global potential could be translated into increases in their consumption. This is not happening in the IIASA analyses. When the above mentioned 3% gain in the global *production potential* is introduced into IIASA's economic model, *projected world cereals production and consumption* are not higher, but actually marginally lower in 2050 than in the baseline (Fischer, 2009, Tables 5.2, 5.3). 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 its cereals production capacity could increase by 1% under this scenario (HadleyA2 with CO2Fert and adaptation). A stronger negative impact is projected for the other food-insecure region South- and S.E. Asia (combined in Fischer, 2009, Tables 5.2, 5.3)[25]: production -3.7%, consumption -1.0%.

3.6.2 IFPRI (new report of Oct. 09) - Regional Effects

We noted earlier that, unlike the IIASA and the World Bank, IFPRI has very substantial negative effects of climate change on projected production in 2050 – near catastrophic ones for some regions (they only give effects on projected production, not on potentials). For example, in their region "Europe and Central Asia" (I think Europe stands for Eastern Europe, does not include Western Europe) projected production is lower than in the baseline by up to 51% for wheat and 38% for maize[26]. It is at least curious, and certainly worth further investigation, that this region includes the areas (Russia and Central Asia of IIASA) which, in the IIASA estimates, benefit the most from climate change, by +3% and +14%, respectively in terms of rainfed cereals production potential on current cultivated land (IIASA scenario Hadley without CO2Fert but with adaptation, Fischer, 2009, Table 4.3).

The IFPRI findings for the two most food-insecure regions are likewise dire: "The negative effects of climate change on crop production are especially pronounced in Sub-Saharan Africa and South Asia. In South Asia, the climate scenario results in a 14-percent decline in rice production relative to the no–climate-change scenario, a 44- to 49-percent decline in wheat production, and a 9- to 19-percent fall in maize production. In Sub-Saharan Africa, the rice, wheat, and maize yield declines with climate change are 15 percent, 34 percent, and 10 percent, respectively" (Nelson *et al*, p.6 and Table 3). In the end, for both regions, but not only[27], the modest gains in per capita food availability (Kcal/person/day) projected in the baseline are more than reversed in the scenarios with climate change (Fig. 3.4): they are projected to have lower Kcal/person/day not only in relation to the baseline projection but also lower than what they started with in 2000, a really catastrophic impact of climate change, given that in 2000 they had very low Kcal/person/day: sub-Saharan Africa 2128 and South Asia 2334 (Alexandratos, 2009).

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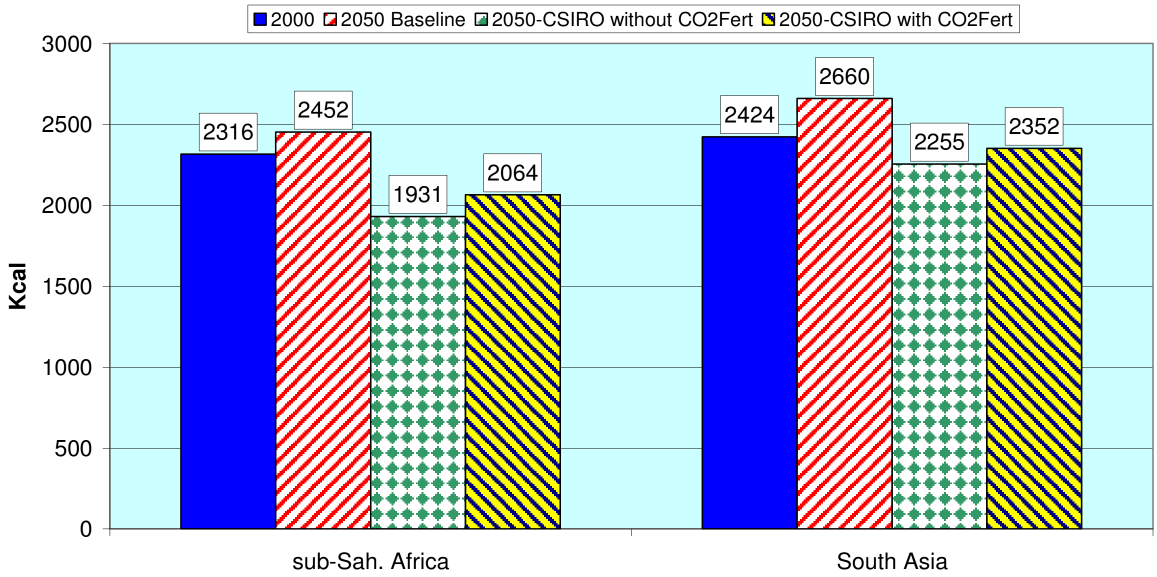
[25] Impacts on rainfed production potentials (Fischer, 2009, Table 4.2) are given in greater detail (by country/country groups) than the economic model projections (Tables 5.2, 5.3). Therefore, we cannot really understand fully how changes in potentials are related to changes in projected production and consumption. It is recalled that the evaluation of impacts on production potentials refers only to rainfed production on presently cultivated land. Therefore, there need not be a close relationship between such potentials and the production projected by the economic model. In the latter, production comes also from irrigated land (of particular importance for South Asia) and from expansion into presently uncultivated land (of importance to sub-Saharan Africa).

[26] These findings refer to the IFPRI NCAR and CSIRO scenarios without CO2Fert but with adaptation, as defined earlier (no results are given for production impacts with CO2Fert).

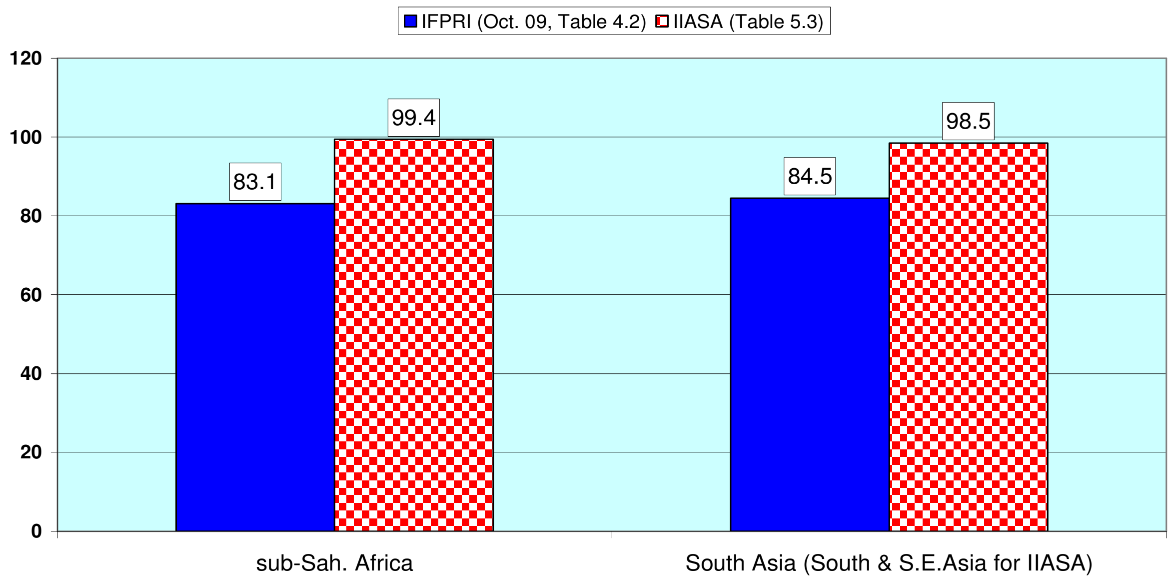
[27] "Calorie availability in 2050 will not only be lower than in the no–climate-change scenario—it will actually decline relative to 2000 levels throughout the developing world" (Nelson *et al*, 2009, p. vii and Fig. 5).

Fig. 3.4 IFPRI (Oct.09): Kcal/person/day, 2000 and 2050 with Clim. Change from CSIRO



Source: Nelson et al (2009, Table 5)

Fig. 3.5. Impact of Climate Change on Cereals Consumption 2050 (GHGs from SRESA2; ClimChange from CSIRO w. CO2Fert) Baselines 2050=100



IFPRI: cereals food consumption; IIASA: all uses. Non-food use of cereals is small in both regions, so the difference in definitions should not unduly distort comparisons.

The IIASA projections are far less pessimistic. The only comparison that can be made between the IIASA and IFPRI is for the impacts on cereals consumption under the scenario CSIRO with CO2Fert. They are shown in Fig. 3.5 for sub-Saharan Africa and South Asia (South & S.E. Asia for IIASA). It is seen that in the IIASA estimates the impacts are minimal (decline of only 0.6% in sub-Saharan Africa from the baseline projection for 2050) but very large in those of IFPRI (-16.9%).

3.7. Some Conclusions

3.7.1 Need to better understand why CC impact evaluations are so different

The large differences among models suggest that, as far as global CC impacts on agriculture are concerned, a lot more work is needed before we form well grounded views on the significance of CC for agriculture and food security. Impacts on the food consumption of the most food-insecure regions, hence also of the world, are either very small (IIASA) or catastrophic (IFPRI), at least up to 2050. As noted earlier, the reasons for these differences may lie in any combination of the features (data, coefficients, exogenous assumptions, etc) embodied in the data bases and the models used to represent the real world conditions. The differences in the representation of the biophysical environments, e.g. the grid resolution used to depict the resource base, how the characteristics of the resource base (soil fertility, etc) are defined, how crop growth models are specified and how any given change in climate variables (precipitation, temperature, etc) may modify them, could all play a role in explaining why results are so different. All these changes affect production potentials which are then used as inputs into the economic models and play a key role in the projections of production, consumption, prices, etc[28]. All the more reason for anyone interested in CC effects on agriculture and food security to want to better understand how climate changes are translated into changes in the production potentials when superimposed on the data depicting the resource base and the crop growth models and how these findings are made to influence the projections of the economic models.

We can get an idea of the relative importance of the biophysical vs. the economic models in determining the differences from Easterling *et al* (2007, Table 5.6). They present projected climate change impacts from the application of the same economic model (of IIASA) to two biophysical data sets (or crop-modelling systems): an application by Fischer using the GAEZ and one by Parry using the DSSAT (the one used by IFPRI). Impacts are only given for the projected numbers of people "at risk of hunger" (another way of saying "numbers undernourished" which presupposes the projection of per capita food consumption) under alternative SRES scenarios and the Hadley climate (GCM) model with CO2Fert. The impacts on the numbers "at risk of hunger" (hence on per capita food consumption) 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 IIASA and IFPRI are more likely to be found in differences in the economic models rather than in the crop-modelling systems. However, we cannot be sure until we know more about both the economic and biophysical models. Regarding the latter, it is noted that much of the declines in yield potentials in the IFPRI analysis occur in irrigated wheat and rice, for which IIASA reports no specific information.

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[28] As a 2002 IIASA report puts it: "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*" (my italics, Fischer, Shah and van Velthuizen, 2002, p. 108).

3.7.2 Probable bias in the comparisons of projections with- and without climate change

Both IFPRI and IIASA estimate CC impacts on agriculture by assuming the changes in the climate variables (temperature, precipitation, etc) originate in, or are related to, the emissions and GHG concentrations generated by the development pathway of the IPCC SRESA2 scenario. As note, this scenario leads to GHG concentrations rising from the current 354 ppm to 536 ppm in 2050. The impacts on agriculture are then compared with those of the baseline (which assumes present climate prevails in the future) in order to draw inferences about what difference CC makes. However, the SRESA2 GHG concentrations are generated by, *inter alia*, the scenario's projected world population of 11.3 billion in 2050[29] which is much higher than the 9.1 billion used in the IIASA and the IFPRI baselines. This implies comparing climate impacts originating in the GHG concentrations of 536 ppm in 2050 with a baseline which, because of its lower projected population, would generate smaller GHG concentrations, under 500 ppm[30]. Therefore, the comparison of the baseline with the CC effects of SRESA2 is bound to overstate the impact of climate change: if the baseline (without CC) had been estimated with the higher projected population of 11.3 b., demand and prices would have resulted as higher than the ones of the actual baseline with the 9.1 b. population. How much higher?

Baseline with high population: We can obtain an idea from the 2002 IIASA report which has estimates for a baseline scenario (without CC effects) with 2050 population of 11.1 b., close enough to that of SRESA2 (Fischer, Shah and van Velthuizen, 2002, Table 4.1). It projects 2050 cereals demand of 3.76 billion tons (their Table 4.3), i.e. higher than the 3.4 billion tons in the EM paper's baseline. Projected prices are also higher: the cereals price index rises to 184 in 2050 (their Table 4.7), rather than to 123 in the EM paper (1990=100 in both cases). This baseline can be compared with a *scenario with climate change effects using the same high population.* It is available in the same 2002 IIASA report (Table 4.10), but estimates of CC impacts on prices only for 2080, not 2050. The 2080 cereals price index with CC effects is 14.4% higher than that of the baseline without CC effects. This is lower than the 23% shown in the EM paper (also for 2080) where the difference is measured from the baseline with projected population of 9.1 b. in 2050 (Fischer, 2009, Table 5.1). In both cases, the CC effects are those of the Hadley GCM with CO2Fert. Ergo, the above discussion illustrates that CC effects on agriculture are probably overstated in both the IIASA and IFPRI papers because they are estimated by comparing effects generated from GHG concentrations associated with a higher projected population than that used in the baselines without climate change.

In conclusion, it would have been more appropriate for the EM papers to have estimated CC effects from GHG concentrations originating in a scenario based on assumptions similar to those of the baseline, e.g. the SRESB2. We can expect that CC effects on agriculture of the lower

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[29] The following identity is commonly used to convey the relationship: Impact = Population × Affluence × Technology (see Nakicenovic and Swart, 2000, Ch. 3). SRESA2 assumes high population growth and slow technological change: both will tend to magnify the climate impact.

[30] There is an IPCC scenario with 2050 population of 9.4 billion (scenario SRESB2): it generates GHG concentrations of 478 ppm (IPCC, 2007a, Table 1) Naturally, the lower GHG concentrations of SRESB2 are due not only to the lower projected population but also to differences in other scenario variables, e.g. developments in the energy efficiency and carbon intensity of growth, more equitable development, more environment conscious policy context, etc (See scenario storylines in Nakicenovic and Swart, 2000, Ch. 4)

GHG concentrations would be smaller than those of SRESA2. This is indeed the case, to judge from the 2002 IIASA report which gives estimates of CC impacts also for the SRESB2 scenario (Table 4.10): the CC impact on 2080 cereals prices is indeed minimal (2.2% higher than the baseline).

Recapitulating (for the IIASA estimates):

- with 2050 population of 9.1 billion of the baseline and GHG 536 ppm (originating from the 11.3 b. population of scenario SRESA2), 2080 prices with CC are 23% higher than the baseline (without CC); and
- with 2050 population of 9.4 b. and GHG 478 ppm (originating from the same 9.4 b. population of scenario SRESB2), 2080 prices with CC are only 2.2% higher than the baseline (without CC).

Hence, the upward bias of the CC effects in the IIASA EM paper. *Mutatis mutandis*, the same comment should apply to the paper of IFPRI.

3.7.3 Climate Change Impacts on Agriculture vs. Impacts on Food Security

The analyses presented above measure effects on food security via the impacts of climate change on production agriculture: they first identify the CC impacts on *potential production*; then they input these changed potentials into the economic models in order to solve for impacts of CC on *projected production* and consumption. If the changes in food consumption depended only on changes in the production potentials resulting from CC we could stop here and then investigate how changes in projected consumption translate into changes in food security, most commonly measured in terms of the numbers undernourished derived as function of per capita food consumption.

However, climate change may affect food consumption and food security via channels other than the mere effects on production potentials and the associated effects on projected prices and consumption.

- In the first place, the CC effects on production have implications for incomes generated in the sector and the wider economy. Incomes and poverty, hence also consumption and food security, will be affected by climate change via this feedback link. This is particularly important for the countries in which agriculture accounts for a significant share of GDP and employment, precisely most countries with food security problems. Depending on the economic model used, such feedback effects are accounted for in the projection results (general equilibrium - GE - models) or they are not (partial equilibrium models). IIASA's economic model is said to be GE (Fischer, 2009, p. 3). In theory, the IIASA projection results should be inclusive of feedback effects. The same applies to the agricultural price projections of the World Bank. IFPRI's IMPACT model is said to be a "partial-equilibrium modeling framework" (Msangi and Rosegrant, 2009) and the consumption projections probably do not account for feedback effects. If they did, projected consumption would have been lower than reported (Fig. 3.4, above), which would further widen the disparities between the IIASA and IFPRI findings.

- Secondly, climate change affects economic growth, incomes, poverty and food security via channels other than the impacts on production agriculture. Sea level rise, population dislocations, destruction of infrastructures, natural catastrophes from extreme events, impacts on biodiversity and growing incidence of disease would all affect the rate and pattern of development, in particular the rate at which poverty may be reduced[31]. They are particularly relevant for the poverty reduction prospects of the developing countries, hence of their food security. Many are located in low latitudes with temperatures close to thresholds beyond which even small increases can have big effects (Cline, 2007, p. 41); they are not well equipped to respond; and their high dependence on agriculture and natural resources enhances their vulnerability. According to the *World Bank Development Report 2010*: "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, p. XX, also p. 6, Box 1).

The preceding discussion suggests that projections of consumption/food security outcomes "with climate change" should account not only for CC change effects via changes in production potentials but also for the lower GDP growth associated with the broader CC impacts. We noted that GE models may account for effects on GDP growth via the changed agricultural production potentials. Do they account for climate damages from other CC-related causes? The WB model has the potential of doing so. As noted the GDP and poverty projections of the World Bank account for climate change damages but only for those operating via the lowering of the rate of agricultural productivity growth[32]. We can assume that when in a later update other damages will be internalized, the macroeconomic and poverty projections for the developing countries will be less optimistic.

I venture to say that the inclusion of climate change effects other than those on production agriculture would not make a big difference for large country aggregates since the agriculture-related damages represent the bulk of the adverse effects of climate change on growth and development in most developing countries. The World Bank projections in the EM paper are rather upbeat (Section 5, below): in the developing countries GDP growth is 5.2% p.a. from 2005-50 and the poverty rate (of the $1.25/day variety) falls from 21.9% in 2005 to 0.4% in 2050 (from 51.7% to 2.8% in sub-Saharan Africa and from 40.5% to zero in South Asia). In conclusion, according to this vision of the World Bank EM paper, climate change will perhaps slow down a little the path towards a more prosperous world with much less abject poverty compared with today. The slowdown cannot, however, be very significant, at least in this vision, given that the adverse impact of climate change via the effects on agricultural productivity are already accounted for in the income and poverty projections.

3.7.4 Climate Change and Food Security in the Context of Socio-economic Development

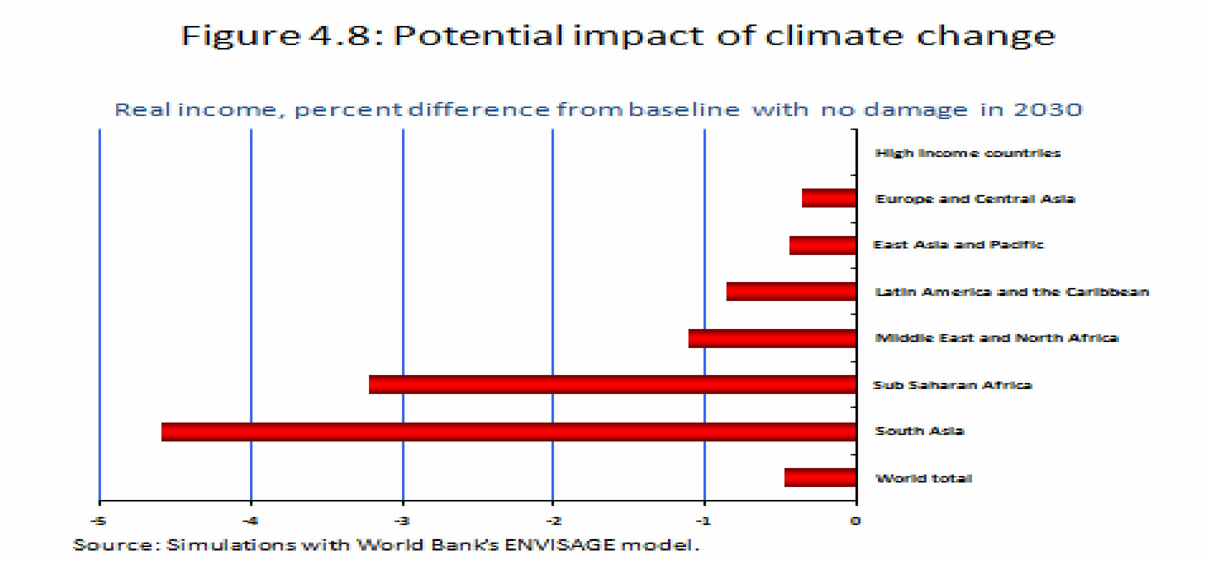
[31] On issues concerning total costs of climate change see Mendelsohn (2007), Weitzman (2007), Economist (2009)
[32] "The climate damages are built into the standard baseline", but "Currently, damages are only incurred in agriculture through impacts on agricultural productivity" (van der Mensbrugghe *et al*, 2009).

From the preceding discussion we seem to have two visions of world futures with climate change impacts.

- The first is one of a significantly more prosperous world in 2050 compared with today, with persistent but significantly reduced poverty and, by implication, less food insecurity. This is the vision of the World Bank EM paper which, as noted, incorporates into the income and poverty projections the impacts of climate change, at least those that affect the rate of development by reducing the growth of agricultural productivity. Interestingly, the authors have a graph (their Figure 4.8 – reproduced below) showing by how much incomes in 2030 would be lower than baseline because of climate change damages. There is some contradiction here since they also say that the baseline includes climate change effects on agriculture. Be that as it may, we note that in the two regions with the highest impacts, South Asia and sub-Saharan Africa, incomes in 2030 would be lower by some 4.5% and 3.5%, respectively. The authors do not report the GDP growth rates from 2005-30 by regions, but it is a safe guess to assume that all this implies that these two regions will lose one year's GDP increase in the 25-year period, a far from catastrophic outcome as concerns total GDP, though things would be far worse for particular population groups.
- The second one is of a world of falling per capita food consumption and growing food insecurity, as depicted by IFPRI's projections. This implies that if the climate change materializes the world in 2050 will be poorer than today (i.e. with falling real incomes per capita, as implied by the falling food consumption), a sharp contrast with the preceding vision. All this is projected to happen because of the sharp declines in crop yield potentials, assuming no corrective action is taken in the form of research investments to prevent the fall in yields, according to IFPRI. Implicit in this vision is very strong transmission from reduced agricultural production potential to depression in the overall economy. Since in the IFPRI projections the declines in food consumption are generalized throughout the developing regions (Nelson *et al*, 2009, Fig. 5, regions only, no country results given), no region is exempt from this predicament, whether agriculture-dependent, industrializing, emerging, or whatever. I leave it to the reader to judge whether this is a realistic depiction of world futures.

Which of the two visions, or any other in between, one subscribes to, will determine attitudes and policy positions vis-à-vis the issue of climate change. In the first vision, climate change impacts are to be modest (at least up to 2050) and will manifest themselves in the context of other factors driving socioeconomic development towards a more prosperous world with less dependence on agriculture than at present. This position is echoed in some of the works addressing issues of climate change, agriculture and food security, e.g. Easterling *et al* (2007: p. 298); Schmidhuber and Tubiello (2007). In this process of development the world will be strengthening its capabilities to take corrective action by means of policies for mitigation and adaptation and, eventually, compensate net losers from climate change impacts. Even in this optimistic outlook the risk of having net losers will remain: agriculture-dependent countries particularly hit by climate change or areas and even whole island economies at risk of being submerged by sea level rise.

Figure from van der Mensbrugghe et al (2009)



The second vision, of an impoverished world implied by IFPRI's projection of widespread declines in per capita food consumption if climate change effects in agriculture[33] (as estimated by IFPRI and assuming the decline in agricultural productivity has the devastating effects on the overall economies implied by the widespread declines in per capita food consumption projected by IFPRI) are permitted to manifest themselves in their full force, suggests that nothing less than massive immediate action for adaptation will prevent this predicament from coming true.

3.7.5 Lessons for FAO Work Integrating Climate Change into Long-Term Assessments?

FAO's long term assessments and projections have not so far addressed the issue of climate change. This is a lacuna that must be filled in future work. What have we learned from the discussion in this paper that could help us integrate climate change effects into our long-term projections? Here follow some preliminary views, all subject to revision and open to discussion:

- The new GAEZ will hopefully provide a better depiction, than we had in the past, of the *biophysical environment* to provide the basis for estimating effects of climate change on production potentials (land suitability classifications and corresponding achievable yields).
- How can the production potentials generated by GAEZ under various climate change scenarios be used in the economic models? So far we have been using them to define resource and yield growth constraints. Is there a more efficient way of using them?
- Definition of baseline *scenario without climate change*. We noted that assuming present climate will prevail in the future might not be a realistic approach. If, according to the *World Bank Development Report 2010,* a 2°C warming above pre-industrial temperatures is the minimum the world is likely to experience, then estimating a baseline

[33] As estimated by IFPRI and assuming the decline in agricultural productivity has the devastating effects on the overall economies implied by the widespread declines in projected per capita food consumption.

projection with present climate is not very useful and can be misleading: it will certainly not represent a likely outcome. Must keep in mind that one of the objectives of our work is to generate a depiction of the future as is likely to be.

- Definition of *scenarios with climate change*: we noted that in order to avoid distortions and ensure comparability of the with- and without climate change outcomes, a scenario 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 would have to be specified in terms of volumes of emissions and the associated GHG concentrations in the future. In turn, the latter could be related to assumptions about mitigation policies: for the baseline, the mitigation policies could be those underlying the above statement from the WDR2010 (assuming we can find out what they are); for the other scenarios, the GHG concentrations and consequent climate changes would have to be derived from alternative assumptions about mitigation policies (e.g. commitments to cut emissions by x%, etc).
- Finally, the *general equilibrium* aspect of the analysis: we noted that if climate change is to be a significant factor affecting agricultural potentials, it will also affect overall development prospects of the countries heavily dependent on agriculture. This means that, at least for these countries, the income growth rates used to project food demand cannot be maintained as immutable exogenous variables. Feedbacks from climate change via effects on agriculture must be brought to bear on the GDP growth assumptions.
- Anything more?

4. BIOFUELS

4.1 Introduction

The use of crops as feedstocks for biofuels has contributed to the energy market intruding into that of agricultural commodities. What happens in the former has an impact on the latter. Impacts can be both positive (e.g. a potentially greatly enlarged market for agricultural produce, eventually easing the treadmill curse of agriculture and benefiting those who can produce more) and negative, e.g. rising food prices adversely affecting the food security of poor consumers. The strength of the impact depends above all on developments in the energy markets (oil prices, etc) and policies promoting biofuels (subsidies, trade, blending mandates).

Of the EM papers, only that of IIASA (Fischer, 2009) has biofuels projections in some detail. The IFPRI paper has many references to biofuels. However, it only shows one projection of crops used for biofuels. This projection is an integral part of IFPRI's baseline scenario (see section on Prices, Fig. 2.5). As there is no variant of the baseline scenario without biofuels, it is not possible to tell what difference biofuels make to the projected levels of other variables, e.g. prices, per capita food consumption, etc., although the paper claims to have analyzed such impacts.

The World Bank paper underlines the importance of biofuels for developments in agricultural prices and for determining agricultural futures. However, the biofuels module of their model was not ready at the time of writing the paper. Therefore, whatever their baseline projections include in terms of agricultural variables (growth rate of productivity and prices of aggregate agriculture) does not account for impacts from any significant penetration of biofuels (personal communication from authors). The Hillebrand paper, although predominantly economy-wide and income distribution/poverty-oriented, does have some discussion of agricultural futures (Section 5, below). However, it is not known if they include biofuels effects, since the paper does not even refer to this issue.

Finally, FAO's long-term agricultural projections (Alexandratos, 2009) do not include provisions for biofuels use of crops[34] because the projections were prepared in 2003-05 from historical data up to 2001 when such use was not a major issue. However, it does show biofuels projections to 2018 from the more recent FAO work for the 2009 OECD-FAO Agricultural Outlook. In what follows, we concentrate on what the IIASA paper (and occasionally the one of IFPRI) has on biofuels.

4.2 IIASA Biofuels Scenarios

The IIASA paper (Fischer, 2009) has several scenarios of possible biofuels outcomes. As far as I can tell, much of it is based on IIASA's work for the OPEC/OFID (Fischer *et al*, 2009). The different scenarios are really variants around the reference scenario projection of *World Energy Outlook 2008* (WEO) of the International Energy Agency (IEA, 2008), as explained in Box 1.

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

Box 4.1 IIASA Biofuels Scenarios

There are five scenarios, as follows:

1. **Baseline Scenario**: Cereals use for biofuels is kept constant in all projection years at the level used in 2008 (83 million tons - mt). This level is assumed to have existed also in year 2000, when actual use was only 15-20 mt. So this is a problem if one wanted to compare projections with historical data[35].

In the other four scenarios, the basis is the Reference scenario projection of total demand for transport fuel of the above mentioned *World Energy Outlook 2008*: demand for transport fuel is projected to increase by 40% from 2006-30. The IIASA extends the projection to 2050, implying a further rise of 18% from 2030-50. From this WEO Scenario, the other IIASA scenarios are generated by assuming alternative rates of (a) achievement of the biofuels mandates (mandatory, voluntary or indicative) in the different countries, and (b) the progress made in 2nd generation biofuels (Tables 7.1 and 8.1 in Fischer, 2009).

2. **Scenario WEO-V1**: Same as the 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% in 2006 to 3.5%, 4.2% and 6.0% in 2020, 2030 and 2050, respectively (total transport fuel is 2830, 3171, and 3750 mtoe in the three years, respectively – Fischer, 2009, Table 6.1). 2nd generation biofuels have a slow start: they contribute 3% of total biofuels in 2020, 13% in 2030 and 30% in 2050. This scenario generates the lowest projection of cereals use for biofuels. I will use the term *Low-BF* scenario for easy reference in further discussions.
3. **Scenario WEO-V2**: Same as WEO-V1 but no second generation biofuels before 2030. Their share in total biofuels is still zero in 2030 and only 10% in 2050.
4. **Scenario TAR-V1**: Mandates are achieved in full by 2020. The authors assume that the rapid path of biofuel development continues in subsequent decades leading to biofuels consumption about twice as high as in WEO-V1. Shares of 2nd generation biofuels in total biofuels as in WEO-V1, leading to 2%, 12% and 26% in the three projection years, respectively (Fischer, 2009, p. 23). This scenario generates the highest projection of cereals use for biofuels. I will use the term *High-BF* scenario for easy reference in further discussions.
5. **Scenario TAR-V3**: Mandates are achieved in full by 2020 (as in scenario TAR-V1). Accelerated development of 2nd generation biofuels leading to shares in total biofuels of 22%, 38% and 55% in the three projection years, respectively.

4.3 Biofuels and the Cereals Projections

This is not the place to judge the plausibility and other aspects of the different scenarios in the context of energy markets (but see below re. assumptions of developments in oil price and policies having a bearing on mandates and other support measures). Rather, we are concerned with examining what the EM papers project for biofuels and what they see as consequences for

[35] There is some confusion as to which scenario is the baseline one, as far as biofuels are concerned. The paper says it has "a baseline projection without any use of agricultural feedstocks for biofuel production, as portrayed in scenario FAO-REF-00..." (p. 33). But then it presents in Table 3.3 cereals projections giving as source scenario FAO-REF-00, but saying in its title that the projections are from "Baseline simulation without considering climate change and biofuel *expansion*" (scenario FAO-REF-01). As it proved impossible to obtain clarification from the author and there is no cereals projection with zero biofuels, in the comparisons in this paper, I will use as the IIASA Baseline the scenario FAO-REF-01 which assumes cereals use for biofuels remains constant at the 2008 level of 83 mt.

production, consumption and prices of agricultural products. Concerning cereals, does their use for biofuels cause consumption for food and feed to be lower that it would have been without biofuels? We start by showing the projections of cereals use for biofuels, first for 2020 **-** in order to compare them with those for 2018 of the OECD-FAO Agricultural Outlook.

Fig. 4.1 shows the projections of IIASA and IFPRI (to 2020) and of OECD-FAO (to 2018), as well as the actual historical data. We note:

1. *The historical data*: cereals use for biofuels was 15-20 million tons (mt) in 99/01 (some 1% of aggregate world use) and had grown rapidly to 105 mt in 2008 (4.8% of world consumption of cereals – all historical data are from the OECD-FAO files). The OECD-FAO projections use these data in their starting years. The ones of IFPRI have the correct numbers for 2000. Those of IIASA, however, assume the use of cereals for biofuels in 2000 was 83 mt (not the real 15-20 mt), a level achieved only later (see discussion in the Section 2.5 regarding discrepancies between the actual historical data and those used for past years in the IFPRI and IIASA analyses)
2. The OECD-FAO projection to 2018 foresees further rapid growth in cereals-based ethanol production, though slower than in the recent past. It is driven mostly by policies (the USA Energy Independence and Security Act - EISA and the EU Renewable Energy Directive – RED). These two account for the great bulk of the projected cereals use for ethanol (80% and 15% of the 175 mt world total in 2018, respectively).
3. The IFPRI projects in its baseline scenario much lower use of cereals for biofuels in 2020, 75 mt which is less than actual quantities of 2008. It looks like this is coming from earlier work and does not account for the rapid expansion of cereals-based biofuels in recent years (their projection for 2008 is only 32 mt). They do, however, indicate that they estimated effects on prices, food consumption and malnutrition of alternative projections of biofuels, but they do not show the cereals quantities involved.
4. In the IIASA's five scenarios (see Box 4.1) cereals use for biofuels in 2020 ranges from 83 mt (Baseline) to 327 mt in the High-BF scenario (scenario TAR-V1). The latter has the highest of all projections because it assumes full achievement of the mandates/targets for biofuels and slow penetration of the 2nd generation biofuels: the bulk of ethanol production implied by the full implementation of mandates/targets comes from cereals and sugar cane. It is noted that the OECD-FAO projection for 2018 is similar to those of two IIASA scenarios for 2020. This probably reflects the reliance of both studies for these scenarios on the energy sector projections of the International Energy Agency (IEA, 2008).

Fig. 4.2 shows the IFPRI and IIASA projections for all years. It is seen that the use of cereals for biofuels nearly peaks in 2030 at 437 mt under the IIASA High-BF scenario (TAR-V1). There is little further growth after 2030. As noted, this scenario assumes full achievement of the mandates/targets for biofuels and slow penetration of the 2nd generation biofuels. The latter kick in after 2030 and this, I suppose, explains the little further growth of cereals use as feedstocks after 2030. Under this scenario, the share of world aggregate cereals consumption (all uses) going to biofuels rises from the actual 4% in 2006/08 to 11.6% in 2020 and to a peak of 13.9% in 2030 before falling back to 12.3% in 2050.

4.4 Impacts on cereal prices

The very rapid growth of cereals use for biofuels in recent years leading to 104 mt in 2008 is thought to have been the key factor on the demand side that caused the price surges (Alexandratos, 2008; Mitchell, 2008). What do the IIASA and IFPRI scenarios imply?

4.4.1 IIASA

The 437 mt for 2030 projected by the IIASA scenario with the fastest growth (TAR-V1) represents a fourfold increase over the 104 mt of 2008. This is substantial and it could be a significant factor in raising prices and reducing consumption of cereals for food and feed. True, the increase is not a sudden spurt in demand: it is spread over a 22 year period (2008-30, 6.4% p.a.), so price and other effects should be much weaker, *ceteris paribus*, than those experienced in the years of price surges when cereals use for biofuels grew 31% p.a. from 2005-08.

Fig. 4.3 shows the price effects of the High- and Low-BF scenarios. The left-hand side of the Figure shows that projected 2050 prices could be 27% (High-BF scenario) or 10% (Low-BF scenario) above the levels projected for the baseline, i.e. if biofuels use of cereals had remained constant at the 83 mt of 2008. The right-hand side re-bases these price projections to the levels reached in the surge years (2006/08=100). It is seen that the High-BF scenario implies that 2050 prices could be 9% above the high ones reached in the surge years. It is reminded that prices in the surge years (average 2006/08) were 52% above those of the pre-surge years (average 2003/05), so the biofuels effects on prices would be much more pronounced if measured from those of the pre-surge years. In conclusion, the impact of biofuels on projected cereal prices could be substantial.

Fig. 4.1 World Cereals Use for Biofuels,
Actual 99/01&2006/08, OECD-FAO 2018, IFPRI & IIASA 2000 & 2020

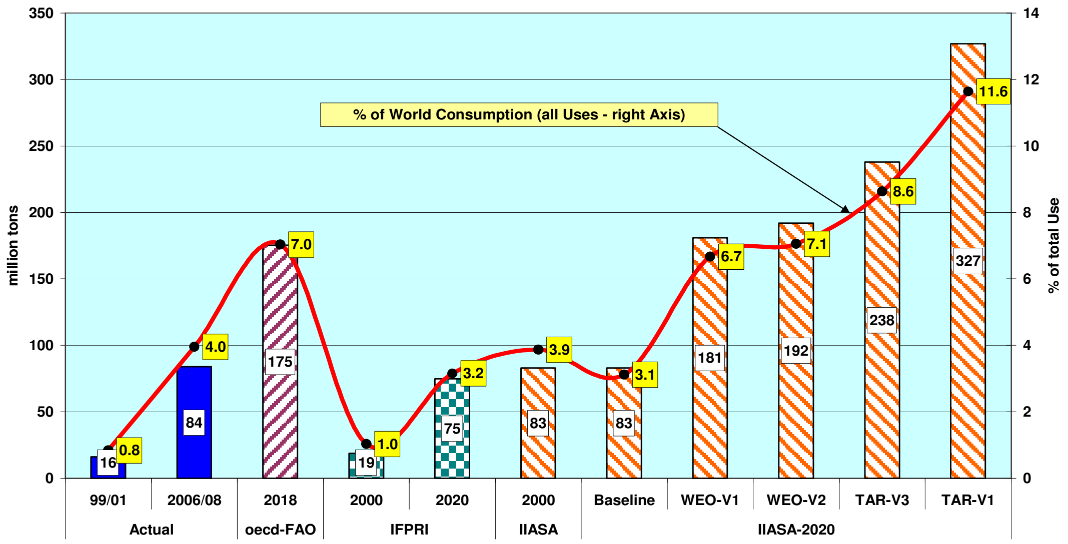
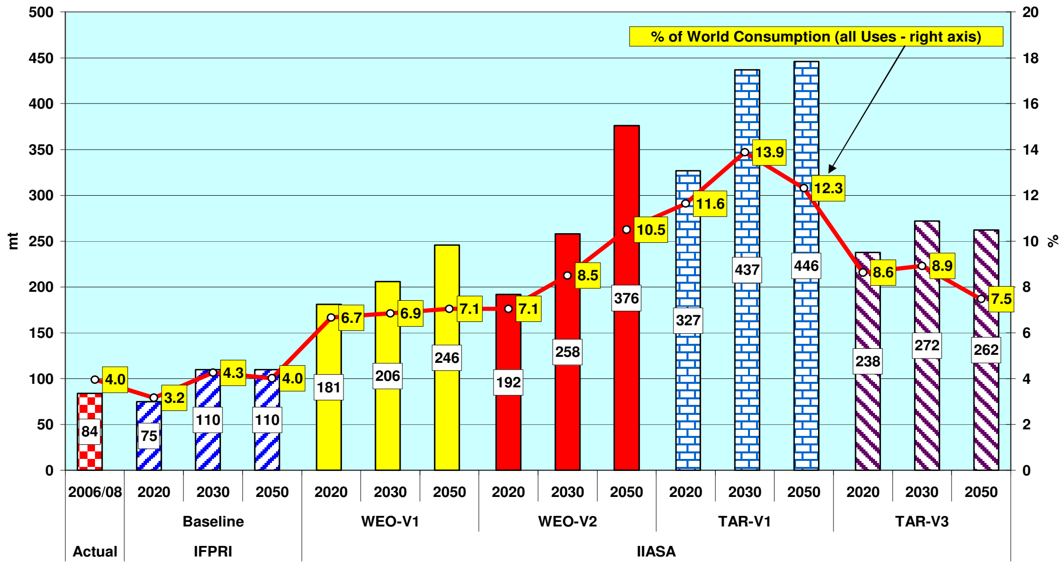


Fig. 4.2 IFPRI & IIASA Projections of Cereals Use for Biofuels, All Years



4.4.2 IFPRI

As noted, the IFPRI paper has several statements on price effects of biofuels expansion[36], but precious little by way of systematic presentation of numbers. One statement has to do with what the growth rate of prices would have been if biofuels (I take this to mean "cereals use for biofuels", but cannot be sure) had not accelerated from 2000-07 but had grown at the same rate as they had from 1990-2000. They conclude that the growth rate of the average grain prices would have been 30% lower than the actual one[37]. Let us see what this may imply. As I do not know what historical data for the period 1990-2007 the authors used, I will use, in what follows, the actual ones as known today:

- Actual growth rates of cereals use for biofuels were: 1990-2000 6.0% p.a. leading to 18 mt of such use in 2000 (of which 16 mt maize in the USA); 2000-07 24.7% p.a. leading to 85 mt in 2007 (of which 77 mt maize in the USA) [38].

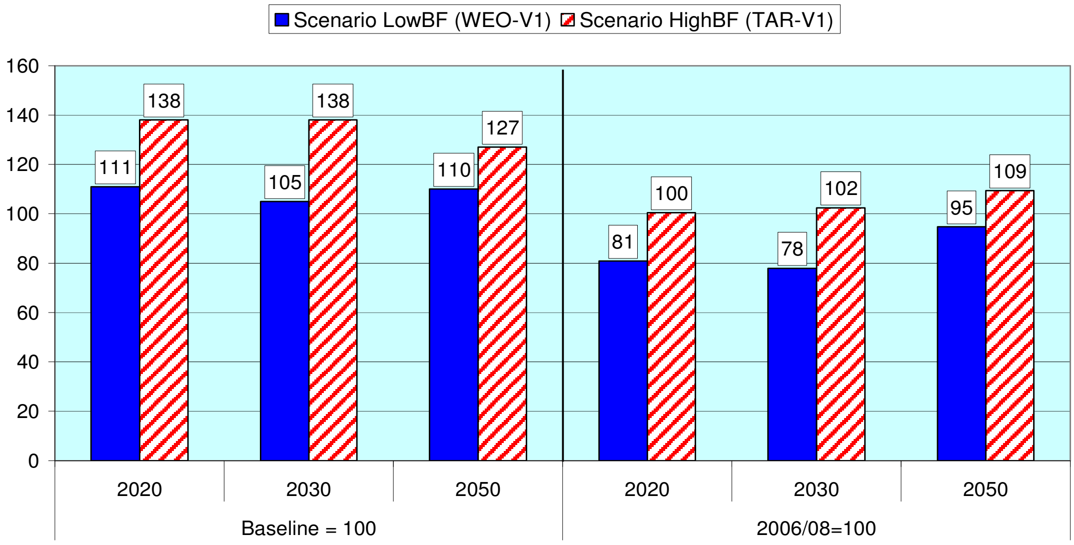
[36] "We look, specifically, at the role that biofuels might play in raising food prices..."; "...our attention will focus on the use of food crops in biofuel production".
[37] "...our simulation results produced a rate of growth in average grain prices that is 30% lower than actual rate of increase in world prices over the 2000-2007 period". A somewhat different terminology is used in another IFPRI paper to refer to findings based on what appears to be the same counterfactual scenario: "The increased biofuel demand during the period, compared with previous historical rates of growth, is estimated to have accounted for 30 percent of the increase in weighted average grain prices" (Rosegrant, 2008, p.2).
[38] Growth rate of the 90s is that of the USA use of maize for ethanol, as there was little cereals use for biofuels outside the USA. Data from 2000-07 are from the OECD-FAO (2009) files.

- If, according to this IFPRI counterfactual scenario, it had grown from 2000-07 at the same rate as in the 90s (6.0% p.a.), use for biofuels in 2007 would have been 27 mt, i.e. 58 mt less than the actual 85 mt.
- This would have resulted in prices growing from 2000-07 at a rate 30% smaller than the actual 7.0% p.a., i.e. at 4.9% p.a. The cereals price index in 2007 would have been 140 instead of the actual 160 (World Bank price index), i.e. prices would have been 13% lower in 2007.
- The reduction of cereals use for biofuels by 58 mt in this counterfactual scenario would have led to a reduction of aggregate demand for cereals (all uses, which was 2120 mt in 2007) by less than the 58 mt since the lower prices would have stimulated demand for non-biofuel uses, essentially food and feed. The IFPRI paper provides no information on this matter. We can guess that, based on IIASA's findings (see below), perhaps about one third of the 58 mt would have appeared as increased demand for food and feed and the balance as reduced production.

The IFPRI paper continues to say: "Following up on this counterfactual experiment, we also carried out a forward-looking set of projections with IMPACT, in which we hold (or 'freeze') the biofuel feedstock demand constant at the observed 2007 levels, rather than continuing along the trend suggested by current policy and plans for future expansion in various key biofuel-producing regions. By carrying out this scenario, we generate results that show grain, oils and cassava prices at least 4% lower than baseline levels in 2015, as well as maize prices that are 14% lower than baseline in 2015". It is not at all clear what this means: it implies that the "frozen" biofuels quantity in 2015 would be that of 2007 which, in terms of cereals, was 85 mt (see above). Therefore in this scenario the "frozen" level should be 85 mt for 2015. However, as noted, the baseline projects only 75 mt for 2020 (by implication even less for 2015), i.e. lower than the actual for 2007 (see Fig. 4.2). I can only guess that the authors were using historical data very different from the actual ones, as the latter are known now.

The IFPRI paper also alludes to another biofuels scenario they estimated, assuming the USA target of producing 22 billion gallons of first generation biofuels by 2022 was met. No results are given as to what this would imply for cereals quantities used for biofuels and impact on prices. They only say that the additional quantity of maize going to biofuels would be considerable and effects on food security would be negative. If such effects were to be offset by additional production through accelerated yield growth, they estimate that cereals yields would have to grow at 1.8% p.a. (over what period??), up from the growth rate of 1.3% p.a. of the baseline.

Fig. 4.3 Cereals Price Effects of Biofuels - IIASA Scenarios



Source: Fischer (2009), Tables 3.4, 7.2

Fig. 4.4 Cereals Consumption, Food/Feed, Biofuels and Total - IIASA High-BF and Low-BF Scenarios

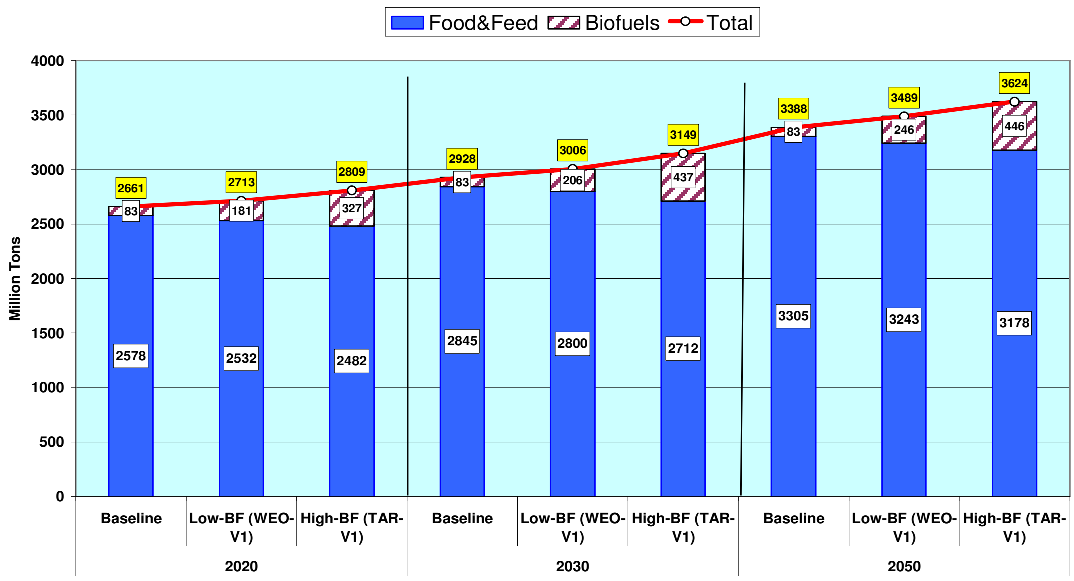
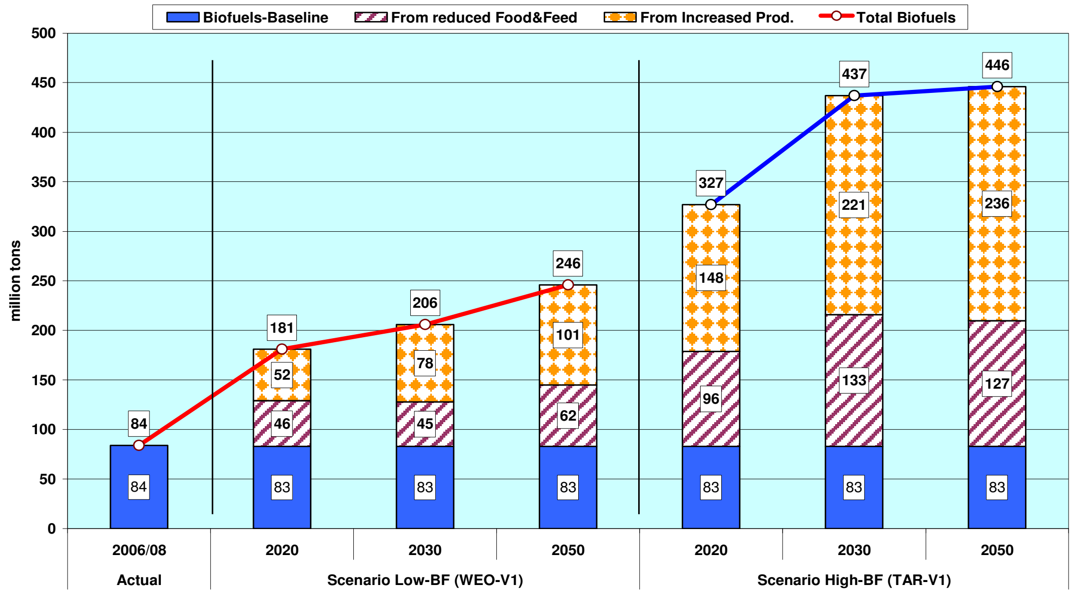


Fig. 4.5 Cereals for Biofuels: Increments from reduced food/feed & from increased Production



4.5 Impact on food/feed consumption

In principle, the higher projected prices, particularly those of the IIASA High-BF scenario, have the potential of depressing demand for food and feed in order to free supplies for biofuels use. What do the scenarios have on this matter? IFPRI shows no specific findings on this matter. IIASA does. Fig. 4.4 shows for the High-BF and Low-BF IIASA scenarios the projected levels of food/feed, biofuels, and total world consumption of cereals. It is seen that, for example, in the year 2030, food/feed consumption falls from 2845 mt in baseline scenario (when biofuels use was assumed to be only 83 mt) to 2712 mt in the High-BF scenario (when biofuels use reaches 437 mt) or to 2800 mt in the Low-BF scenario (cereals biofuels 206 mt).

In the end, the IIASA High-BF scenario implies that out of the total increase in cereals use for biofuels in 2030 in the High-BF scenario of 354 mt (437 minus the 83 of the baseline), 133 mt (or 38%) will come from reduced food/feed consumption and the balance (62%) from increased production. Fig. 4.5 illustrates these outcomes in more detail. Overall, more of the incremental use of cereals for biofuels would come from increased production than from declines in the consumption for non-biofuels uses. Both are the result of the projected higher prices in the scenarios with the increased biofuels use compared with those of the baseline.

Naturally, we would like to know what these projected developments imply for per capita food consumption and nutrition. Unfortunately, the IIASA paper shows fairly detailed effects of the biofuels scenarios on the combined consumption of cereals for non-biofuels purposes, but gives much less detail for effects on food alone. Their Figures 7.1 and 7.3 imply that about 30% of the total decline in the combined food/feed use comes from food, mostly from the developing countries, and the rest from feed, mostly from the developed countries. They do, however, imply that they estimated (but do not show) effects on per capita food consumption in terms of Kcal/person/day (all food, not only cereals) since they show impacts on the numbers at “risk of hunger” (i.e., numbers undernourished), which depends on the values of the Kcal/person/day.

We noted earlier (in the section on Prices) that the hunger estimates presented by IIASA should be viewed with caution because of (a) the cereals consumption historical data do not correspond to the actual ones, hence also the projections are affected (higher for cereals for all uses, perhaps also for total food though this cannot be known for sure), and (b) the method used to estimate risk of hunger may be flawed. Therefore, we retain the implications for percentage changes between the baseline and the biofuels scenarios, but effects on the absolute levels of food consumption and the numbers at risk of hunger remain uncertain.

4.6 Biofuels and Land Use

The IIASA biofuels scenarios provide estimates of the extent to which cultivated land (arable land and land in permanent crops in the FAOSTAT terminology) would need to expand beyond what is envisaged in the baseline in order to produce the required crop feedstocks for the biofuels industry. We first note that cultivated land is projected to increase in the baseline scenario by 166 million Ha (mHa) from 2000-2050. Fig. 4.6 shows this baseline increase and the additional increases needed for the production of crops for biofuels under the High-BF and Low-BF scenarios. The Figure also shows the FAOAT2030/50 land projections (see below).

At first glance, biofuels seem to add little to total projected land use. For example, in 2050 total cultivated land would be 1,727 mHa in the baseline, 1,748 mHa in the Low-BF scenario and 1,775 mHa in the High-BF scenario. Apparently, these increases in land for biofuels do not include land required for the production of lignocellulosic biomass for the 2nd generation biofuels embodied in the biofuels projections (Fischer, 2009, p. 33). The authors estimate that some 50 mHa of land would be required in 2030 for the production of 2nd generation feedstocks in scenario (TAR-V1) with the highest production of 2nd generation biofuels (Fischer, 2009, p. 38).

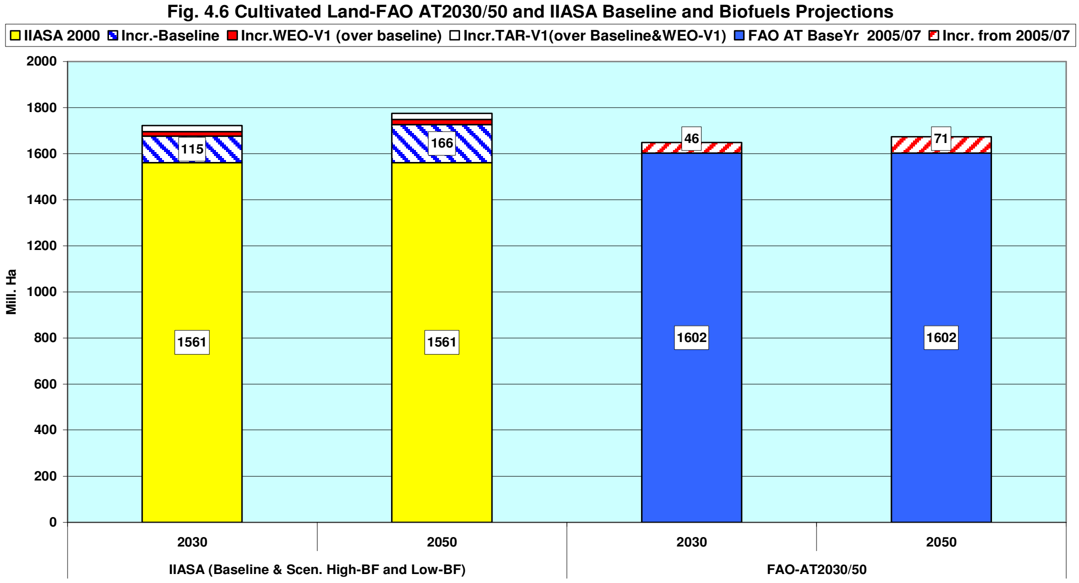
What matters, of course, is whether the projected land expansion, in the baseline or for increased biofuels, is a feasible proposition. A key criterion is the existence of land reserves for expansion. The paper does not address this issue directly, i.e. it does not provide estimates of land with crop production potential, into which the expansion would take place[39]. This makes it difficult for the reader to judge what the land expansion projections imply in terms of the part of land reserves that may have to be subtracted from other uses, e.g. grassland or forest.

In FAO’s long-term projections, the estimates of land reserves with crop production potential in each country are key variables for evaluating the possible sources of crop production growth. The estimates used in FAO’s AT2030/50 projections suggest that the land with rainfed crop production potential of various suitability classes amounts to 4.2 billion Ha for the world as a whole (Bruinsma, 2009, Table 7). This estimate comes from the old GAEZ and includes all sorts

[39] The author alludes to estimates of land with cultivation potential but does not show them: “Scenarios of climate change were developed in order to estimate their effects on crop yields, extents of land with cultivation potential, and the number and type of crop combinations that can be cultivated (Fischer, 2009:9)

of potentially cultivable land, i.e. also land under forest, in protected areas and in human settlements. The part really available for expansion without deforestation and disturbance of protected areas must be much smaller (we shall know more when we get access to the GAEZ2009 estimates).

Fig. 4.6 Cultivated Land-FAO AT2030/50 and IIASA Baseline and Biofuels Projections



Sources: IIASA, Fischer (2009), Tables 3.7, 7.6; FAO/AT: Bruinsma (2009), Table 7

Of these 4.2 billion Ha in the old GAEZ estimate, 1.6 billion Ha are in crop production use currently (same as used in the IIASA for 2000). The FAO AT2030/50 projects only a small increase by 2050 – only 70 mHa. This contrasts sharply with the IIASA projection of 166 mHa increase in the baseline scenario. True, the IIASA production projections are higher than those of FAO if we judge from the projected cereals production: the latter goes from 2,143 mt in 2000 to 3,400 mt in 2050, vs. from 1,900 mt to 3,000 mt in FAO's AT (see Section 2.5 on apparent inaccuracies in IIASA's historical data). However, this difference hardly justifies the higher land use projections of IIASA, though we cannot be sure, since no land use projections for cereals are shown. We can only guess that the IIASA projections imply less intensification than the AT, i.e. smaller increases in yields and/or cropping intensities[40].

As noted, the IIASA paper provides no estimate of land with crop production potential. It does, however, provide an estimate of land "potentially useable" for production of *lignocellulosic*

[40] There is an inherent inconsistency in IIASA's numbers: the cultivated land data agree with those of AT and other studies (they all come from FAOSTAT's data for arable land and land under permanent crops) but cereals production in 2000 is higher. This implies that the implied yields and/or cropping intensities derived from the interface between land and production may be biased and do not provide a good basis for the projections and analyses concerning sources of growth (yield growth vs. area expansion) in the future.

biofuel feedstocks (their Table 8.5). This estimate is apparently based on the OFID work (Fischer *et al*, 2009, Table 3.6-7 which is the same as Table 8.5 of the IIASA paper) using the GAEZ 2009 evaluation of land suitability. The latter is not yet available to FAO. The authors derive this estimate by subtracting from the 13.6 billion ha of the world land surface the parts that are not suitable either because of their soil/climate/terrain conditions (e.g. barren land, steep slopes, etc), because they are already in other uses (cultivated and built-up areas), or because they are under forest cover or non-forest protected areas. What remains is 1.75 b. ha of grassland and woodland that has potential for lignocellulosic (only?) feedstocks, though part of it is of low potential productivity: the OFID report (Table 2.7-3e) classifies only 860 mHa of this land in classes Very Suitable (VS), Suitable (S), and Moderately Suitable (MS) for such feedstocks. Figure 4.7 shows the resulting classification of all land surface of the globe.

The authors point out that not all this grass/wood land may be considered to be available for the production of lignocellulosic feedstocks. They estimate that much of it is being used for livestock grazing (obviously, more will be needed in the future, as herds expand, but the authors do not address the issue of such future needs). In the end, they estimate that some 700-800 mHa (out of the total 1.75 billion) of such land may be available at present for lignocellulosic feedstock production. On this basis, the authors conclude that there is significant land expansion potential for lignocellulosic feedstocks. This is, however, less comforting than it appears: surely, this same grass/wood land or part of it, is the only area into which conventional (non-biofuel) agriculture may expand in the future, if all forest and protected areas, as well as those needed for livestock grazing, are entirely or largely off-limits.

The author suggests that competition for land may be limited as "...different quality land could possibly be used for production [of feedstocks for 2nd generation biofuels], thus limiting or avoiding land use competition with food production as lignocellulosic feedstocks are expected to be mainly grown outside cultivated land" (Fischer, 2009, p. 34). They also say that "land demand for producing second-generation feedstocks as required for the most demanding TAR-V3 scenario …could be met without having to compete for cultivated land….and production of lignocellulosic feedstocks on some 100 million hectares would be sufficient to achieve the biofuels target share in world transport fuels in 2050" (p. 38).

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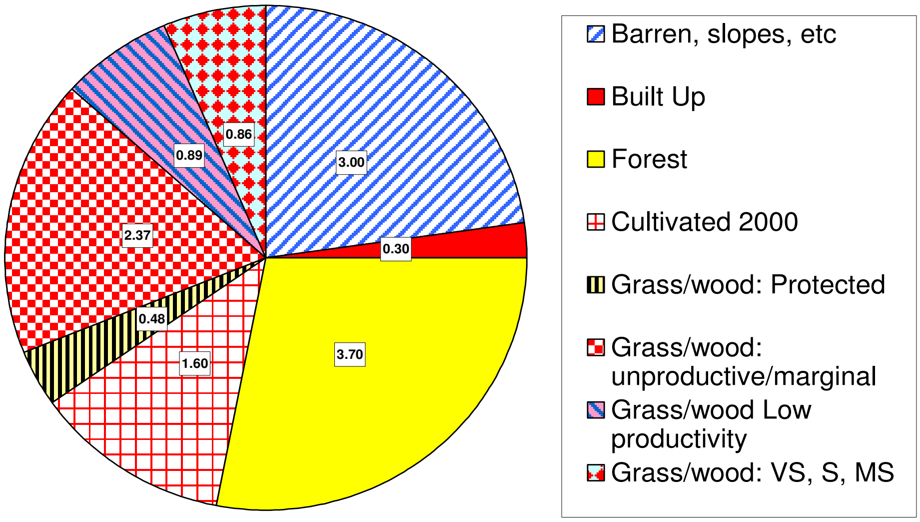
Fig. 4.7 Land Areas by Suitability class for lignocellulosic biofuels feedstock crops (billion Ha)



Source: Fischer (2009), Table 8.5; OFID (2008), Table 2.7-3e

4.7 Conclusions

4.7.1 Biofuels and Food Security

The EM papers with biofuels scenarios estimate, or refer to, negative impacts on food consumption and nutrition consequent upon the expansion of biofuels and the increased prices that they cause. However, they pay less attention to the significance for food consumption and nutrition of the higher growth of agriculture that accompanies biofuel expansion. Here follow a few comments:

- The negative impacts on nutrition (hence, implicitly, on food consumption) are highlighted and discussed, though not always in sufficient detail (e.g. absence of the Kcal/person/year projections) that would enable the reader to fully understand how they were derived.
- It is not known if offsetting positive effects on nutrition are accounted for, i.e. those associated with the biofuels-related higher prices and agricultural production and consequent impacts in raising rural incomes and food consumption of the parts of the populations benefiting. As noted (see section on Climate Change) the IFPRI model is a partial equilibrium one, so it probably does not capture feedbacks from agricultural production to GDP and to food demand and nutrition. The IIASA model is GE. It is said (Fischer, 2009, Annex 1 and Box 1) that it generates "incomes by group and/or sector". In principle, these income effects should feed back into the variables that determine food consumption and nutrition outcomes.
- In conclusion, future work on the analysis of 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 whole biofuels issue (see, for example, ODI, 2009).

4.7.2 Biofuels and Resource Scarcities

The IIASA paper addresses land use (but not irrigation) issues but do not give estimates of land reserves that are suitable in varying degrees for expansion of agriculture. In the absence of such estimates, we have no way of evaluating the feasibility of the land expansion results of the baseline projections as well as the additional land required for biofuel expansion. Moreover, we have no way of knowing if and to what extent the land declared as suitable for 2nd generation biofuel feedstock may overlap with land suitable for food crops. Yet this is necessary if we are to address the issue whether the eventual advent of 2nd generation biofuels will ease the perceived negative effects of biofuels on food security. Naturally, this information alone would not be sufficient to answer the question. Even if there were plenty of land with production potential only for lignocellulosic feedstocks, there can be no assurance that the cultivation of such feedstocks would expand only into that type of land: it could invade also, or in priority, the land suitable for food crops if economic realities so dictated.

In conclusion, the issue whether the advent of second generation biofuels will remove the food vs. fuel competition remains open and depends on much more than just the availability of land with lignocellulosic biomass production potential.

4.7.3 Biofuels and Interface of the Energy/Agriculture Markets

As far as I can tell, developments in the energy markets do not enter the analyses of biofuels in the EM papers, e.g. questions like what happens if real oil prices rise to $200/barrel are not posed. The only link is the one implicit in the adoption, in IIASA's WEO-V1 (LOW-BF) scenario, of the World Energy Outlook 2008 reference scenario projection of total transport fuel to 2030 and the part of it to come from biofuels. All other biofuels projections are derived by exogenous assumptions concerning the rate of implementation of mandates and the shares of 2nd generation biofuels in the total biofuels, with total transport fuel remaining the same. 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 (used as basis for IIASA's scenarios). These are: average $100/bbl over the period 2008-15 rising to $120/bbl by 2030 (real dollars of 2007; in nominal terms 2030 prices are assumed to reach $200/bbl, IEA, 2008:59).

If we assumed the future of biofuels will continue to depend predominantly on mandates, we can expect to see a gradual easing of the food/feed competition and the associated concerns about food security impacts. 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: already in the USA demand for ethanol created by the 10% blend mandate may soon be filled and act as a constraint on further growth of the ethanol sector (in jargon, it is about to hit the "blend wall"); and with falling demand for transport fuel in the USA during the current crisis, the 10% mandate may not allow for the absorption of the full 15 b. gallons of ethanol targeted for 2012. 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 foreseen by some for the not-too-distant future (e.g. Stevens, 2008; IEA, 2008) were to materialize.

Such an event would alter the economic fundamentals driving the biofuels sector and make it less dependent on mandates and other support policies and more on market forces. In such circumstances intensified competition for feedstock crops (and the underlying resources) will tend to siphon off supplies and resources from the food sector to the detriment of the food security of the weaker population groups. The eventual advent of 2^{nd} generation biofuels may ease the impact, but will not eliminate it as the production of lignocellulosic feedstocks need not be confined to land with no food-crop production potential. In conclusion, analysis of the longer term aspects of the issue food vs. fuel requires that biofuel outcomes be explored in the context of alternative energy futures and not only of alternative mandates and other support policies within one single energy future.

5. DEMOGRAPHY, GDP, GLOBAL INEQUALITY, POVERTY

5.1 Demography

Authors who use in their quantitative analyses, or merely refer to, population projections generally state that they use those of the United Nations, not always specifying which issue of the biennial UN projections. There have been four issues of such UN projections (or assessments) over the last 5 years: the one of 2002, published in 2004, and on every two years until the latest one of 2008. The world projected population (Medium Variant projection) has been changing in the successive Assessments, moving in the range 8.9 billion (2002 Assessment) to 9.2 billion in the latest 2008 Assessment. For the world as a whole, the differences in the projected 2050 population are not so large as to affect significantly the issues addressed here.

However, it is important to note that the differences in the world totals reflect predominantly higher projected populations of sub-Saharan Africa (1557 m. in the 2002 Assessment and 1753 m. in that of 2008), the region with the most severe problems of poverty and hunger. Obviously, 200 m. more in the region's projected population can have a significant impact on the prospects for improving food security. For example, the 2050 projected incidence of undernourishment of 5.8% (in FAO, 2006, table 2.3), when applied to a population higher by 200 m., would add some 12 m. to the region's projected numbers of undernourished, *ceteris paribus*. Naturally, other things do not remain equal when the demographic situation changes and the projected numbers increase by more than the 12 m., including because of revisions of the historical data and the parameters used in the estimation (Table 6.1, below)

5.2 Overall Economy and Global Inequality

The overall economy prospects enter the projections in two ways: (a) in the form of economy wide models aimed at generating overall economy outcomes (GDP, per capita incomes, poverty, sometimes distinguishing agriculture as one of the sectors in the models), and (b) as exogenous assumptions in the form of projected per capita incomes in analyses, often of the partial equilibrium type, aimed at producing more or less detailed outcomes for agriculture and food consumption.

There are two papers in the first category, by the World Bank and Hillebrand. They address specifically the issue how the world economy may grow in the period to 2050 and how income differentials between the rich (developed countries) and the poor (developing countries) may evolve. The common theme is "convergence": per capita incomes in the developing countries are projected to grow faster than in the developed ones so that by 2050 the income divide will have narrowed compared with the present, at least in relative terms (ratio of per capita GDP developed/developing) and at the level of the two large country aggregates. The magnitude of the income divide and how much it may narrow depends on how one measures the starting situation in terms of the GDP and on the differential GDP growth rates assumed for the two country groups (Fig. 5.1).

The World Bank paper uses market exchange rates (MERs) to measure GDP. The Low and Middle Income countries (LMYs[41]) account for 21% of global GDP (WDI data for 2005, GDP in constant 2000$). But they account for 84% of world population; the ratio of per capita GDP of the High income countries (HICs) to that of the LMYs is 1 to 20 – a huge divide. The divide has been narrowing, though very slowly: it was 1 to 22 in 1990. Will it narrow substantially by 2050? The working hypothesis in the WB baseline scenario is for GDP growth rates of 1.6% p.a. for the HICs and 5.2% for the LMYs, 2.9% for the World. These growth rate differentials make a huge difference for the per capita income divide. Notwithstanding the faster population growth of the LMYs, the ratio of their per capita GDP to that of the HICs improves drastically: from 1 to 20 in 2005 to nearly 1 to 5 in 2050.

Hillebrand's paper addresses the same issue, i.e. economic growth to 2050, and presents two scenarios: a high one (called "market first", see paper for assumptions) and a low one (called "trend") with world GDP growing 3.8% p.a. and 2.8% p.a. from 2005-50 in the two scenarios, respectively. GDP is measured in PPP 2005$, which give higher weight to the developing countries (represented by the country aggregate "non-OECD"). With GDP thus measured, the non-OECD countries account for 46% of world GDP in 2005, a huge difference from the 21% when GDP is measured at market exchange rates. As a consequence, the per capita GDP divide is much narrower: the ratio non-OECD/OECD per capita GDP is 1 to 7.3 in 2005 and falls to 1 to 5.3 or 6.1 in the two scenario projections by 2050.

In the end, the two papers, starting with huge differences in the measure of global income inequalities or gaps (because of the different methods of valuing GDPs in 2005 – MERs vs. PPPs) come to nearly identical conclusions about what relative inequality could be in 2050 for the large country groups considered here: the ratio of per capita GDPs between the rich and the poor projected for 2050 would be in the range 5-6 in all three projections. This result reflects predominantly the views embodied in the scenario hypotheses. The World Bank is very upbeat on the LMYs prospects and rather conservative on those of the HICs. Hillebrand's views in both scenarios are in the opposite direction, though both of them have faster growth in the non-OECD group than in the OECD[42].

The declines in relative inequality (ratio of per capita GDPs) notwithstanding, both projections imply widening gaps in absolute per capita incomes. People who are concerned about absolute gaps may see this as deterioration. But if we are concerned with raising the income levels of the

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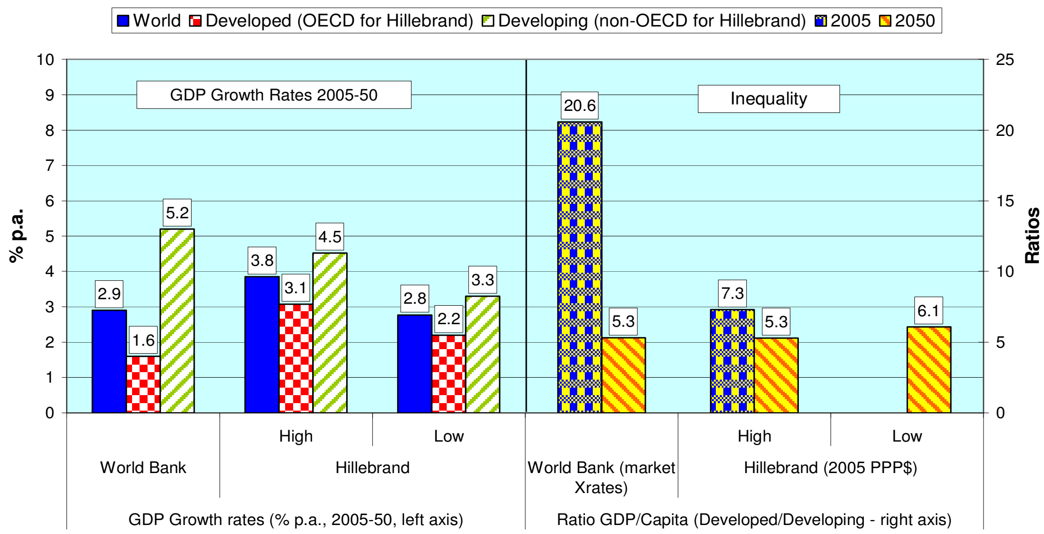
[41] Note that, in the GDP scenarios, none of the two papers uses the term developed and developing countries. However, the WB uses the term "developing" in its poverty estimates (see below). The large country groups used in the GDP scenarios are largely overlapping but not identical. The World Bank uses its country classification for the "High Income" and "Low & middle income" countries (available in the Bank's WDI website). The two groups account for 16% and 84% of world population, respectively. Hillebrand uses the country groups OECD and non-OECD, with shares in world population 14% and 86%, respectively (Hillebrand's OECD group comprises only the countries that were OECD members in 1981). The UN uses the terms "more developed" (19% of world population in 2005 in the 2006 UN population assessment) and "less developed" (81%). The term developed and developing is used in FAO (2006). The two groups' shares in world population (from the 2002 UN population assessment – used in FAO, 2006) are 22% and 78%, respectively.

[42]It is worth mentioning here the issue raised by Castles and Henderson that using MERs rather than PPPs 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*, 15/02/2003) and "Hot Potato Revisited" (*Economist*, 8/11/2003)

low income countries and fighting absolute poverty, the projections imply significant improvement, no matter that absolute gaps increase. In practice, the two are interconnected: achieving rising incomes for the poor often depends on the incomes of the rich growing in tandem, a point made by Hillebrand[43]. The link may however, be weaker in the future than in the past following the emergence of growth poles in the non-OECD area.

Fig. 5.1 GDP Growth Rates and Ratios Incomes/Capita, 2005-50



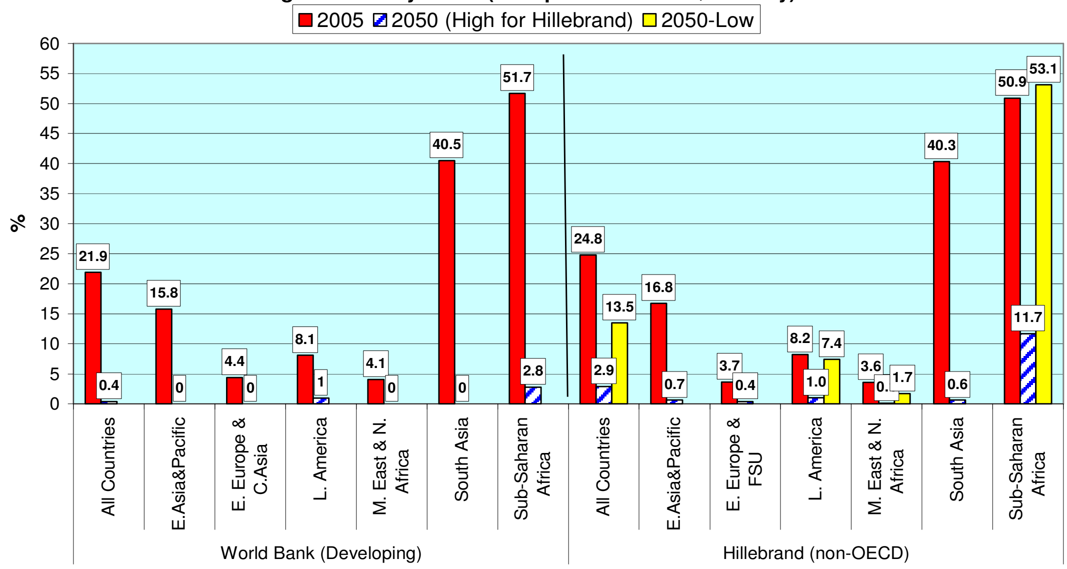
Sources: World Bank: text and own calculations using WDI GDPs and UN Proj. population; Hillebrand, Table 1

[43] "High OECD growth by itself probably hurts the global inequality numbers, but it is helpful to economic growth, and hence poverty reduction, in the non-OECD countries".

5.3 Poverty

For the World Bank scenario, poverty (of the $1.25 PPP) in the developing countries is projected to virtually disappear. Only sub-Saharan Africa and Latin America are projected to have measurable poverty rates in 2050, 2.8% and 1.0%, respectively. Hillebrand 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 level of 52% in 2005 (see Section 6, below).

Fig. 5.2 Poverty Rates (% Popul. under PPP$1.25/day)



Sources: World Bank, Table 6.1; Hillebrand, Tables 1, 12

5.4 Some Comments

Concerning our more specific concern regarding food, agriculture and nutrition, in principle, the projected narrowing of the relative (ratio) income divide should lead to an even sharper narrowing in the divide (both absolute and relative) of food consumption levels because the latter, in contrast to income, is a bounded variable[44]. The WB paper does not explore this particular aspect (food and nutrition) of the projections of income and implied poverty and global inequality. Hillebrand does. In his two scenarios the non-OECD/OECD ratio of per capita food consumption (Kcal/person/day) falls from 1.29 in 2005 to 1.16 (“market first” scenario) or to 1.21 (trend scenario). These relatively modest changes in the ratios do not tell much in terms of food welfare and nutrition. What matters are absolute levels of food consumption. The 2050 outlook, as reflected in his two scenario projections, is for Kcal/person/day in the non-OECD countries to increase from an inadequate 2662 in 2005 to 3135 and 3013, in the two scenarios, respectively. We shall have more to say on agriculture and nutrition in next section on sub-Saharan Africa. Suffice to say here that Hillebrand’s projected food consumption levels for the

[44] A poor person, to be alive, must consume a minimum amount of food (basal metabolism plus a varying amount of calories for a minimum activity), while physiology limits the amount of food a rich person can consume.

non-OECD group (high scenario) would be compatible with significant reduction of undernourishment. However, the devil is in the detail: an adequate average of this large country group does not mean that each and every country, or even region, will be in that happy position. In the next section we point out that his food consumption projections for sub-Saharan Africa are probably too pessimistic.

This brings us to raising the issue of likely rising inequalities within the group of the low-income (or the non-OECD) countries. The WB paper states clearly that the process of convergence between the HICs and LMYs and declining inequality at the global level will be accompanied by "higher within-country and within-region income inequality". For example the per capita GDP ratio of East Asia & Pacific LMYs to that of sub-Saharan Africa will rise from about 2.5 at present to 5.7 in 2050[45]. Hillebrand does not show projected per capita GDPs for finer country groups within the non-OECD area, so we cannot estimate changes in income gaps. However, his projected poverty rates and food consumption levels (discussed below) make it clear that there will be increasing differentiation, with sub-Saharan Africa making much less progress than the other regions in the non-OECD group.

A final point is worth mentioning before closing these comments on the overall economy dimensions of the world to 2050. It has to do with the view implicit in the scenario projections that world economic activity can continue growing unimpeded by constraints imposed by natural resources and the environment. In the two papers, the world economy in 2050 is a multiple of that in 2005, 3.7 times larger in the WB scenario and 3.4-5.5 times larger in Hillebrand's two scenarios[46]. The papers do not pose explicitly the issue of such constraints and possible impacts on global growth. Hillebrand refers briefly to the Club of Rome's *Limits to Growth*. The World Bank paper reports possible impacts of climate change on agriculture (see Section 3, above); it also speaks of exploring impacts of rising energy prices, again on agriculture, but does not pursue the matter. This can mean either of two things: (a) that such constraints will not prove binding in the 45-year projection period, or (b) more likely, in time-honored fashion, a more prosperous world will be finding ways around such constraints, as and when they arise – a Julian Simon concept of economic progress (Simon, 1996). Hillebrand, whose poverty reduction

[45] "At market exchange rates, there is a narrowing of the income gap, but it remains substantial. In 2005, per capita incomes were some 20 times higher in high-income countries relative to developing. This ratio drops to 6 by 2050 though varies highly across regions—with a low of 3.5 in East Asia and Pacific and a high of 20 for sub-Saharan Africa" Therefore, if Yhic/Yssah=20 and Yhic/Yeap=3.5, then Yeap/Yssah=20/3.5=5.74.

[46] Both papers emphasize that their long-term projections are scenarios rather than forecasts. World Bank: "Though we regularly project income growth over the medium- and long-term horizons, one should keep in mind that these are strictly scenario-based (or what-if?) projections and not statistically-based projections as are the more standard short-term forecasts of economic growth. Our projections use a hybrid system where in the short- and medium-term we rely more on estimates of potential growth using statistical techniques, but over the longer-term we switch to a more judgmental forecast that relies on two assumptions: 1) long-term per capita growth in high-income countries will slow to 1.0-1.5 percent per annum; and 2) developing countries will converge towards the per capita incomes of the high-income countries, but at different rates". Hillebrand: "There is no scientifically sound methodology to forecast global incomes and consumption decades in the future. Most long-term projections, including this one, rely on scenarios. The researcher posits a set of assumptions about the key drivers of growth, uses a model that relates these factors to economic outcomes, and produces projections that are presumed to be part of a range of plausible outcomes".

projections depend on economic growth[47], explicitly recognizes that *"Resource constraints, if not met by technological solutions, will surely make the poverty estimates shown here worse"*.

We cannot address these broader issues now. It is, however, worth giving a thought to the possibility of binding constraints in the sphere of natural resources and the environment when we deal with long-term processes involving huge increases in economic activity. In the end, it may not be agricultural resources that represent the main binding constraints to solving the hunger problem 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 the not too distant future. This possibility was raised already 15 years ago in FAO's 1995 edition of *World Agriculture: towards 2010* (Alexandratos, 1995: 136-37).

[47] He assumes no changes in within-country income distribution and in the part of GDP devoted to private consumption.

6. SUB-SAHARAN AFRICA (SSA)

The future of agriculture and food security of this region was the topic of separate sessions in the Expert Group's agenda. Not all contributions provided quantitative projections. Those which did, had projections of often disparate variables (income growth rates, poverty rates, food consumption, numbers undernourished, etc) so that straightforward comparisons cannot always be made. The main variables are shown in Table 6.1

6.1 GDP and Poverty rates

In the papers by IFPRI, IIASA and FAO, the GDP growth rates are exogenous inputs into the agricultural projections[48]. As noted, only the papers by the World Bank and Hillebrand have GDP projections derived from economy-wide models. The World Bank paper does not show GDP projections by region, so we cannot know how SSA fares in their projections. However, they do show projections of poverty rates by region. The poverty rate in SSA is projected to fall drastically (see below). This implies that whatever GDP growth rate underlies their poverty projections must be fairly robust and generally above those used in the other papers.

The GDP per capita growth rates of the other papers are shown in Table 6.1. Three of them are in the range 2.3-2.5% p.a. for 2005-50 and only IFPRI has a significantly lower rate, 1.9% p.a. The implications for the growth of per capita food consumption are explored below, after we examine projections of the poverty rates. Two papers (World Bank, Hillebrand) project poverty rates. The World Bank paper is upbeat: it sees absolute poverty (of the $1.25/day variety) as virtually disappearing by 2050 in SSA, falling from the current 51.7% of the population to only 2.8% (Table 6.1). Apparently, it is economic growth that drives the drastic poverty reductions, since such reductions happen despite the assumption that within-country income distribution becomes somewhat more unequal.

[48] IIASA's model is said to be GE (see Section 3.7.3, above). Therefore, the exogenous GDP has been, in principle, modified in the process of receiving feedbacks from changes originating in the agriculture sector solution.

Table 6.1 Key numbers for sub-Saharan Africa

	Actual	Projections	
	A. GDP/Capita, % p.a.		
	2000-05	2000-50	2005-50*
Hillebrand (2009, Table 8)-High	1.9		2.5
FAO - AT2030/50 (FAO, 2006, Table 2.5)	1.9	2.3	2.4
IFPRI- EM paper (Pers. Communication)	1.9	1.9	1.9
IIASA (Fischer, 2009, Tables 3.1, 3.2)	1.9	2.2	2.3
	B. Poverty, % Pop. with <$1.25/day (PPP$ of 2005)		
	2005		2050
Hillebrand (2009, Table12)-High	51.2		11.7
Hillebrand (2009, Table12)-Low			53.1
World Bank	51.7		2.8
	C. Food Consumption, Kcal/person/day		
	Data used in projections		Projections
	2000	2005	2050
Hillebrand (2009, Table 9)-High		2,256	2,588
Hillebrand (2009, Table 11)-Low		2,256	2,507
FAO - AT2030/50 (original)	2,194		2,830
FAO - AT2030/50 (actual & Rev. Proj. for EM)	2,128	2,167	2,708
IFPRI (New paper-Oct.09)	2,316		2,452
	D. Undenourished, % of Population		
Hillebrand (2009, Table 9)-High	30.7		18.5
Hillebrand (2009, Table 11)-Low			21.4
FAO - AT2030/50 (original)	33.3		5.8
FAO - AT2030/50 (actual & Rev. Proj. for EM)	32.0	30.5	7.0
IIASA (Fischer, 2009, Tables 3.1, 3.5), at risk of hunger	29.9		12.6
	E. Undernourished, million		
FAO - AT2030/50 (FAO, 2006, Table 2.3)	201		88
FAO - AT2030/50 (Rev. in Alexandratos, 2009, Table 3)	202	213	118
IFPRI (Nelson *et al,* 2009, Table 6)-Children only	33		42
IIASA (Fischer, 2009, Table 3.5), at risk of hunger	196		239

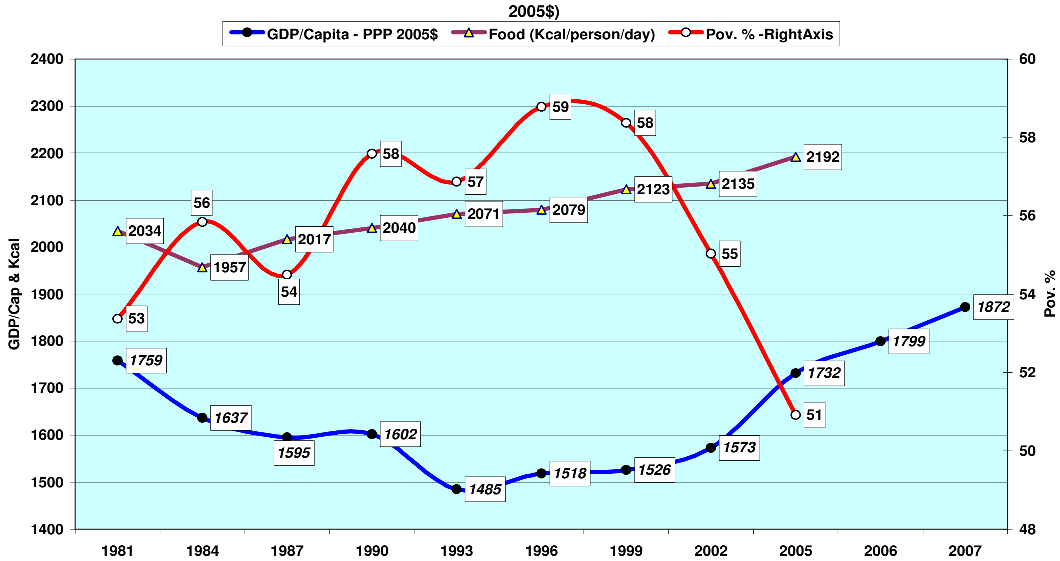
*Except for Hillebrand's, the growth rates 2005-50 are derived from those 2000-50 and the actual one of 2000-05

Hillebrand's paper is less optimistic: the region's ($1.25) poverty rate declines to 11.7% by 2050 in the High GDP growth scenario when the region's per capita GDP grows 2.5% p.a. It assumes no changes in within-country income distribution and the part of GDP devoted to private consumption. Therefore, also here it is economic growth that drives declines in the poverty rates rather than internal redistribution. Hillebrand's lower-growth Trend scenario (GDP growth for

Trend scenario not given in the paper for sub-Saharan Africa) is outright pessimistic: poverty actually increases a little (to 53.1%). Two questions arise:

1. Does the empirical evidence support the proposition that sustained economic growth leads to declines in the poverty rates? The latest WDI data have poverty estimates for every 3 years from 1981-2005. The data for SSA are graphed in Fig 6.1 together with the evolution of per capita incomes in the region (both in PPP$ of 2005). It is seen that there is a fairly close (negative) correlation between the two[49]. The poverty rate started falling from 1999 when the growth of per capita GDP accelerated (2.2% p.a., or 2.6% p.a. when GDP is measured in PPP$ - more appropriate for juxtaposing to poverty rates which are also measured at PPP$ 1.25). Both above mentioned macroeconomic projections assume a continuation of the fast 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.

Fig. 6.1 sub-Saharan Africa, GDP/capita (PPP2005$), Food/Capita & Poverty (% population under 1.25/day PPP 2005$)



Source: GDP and Poverty: WB, WDI, Accessed 04Sept09; Kcal: Faostat (data used for SOFI, 2008)

2. Is it a realistic prospect that the relatively high growth rates of per capita incomes achieved in the decade to 2008 can be sustained for several decades? Both papers emphasize that the economic growth projections are based on scenario assumptions (see Section 5.4, above). One reason for skepticism has to do with the region's initial poverty conditions: starting with 52% of the population below this very low ($1.25) poverty line, 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 climate necessary for sustaining high economic

[49] This is assuming the two data sets are independent, i.e. the poverty rate is not estimated as F(Income)

growth rates for several decades? We cannot possibly answer these questions, but it is worth posing them nonetheless. Moreover, we must keep 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 pretty low (see below) and 45 years into the future is a long time to wait for such an outcome.

6.2 Poverty vs. Food Consumption and Undernourishment

Of prime interest for the issue at hand is, of course, what may happen to the food situation, in particular whether the projected reductions in the 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 nonfood spending" (World Bank, 2009, p. 66). In turn, the international poverty line of $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, p. 185; also, Ravallion, Chen and Sangraula, 2009). Assuming the latter are also based on the "bundle of food" principle, the $1.25 will not be sufficient to ensure that "nutritional requirements for good health and normal activity levels" are met. Therefore, we should not be surprised if other studies, using similar assumptions of per capita income growth, find that undernourishment rates in 2050 are projected to be higher than the $1.25 poverty rates.

Table 6.1 presents, together with the GDP growth rates and the poverty rates, also the projected per capita food consumption (Kcal/person/day). The latter is the main variable used to estimate possible changes in the incidence of undernourishment, also shown in the Table. Not all papers have such projections. Here follows a brief description of what they have on this matter.

- FAO's projection is the most optimistic of all: Kcal/person/day rises from 2167 in 2003/05 to 2708 in 2050 and the percent of population undernourished falls from 32% to 7.0%. However, the absolute numbers undernourished are not halved (from the some 170 million in 90/92, the base year of the 1996 WFS target of halving by 2015) even by 2050, assuming the halving target is applied to the region. These developments in the absolute numbers undernourished, despite the significant decline in the percent of the population, reflect the very rapid population growth of the region, +142% in 2005-50 vs. +38% in the rest of the developing countries. This, of course, raises the issue how to compare relative performance among countries/groups regarding how much progress they make towards the target. Defining the target in absolute numbers rather than as percent of population will tend to penalize (i.e. make appear as making less progress) countries with high demographic growth.
- Hillebrand's growth rate of per capita income of 2.5% p.a. 2005-50 (High scenario, not given for Low scenario) is associated with an increase in Kcal/person/day from 2256 in 2005 to 2588 in 2050. The implicit income elasticity is unrealistically low (0.12) given the starting very low level, even when food is expressed in calories rather than quantities of individual commodities[50]. How does he derive this result? His model has an agriculture module, but the crop sector is represented in terms of physical quantities, all crops

[50] See Skoufias (2002) and Ohri-Vachaspati et al (1998) for estimates of calorie-income elasticities

together as one variable (adding up grains, roots, vegetables, etc in tons), which is not helpful. It also includes meat, dairy and fish. It is not known if the calorie projections are linked to the agriculture module. Probably not, since: "Calories consumed per capita are estimated as a function of GDP per capita and relative prices" (personal communication[51]). The "percent of population malnourished" falls in this High scenario from 30.7% in 2005 to 18.5% in 2050. This looks like a very pessimistic outcome, even accounting for the low projected calories per capita (again, it is not explained how the estimate of malnourished is derived). To test it, I use the FAO method but treating the region as one country and assuming the FAO average CV for the region (simple average: 0.29) for 2003/05 and the weighted average calorie requirements (MDER) for 2050 (1850 Kcal) apply: for Hillebrand's 2588 calories in 2050 the percent of population malnourished should fall to 15% rather than his 18.5%. I conclude that for the very respectable income per capita growth rate of 2.5% for 45 years, Hillebrand's projected food consumption and hunger are definitely on the pessimistic side.

- IFPRI projects Kcal/person/day (in the revised paper of October 2009, Nelson *et al*, 2009) and also numbers of malnourished children in millions, though not as percent of the respective population in the age bracket 0-5 years. The numbers are projected (their Table 6) to increase in the baseline projection from 33 m. in 2000 to 42 m. in 2050. Overall, therefore, IFPRI sees no decline but some increase in absolute numbers, though this probably implies a decline as percent of the population in the relevant age group. This is a very pessimistic vision of the future, seeing also that we are considering a 50-year horizon. The main reason seems to be that IFPRI projects little growth in the food consumption per capita (Kcal/person/day): it rises from 2316 Kcal in 2000 to just 2452 Kcal over a period of 50 years. Is this sluggish growth due to IFPRI's lower growth rate assumption for GDP/Capita and the projected price increases (see Figure 2.4, above)? We cannot be sure: there are also data problems that prevent us from gaining a better understanding of the projections. Just as in the case of cereals (noted earlier, Fig. 2.6), IFPRI uses base year (2000) data which are very different from the actual ones: Kcal/capita are given as 2316 in 2000 when the actual figure in the historical data is 2128 (Fig. 6.1). It is not known why the data used in the IFPRI model are so different from actual historical data.

- The IIASA paper projects "numbers at risk of hunger" which is another way of saying numbers undernourished using FAO terminology. However, as noted earlier (Section 2.5), the estimation method may be flawed. Overall, their method tends to overestimate the numbers undernourished compared with that of FAO. Controlling (roughly) for such overestimation, IIASA's projection that the proportion of undernourished in the population could fall to 12.6% by 2050 could be fairly compatible that of FAO. From this, we can indirectly deduce that their baseline projection of per capita food consumption (which is not given in the paper) would not be too different from that of FAO.

6.3 What Drives Food Consumption in sub-Saharan Africa?

[51] It is, of course, possible that the implicit income elasticity is so low because projected food prices rise significantly. The author does not say anything on this matter.

Making statements about food security in the future requires, in the first place, that we have a credible projection of food consumption per capita. This is the key variable that determines nutrition outcomes, at least so long as we continue to use the FAO/SOFI method of estimation. The models generally derive it as function of GDP/capita and prices. However, at least for the regional average of SSA, the evidence suggests that it is more closely related to the evolution of domestic food production than to anything else. This is clearly seen in Fig. 6.2. We have addressed this issue on other occasions when the evolution of per capita food consumption (Kcal/person/day as derived from the Food Balance Sheets) seemed to bear little relationship to the evolution of per capita incomes (see FAO, 2006, Fig. 2.2, example of Nigeria). Apparently, in most countries of SSA, with limited shares of imported food in total supplies, high economic dependence on agriculture and little non-food use of food commodities, food consumption follows the evolution of production and, to a lesser extent, food imports[52]. As explained in the methodology of the AT projections, in such cases the growth of food consumption is derived iteratively in the process of evaluating the scope for increasing production and trade. Therefore, much of the onus for the credibility of the food production projections falls on that of the food production projections. If the projected production were not to materialize, so would the projected consumption. Fig. 6.3 shows this relationship in FAO's AT projections.

This brings us to pose the question whether the FAO production projections of SSA are on the high side compared with those of the other studies. We can only compare cereals projections, since projections for total agriculture are not given in all papers. IFPRI, which has the smallest increase in per capita food consumption, has also the lowest growth rate of cereals production in its baseline projection, 1.7% p.a. from 2000-50 (Nelson *et al*, 2009, Table 3). IIASA has a high growth rate of cereals production for the same period (2.5% p.a., Fischer, 2009, Table 3.3). FAO's projection is in-between, 2.1% p.a. (FAO, 2006, Table 3.3 – including South Africa in the SSA region, for comparability). For the record, it is noted that SSA's cereals production increased 4.5% p.a. in the first 8 years (2000-08) of the projection period. These years have seen rapid growth of production (over 4% p.a.) in several major producers of the region (Ethiopia, Nigeria, Sudan, etc; see Alexandratos, 2009, Table A.1). Such high growth rates were partly due to recoveries and good weather: they are not indicative of long-run prospects. However, there is no reason to think that the region's cereals production cannot grow at a rate just above that of the population (2.0% p.a.). In considering these things, we must keep in mind that for the SSA region the cereals sector is a relatively smaller component of the food sector than in other regions: it accounts for some 17% of total food production. In South Asia it accounts for twice as much. Therefore, comparing cereals only projections is not a very good indicator of the potential links between production and consumption.

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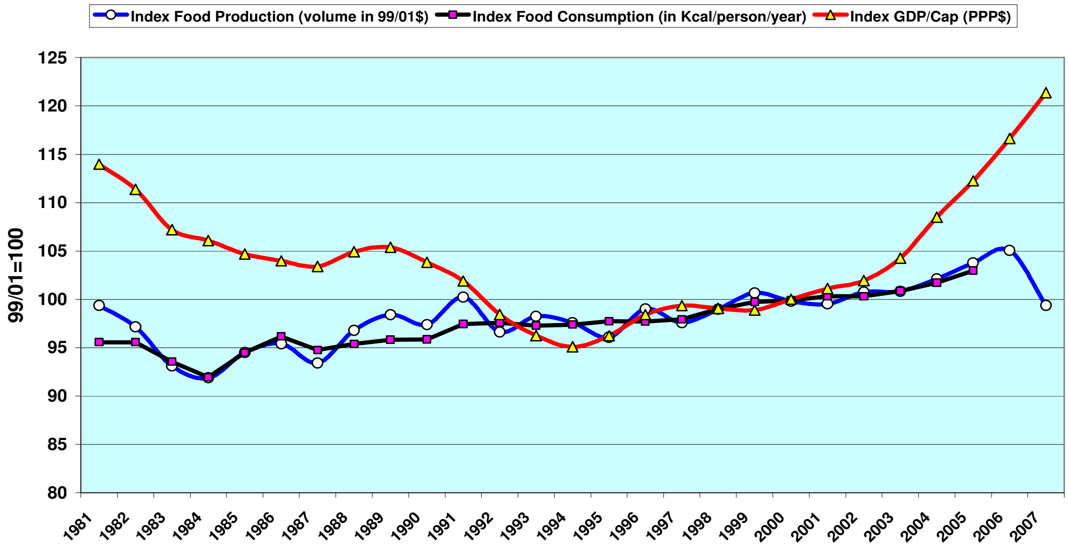
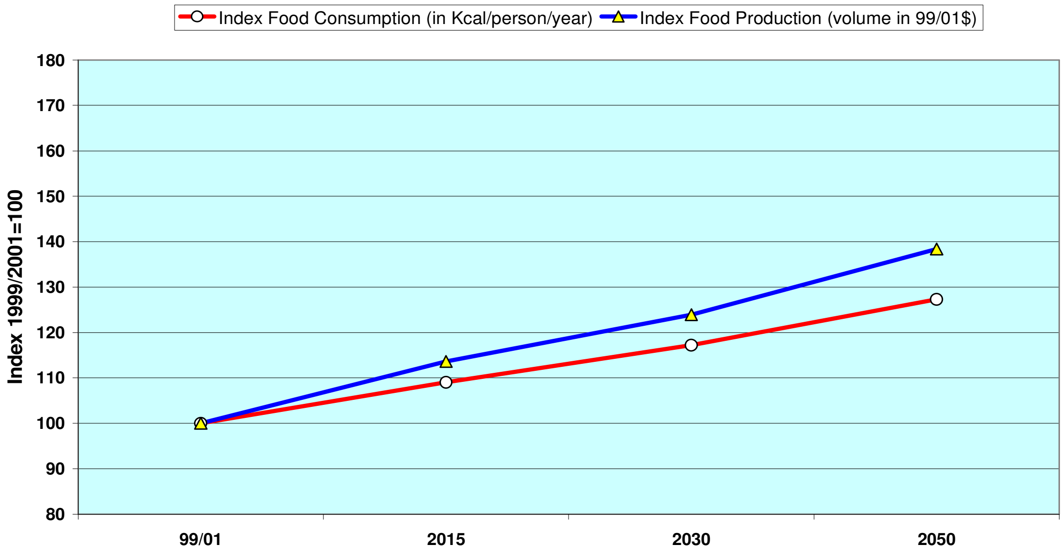
[52] In the food balance sheets, food consumption is derived as part of the utilization of total supplies of each food product (=production + net imports + net changes in stocks). It is therefore natural to expect a close correlation between production and consumption in the countries with little net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

Fig. 6.2 Food Production, Consumption and GDP, Indices, all per capita (1999/01=100)



Sources: Production: FAOSTAT PINs; Kcal: Faostat (data used in SOFI 2008); GDP: World Bank, WDI

Fig. 6.3 FAO's AT 2030/50: Per capita Food Production and Consumption



Sources: Production, FAO (2006) files; Consumption, Alexandratos (2009), Table 4

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