HLPE REPORT 3

Food security and climate change

A report by

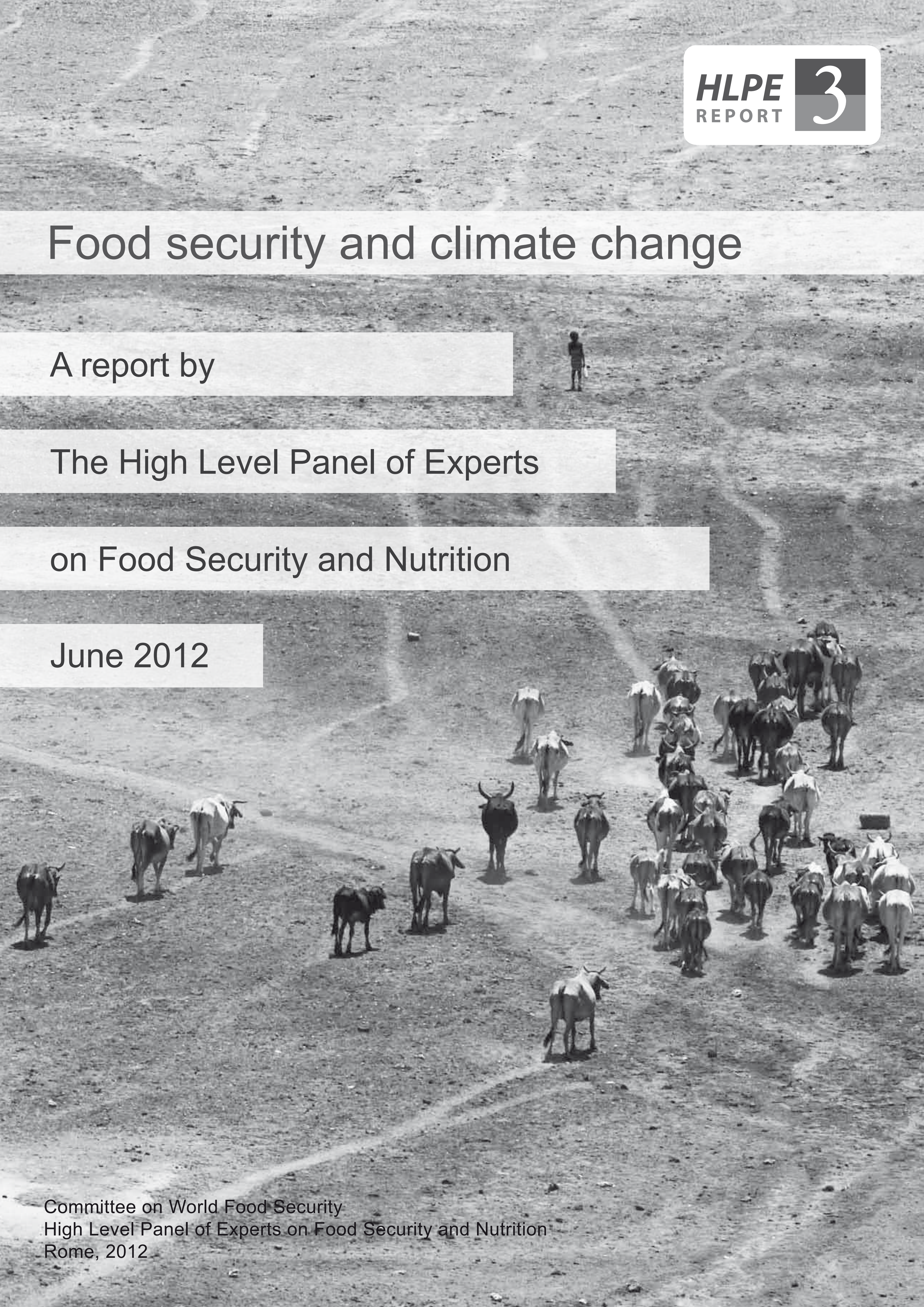
The High Level Panel of Experts

on Food Security and Nutrition

June 2012

CFS Committee on World Food Security

HLPE High Level Panel of Experts



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Rome, 2012

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This report by the High Level Panel of Experts on Food Security and Nutrition (HLPE) has been approved by the HLPE Steering Committee.

The views expressed do not necessarily reflect the official views of the Committee on World Food Security, of its members, participants, or of the Secretariat.

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FOREWORD

The High Level Panel of Experts on Food Security and Nutrition (HLPE) was established in 2010 as part of the reform of the World Committee on Food Security (CFS). The main role of the HLPE is to provide, at request of the CFS, policy-oriented analysis and advice, to underpin policy formulation and the work of CFS. Thus, the HLPE serves as CFS's science-policy interface, thereby helping to generate synergy between science and public policy and action. The HLPE functions through a Steering Committee comprising 15 distinguished experts from around the world, and which I have the honor to Chair.

Our reports are demand driven, specifically requested by the CFS and prepared for discussion at CFS's annual plenary meetings. In 2010, the HLPE prepared two reports, one dealing with Land Tenure and International Investments in Agriculture, and another, dealing with Price Volatility and Food Security. These reports nourished the policy debates at the 37th CFS meeting in October 2011. They were highly commended with reference to their contemporary relevance and feasibility of implementation.

At its meeting held in October 2010, the CFS requested the HLPE to prepare reports on Climate Change and Food Security, and Social Protection for Food Security, which we are presenting this year.

Food insecurity and climate change are, more than ever, the two major global challenges humanity is facing, and climate change is increasingly perceived as one of the greatest challenges for food security. This is why in 2010, the Committee requested the HLPE to work on Climate Change and Food Security and more specifically to *review existing assessments and initiatives on the effects of climate change on food security and nutrition, with a focus on the most affected and vulnerable regions and populations and the interface between climate change and agricultural productivity, including the challenges and opportunities of adaptation and mitigation policies and actions for food security and nutrition.*

The present report on *Climate Change and Food Security* was finalized and approved by the Steering Committee at its meeting held in St. Petersburg, Russia, 5-8 June 2012.

The HLPE attaches as much importance to the process[1] adopted in the preparation of the reports, as to the product. The HLPE runs extensive open electronic consultations for transparency and openness to all forms of knowledge, and peer reviews. We are convinced this is key to the quality, relevance and scientific legitimacy of our reports.

1 The procedure is described in more detail in Appendix.

The Project Team for the preparation of this report was led by Dr Gerald Nelson (USA) and had as its Members Zucong Cai (China), Charles Godfray (UK), Rashid Hassan (Sudan and South Africa), Maureen Santos (Brazil) and Hema Swaminathan (India). The Steering Committee's oversight for this study was convened by Prof Huajun Tang. On behalf of the Steering Committee, I wish to record my appreciation to the Project Team as well as to Prof Huajun Tang and all Members of the Steering Committee for their active involvement in the preparation and finalization of the report. Sincere thanks also go to Vincent Gitz, HLPE Coordinator and head of the Secretariat of HLPE, for untiring efforts and exceptional work, without which the report could not have been completed within the prescribed time frame. Above all, we are indebted to the Invisible College of participants in our open electronic consultations and to our anonymous peer reviewers. They all provided valuable comments and inputs, an indisputable strength to our process and to the quality of our work.

The multidimensional impact of climate change on life in our Planet is being studied in detail by the Intergovernmental Panel on Climate Change (IPCC) and is also being discussed at annual meetings of the Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC) adopted at Rio de Janeiro in 1992. This year marks the 20th anniversary of the Rio Conference and, just as we are releasing this report, extensive discussions have been held at the Rio+20 Conference on the progress made in the mitigation of climate change as well as adaptation to the consequences of climate change, such as increases in mean temperatures, adverse changes in precipitation, sea level rise and concerns about the occurrence of extreme climatic events like drought, floods and coastal storms. Since anthropogenic factors are mainly responsible for the present trends in global warming, it is only human action and intervention that can help to alleviate the adverse impacts of climate change.

In 1979, I was invited by the World Meteorological Organization (WMO) to deliver a Plenary Lecture on "Climate and Agriculture" at the World Climate Conference held in Geneva. In 1989, I was again invited by the WMO to deliver a Plenary Lecture, but this time on "Climate *Change* and Agriculture". Thus, within a period of a decade, at WMO Climate Conferences, climate *change* issues started dominating the discussions. The IPCC was created in 1988 to provide scientific assessments on what is happening to the world's climate and its implications for human wellbeing. Thanks to IPCC's work, climate change and its potential manifestations are now much better known. The IPCC has also helped to raise awareness and bring climate change on top of the policy agenda.

We hope our report will help to raise awareness of the primary importance to integrate food security and climate change concerns. These challenges are inextricably linked, and so, we think, should be the world's responses.

This report calls attention to the urgent need for action at all levels, starting with local communities and extending up to global organizations. Every nation will have to develop its own strategy to manage climate change and risks. The coping capacity of the poor will have to be strengthened, since poor nations and the poor in all nations will be the first and most to suffer of adverse changes in climate. Anticipatory action will be needed to safeguard the lives and livelihoods of coastal communities. Countries will have to be prepared, where necessary, to resettle “climate refugees”. Food production has to be insulated to the extent possible from climate change impacts, since agriculture constitutes the major source of livelihood in rural areas in most of the developing countries. Sub-Saharan Africa and South Asia are amongst the most vulnerable regions to changes in temperature and precipitation. These are also regions with the highest malnutrition burden. Therefore, concerted action on the part of the global community will be essential to avoid climate change becoming a major calamity.

We hope that our study will be helpful to Member Countries of CFS in developing a strategy for climate resilient agriculture and food security. This year, a dialogue on Agriculture and Food Security has been launched under the UNFCCC. The discussions started in Bonn in May 2012 and will go on in Doha towards the end of the year. I hope that in all these deliberations our suggestions will receive due consideration, for promoting food security, climate smart agriculture and climate resilient food systems. If climate change adaptation and mitigation strategies go wrong, food, water and livelihood security will be endangered, with serious consequences to the lives and livelihoods of millions of children, women and men on our Planet.

Finally I will record my appreciation to the Chairman and Members of the CFS and CFS Bureau and Advisory Group for their guidance and encouragement.

M S Swaminathan, 22 June 2012

SUMMARY AND RECOMMENDATIONS

With many of the resources needed for sustainable food security already stretched, the food security challenges are huge. Climate change will make it even harder to overcome them, as it reduces the productivity of the majority of existing food systems and harms the livelihoods of those already vulnerable to food insecurity. The likelihood of the nations of the world being able to meet the 2°C target of maximal average temperature rise set by the UNFCCC negotiations in Cancun is diminishing with time. If negotiations for global climate policies fail, temperature rises of the order of 4°C by the end of the century, corresponding to the best estimate of the higher emissions scenarios of the IPCC, cannot be discarded. While some might benefit, people in some regions will be affected more than others by changes in average temperature and precipitation. In addition, the likelihood of increased variability and extreme events means that management of risk, both locally and internationally, will be even more important than it is today.

Population growth will continue through 2050 and be accompanied by unprecedented rates of urbanization. These changes will take place mostly in today's developing countries, many of whom will very likely achieve middle-income status. The outcome will be rapid growth in demand for food, both in quantity and quality. Government policies to raise the share of biofuels in energy consumption increase the challenges to our collective ability to achieve sustainable food security.

Contemporary climate change is a consequence of greenhouse gas (GHG) emissions from human activities. According to the IPCC, most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. Agricultural activities including indirect effects through deforestation and other forms of land conversion account for about one third of total global warming potential from GHG emissions today so reducing the direct and indirect emissions from agriculture is an essential part of the larger effort to slow the pace of climate change.

Principal observations

1. Food security vulnerability to climate change begins with biophysical effects at the level of individual farms on plants and animals and the systems in which they are managed. These effects alter livelihoods in rural areas directly and urban areas indirectly. International markets transmit the effects of climate change elsewhere and can affect local food security, both for better and worse, by altering domestic prices and influencing livelihoods.

2. Climate change affects plants, animals and natural systems in many ways. Changes in temperature and rainfall regime may have considerable impacts on agricultural productivity. Average temperature effects are important, but there are other temperature effects too. Little is known in general about the impacts of climate change on the pests and diseases of crops, livestock and fish, but they could be substantial. Climate change will result in multiple stresses for animals and plants in many agricultural and aquatic systems in the coming decades. There is a great deal that is yet unknown about how stresses may combine. Irregular precipitation that already affects the livelihood and production of a large number of rural families is expected to become more serious in the face of climate change.

3. A social vulnerability lens is essential to understand why certain individuals, households, or communities experience differences in food insecurity risks, even when they are in the same geographic region. Vulnerability to food insecurity arises both from biophysical and socio-economic reasons with both nutritional and livelihood effects. Pre-existing conditions of vulnerability make poor people more exposed to the effects of climate change, as social, economic and agro-environmental circumstances may become more severe with climate change.

4. The poor and other vulnerable groups are likely to be at high risk to food insecurity brought about by climate change. Who are the poor? They are people who have few assets and low income earning potential. They include small-holders and landless people in the countryside and marginalized ethnic and Indigenous Peoples. Today they are likely to be located in rural areas and be female and children, but the share of urban poverty is growing and the poor are urbanizing more rapidly than the population as a whole. From a geographic perspective, the vast majority are located in two regions – Sub-Saharan Africa and South Asia - where climate change is likely to be especially pronounced. But food insecurity is reported even in the richest countries and it is possible that development pathways that worsen inequality ignore marginalized groups, or result in degradation of the environment will make more people susceptible to food insecurity from climate change in the future. Small-scale farmers and landless laborers, with limited resources of their own and also likely to be underserved by public and private activities, are particularly susceptible to the socioeconomic effects of climate change, especially if increased variability is not accompanied by improved social safety nets (see the HLPE Report on Social Protection for Food Security). Dryland agriculture in arid and semi-arid regions, where over 40 percent of the world's population and more than 650 million of the poorest and most food insecure people live, is particularly vulnerable to the risks of climate change and variability, drought in particular. In some regions of the world, significant agricultural production takes place in low-lying coastal areas and where current population densities are high. In these regions, and particularly in small island states, a major threat of climate change is from saline intrusion, sea level rise and increased flooding.

5. Adaptation of the food system will require complex social, economic and biophysical adjustments to food production, processing and consumption. Such changes will be most difficult for the poorest and most vulnerable regions and populations. Moreover, climate change models suggest that severe effects are likely to be felt in tropical regions, especially the expected further drying of the arid tropics. Many of the poorest countries are found in these regions and hence the nations least able to adapt may be the most affected. Any hope of making substantial progress on the poverty and hunger Millennium Development Goals thus requires successful adaptation in least-developed countries. But all countries will eventually be challenged by climate change.

6. There are important uncertainties in the way climate will change, magnified at regional and local scales where individual decisions are made. Adaptation should thus be seen in the broader context of building a more resilient food system. Lack of sustainability in food production is a key threat to resilience and needs to be addressed by changes in the way we produce food, by moderating demand for foods such as ruminant products whose production generates especially large contributions to GHG emissions, and in the design of national and international food system governance. Identifying and supporting food production and distribution practices that are more resource efficient *and* have fewer environmental externalities should be high priority. Considering the diversity of environmental and social settings in which food production takes place, solutions for improving sustainability will differ. No single approach will be universally applicable and a much better and sophisticated evidence base is needed to help guide the implementation of the most appropriate, context-specific measures. The communities at greatest risk of food insecurity tend to be in low-income countries. Most measures that facilitate sustainable development with an emphasis on improving the livelihoods of the poorest sectors of society will increase general resilience and assist in climate change adaptation.

7. Examples of strategies for community based adaptation include improving water management practices such as building infrastructure for more efficient irrigation systems and small-scale water capture, storage and use, adopting practices to conserving soil moisture, organic matter and nutrients, using short-cycle varieties and setting up community-based seeds and grain banks. Farmers and food producers alone cannot adapt successfully to climate change. They need to be supported by government and by the private sector, and there is also an important role for civil society organisations.

8. Agriculture is an important driver of climate change. Crop and livestock agriculture globally accounts for about 15 percent of total emissions today. Direct GHG emissions from agriculture include methane (CH_4) emissions from flooded rice fields and livestock, nitrous oxide (N_2O) emissions from the use of organic and inorganic nitrogen fertilizers, and carbon dioxide (CO_2) emissions from loss of soil organic carbon in croplands as a result of agricultural practices and in pastures as a result of increased grazing intensity. Agriculture also causes emissions that are accounted for in other sectors (industry, transport, and energy supply, etc.), from production of fertilizers, herbicides, pesticides, and from energy consumption for tillage, irrigation, fertilization, harvest, and transport. Land use change, much of which is driven by expansion of agricultural area, adds another 15 to 17 percent. And future income and population growth will increase agricultural emissions dramatically unless low-emissions growth strategies for agriculture are found.

9. The dramatic effect of land use change on GHG emissions[2] emphasizes the importance of finding agricultural development strategies that reduce conversion of non-agricultural land to agricultural activities.

10. In the future, most direct increases in agricultural GHG emissions can be expected to take place in regions where crop and livestock production increases, leading to more CH_4 and N_2O emissions. Hence policies and programs to manage CH_4 and N_2O emissions will be particularly important.

11. To compare practices and systems there is a need to consider all emissions generated both directly and indirectly. There is an urgent need for a better assessment of various farming systems taking into account all emissions, direct and indirect.

12. Producing animal products from vegetal and feed input involves biological processes and associated energy requirements and losses, meaning that 1 calorie of animal product requires the production upstream of more than 1 calorie of plant origin to feed the animal. Therefore the proportion of livestock products in a diet is one of the key drivers of its emissions. Slowing the global growth in consumption of livestock products will help to slow the growth of agricultural and food sector emissions. However, many livelihoods depend on livestock, and ruminant animals are very valuable since they can digest cellulose and agricultural residues. Furthermore, in developing countries where indigenous diets include animal protein, high quality protein from livestock products (milk, meat and eggs) will help to improve nutrition.

13. Reduction of food losses and waste could also contribute significantly to mitigate GHG emissions.

14. The last decade has seen a very large increase in the amount of cropland devoted to growing crops for biofuels, both ethanol and biodiesel. Biofuel policies have been criticized on the grounds that they can lead to increased food prices (and hence reduce food security) and that they do little to reduce and may even increase greenhouse gas emissions. There is little evidence that the majority of current policies associated with first generation biofuels contribute to climate change mitigation. The HLPE will review the role of biofuels with respect to food security in a study to be released in 2013.

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[2] Other negative consequences include loss of biodiversity and changes in ground and surface water availability.

Recommendations

1. Integrate food security and climate change concerns

Policies and programs designed to respond to climate change should be complementary to, not independent of, those needed for sustainable food security. Climate change is one of a variety of threats to food security. Interventions designed to increase general food system resilience are highly likely to contribute to climate change adaptation as well. Efforts to increase expenditure just on adaptation would be better directed toward increasing overall expenditures on sustainable food security with particular attention being paid to the unique and uncertain threats from climate change that require action today (public, private and other sectors). In doing so, farmers should be put at the center and location-specific approaches ensuring the needs of communities devised, and taking advantage of their knowledge.

1 a) Increase immediately investments for food security and resilience to climate change

Even without the threats from climate change, meeting food security goals will require substantially more investments to increase productivity. They should also be aimed at increasing the general resilience of the food system.

Investment in the physical infrastructure that allows food producers to be connected to markets and for large urban areas to be supplied with food is critical for general food system resilience and food security. Investments are needed to improve the transportation and marketing infrastructure.

The likely greater frequency of extreme events will increase the risk of disruption of supply networks and place an increased premium on diversified sourcing. Food chain intermediaries and retailers may need access to greater reserve stocks. Investments are also needed to facilitate stock holding and reduce food losses.

1 b) Refocus research for adaptation and mitigation to address a more complex set of objectives, and invest in public research for adaptation

Research on agriculture should fully integrate climate adaptation and mitigation aspects. Though research to increase yields is essential to meet broader food security goals, a continuing and accelerating refocusing of research to address a more complex set of objectives is required to meet the challenges of making food production sustainable and responding to climate change. Assessment of neglected crops, fruit and vegetable productivity; effects of stress combinations; biodiversity and agrosystem efficiency and the efficient provision of ecosystem services, deserve more attention.

Research on mitigation practices should take into account their impacts on food security.

Refocusing research will require meaningful engagement and involvement from the start with farmers and the intended beneficiaries, and a genuine dialogue to understand their needs, taking into account the difficulties that can exist in obtaining the views of women and disadvantaged groups.

1 c) Modernize extension services

Modern revitalized extension services based on different funding models that can involve the public, private and civil society sectors, are urgently needed to face the food security challenges from climate change. To make sure that productivity and resilience enhancing technologies are adopted, extension programs should target those who make the management decisions. A 21st century extension service should work closely with research and the private sector and civil society to increase skills in raising yields sustainably and in dealing with the challenges of climate change.

1 d) <u>Build capacities</u>

In many countries, the physical, institutional, social, biological, and human capacity to deal with climate change and food security challenges is not adequate. Also essential is investment in human capital, particularly education and health infrastructure to build resilience to food insecurity and be aware of and respond effectively to climate change risks.

Information for adaptation and mitigation is an essential element in building resilience and the capacity of populations and nations to anticipate and manage climate change. Knowledge systems with regard to climate change are dynamic and emerging as more information and research become available. Governments and other actors need to strengthen their capacity for responsive and innovative information collection, management and dissemination systems, which can reach everyone, with particular focus on the most vulnerable groups.

Deliberate efforts to build these capacities are urgently needed.

2. Increase resilience of food systems to climate change

Adverse effects of climate change are already apparent in some regions and the eventual effect in all regions is likely to be very negative. Increasing resilience of food systems must be done at every level, from the field to landscape and markets. It generally involves a comprehensive set of actions which have to be coordinated. Farmers and food producers alone cannot adapt successfully to climate change. They need support from government and from the private sector, and there is also an important role for civil society organisations. Climate-change adaptation will certainly require new practices and changes in the livelihood strategies of most if not all food producers as well as other actors throughout the food chain, involving farmers, retailers and intermediaries in the food chain, agri-business, the financial sector and civil society. It will require action and oversight by governments, international organizations, and civil society organizations concerned with food security and sovereignty, hunger and sustainable development. Adaptation measures have to be specific to local circumstances. Climate change adaptation must take into account socially disadvantaged groups, gender differences and in particular the role of women as decision makers in food systems. Many of the recommendations below would be no-regret as they contribute to sustainable food security even without considering climate change, but all have increased urgency with the growing effects from climate change

2 a) <u>Base adaptation measures on assessment of risks and vulnerabilities</u>

Anticipatory adaptation to climate change requires regular assessment of both risks and vulnerability, updated as more information becomes available. Middle- and high-income countries are increasingly carrying out regular assessments but nations without this capacity need external assistance. Careful communication of the inevitable uncertainties to policy makers and more broadly is of great importance.

2 b) <u>Facilitate exchange of practices</u>

Examples of strategies for community based adaptation include improved water management practices such as building infrastructure for more efficient irrigation systems and small-scale water capture, storage and use, adopting practices to conserving soil moisture, organic matter and nutrients, using short-cycle varieties, and setting up community-based seeds and grain banks. The main issues here are dissemination of existing information and knowledge, improving human and social capacity and putting in place the policies that support best practices.

2 c) Facilitate greater diversity in the field and give broader access to genetic resources

Diversification of production is a way to increase resilience of farming systems to shocks in an environment of increasing uncertainties. Efficient adaptation will require access (both physical and legal through appropriate intellectual property rules) to genetic resources, both of existing crops, livestock and their wild relatives, as well as varieties that may be used in the future. Crop genes for drought and flood tolerance should be identified and shared. Yield stability traits of species under variable conditions are particularly important domains where more understanding and research is needed. Food producers, public and private sector institutions, research communities, and governments need to increase cooperation and ensure dissemination, distribution and creation of knowledge and transfer of technologies to characterize, conserve and curate genetic resources both in situ and in seed banks, germplasm stores and related facilities to support adaptation to climate change. All that is possible must be done to minimize genetic erosion of the remaining biodiversity both *in situ* and in gene banks. Adoption by all countries of the International Treaty on Plant Genetic Resources for Food and Agriculture, as well as urgent implementation of its articles 5 (conservation), 6 (sustainable use) and 9 (farmers' rights) would be positive steps in this regard. To increase agricultural biodiversity, measures to develop markets for underutilized species and educate consumers about the importance of dietary diversity would help. The Commission on Genetic Resources for Food and Agriculture could consider identifying priority measures and developing a plan of action on the conservation and use of genetic resources for adaptation to climate change. There is an on-going debate on whether the current intellectual property rights regimes support or hinder development and use of improved plant and animal varieties and agriculture biodiversity. The issue of genetic resources, including intellectual property rights and farmers' rights, is a topic the CFS may wish to recommend for an HLPE study.

2 d) Make weather forecasting available to farmers

One of the challenges of climate change is likely to be coping with a more variable pattern of weather. Access to weather forecasting can improve farmers' ability to cope with increased variability and extreme events provided the information can be disseminated in time to those who need it. Suitably resourced and designed information and communication technology (ICT) can provide this link to national meteorological services.

2 e) Develop integrated land-use policies for adaptation

Efficient climate change adaptation will put a greater premium on the development of integrated land-use policies. Changes in precipitation patterns (in particular the frequency of extreme events) and in seasonal rivers flows will increase the importance of optimising water resources at catchment and aquifer scale. Passive policy measures such as the preservation of forests and mangroves can be as important as active interventions. Mechanisms such as REDD (to protect forests) and other means of payment for ecosystem services should also be included among the tools to increase ecosystem and community resilience to climate change. Urban and peri-urban agriculture can also play an important role in the adaptation of cities.

2 f) Facilitate access of farmers to financial services

To enable farmers to make the necessary changes in their systems, governments need to make financial markets more accessible to small-holders. This includes better access to credit and to insurance schemes to cover these investments and better manage financial consequences of weather risk.

2 g) Promote an international trading regime that incorporates the concept of food security and contributes to the resilience of food systems

As a result of the food crisis of 2008, food security has become a more critical issue in agricultural trade negotiations than in the past. The notion of access to supplies is considered today as important as the traditional notion of access to markets. Current WTO provisions and rules are unclear or deficient regarding food security matters and the Doha negotiating mandate does not allow much room to make progress in addressing these concerns. Moreover, climate change will make the challenge of achieving food security much harder, and it is clear that global food trade will have an important role to play in a world facing climate change. Incorporating all these important issues in any future agricultural trade negotiations would be a step in the right direction.

2 h) Prioritize the actions proposed in National Adaptation Programs of Actions (NAPAs)

Adapting agriculture to climate change and having national adaptation plans is globally very important. The NAPAs, submitted to the UNFCCC by the least developed countries, have highlighted agriculture and food security investments as a priority. They provide a starting point for prioritizing new national investments. Priority measures designed by LDCs in their NAPAs should be financed and implemented. Countries should build upon the experience of the NAPAs to prepare national adaptation plans.

2 i) Food and water security in inland areas

Setting up drought contingency funds and building regional strategic grain reserves, as well as farm and household level grain storage facilities, will be important for food security under climate change.

Both the increase of supply and demand management of water should receive concurrent attention for strengthening water security for crops, farm animals, domestic needs and industry. A sustainable water security system should be developed for each agro-ecological region. There should be a participatory water management system that includes farm families, so that local communities have a stake in both water conservation and sustainable and equitable use.

2 j) Ensure people are more resilient to climate-change enhanced water availability risks

Water is a limited natural resource and a public commodity fundamental to life and health, essential to the realization of the right to adequate food. CFS and national governments should promote and develop research and support programmes aiming at promoting universal access to good quality and sufficient water in rural areas. Participatory methodologies and a leading role for communities are key elements in development of efficient and equitable means of collecting, storing, managing and distributing clean water in ways that respect and protect biomes, preserve natural resources and stimulate the recovery of degraded areas.

2 k) Climate change and water in coastal areas

Nearly one third of the human population lives along the coast. Sea level rise is likely to adversely affect both coastal agriculture and the livelihood security of coastal communities. Anticipatory research and action will be needed to prepare coastal communities to meet the challenges from sea level rise and saline water intrusion. Anticipatory action plans for coastal ecological and livelihood security should include the following: (i) Mangrove bio-shields along seacoasts in compatible agro-climatic zones; (ii) Breeding saline-tolerant rice and other crop varieties; (iii) Development of agro-forestry and coastal aquaculture systems of land and water management; (iv) Conservation and use of halophytes – plants that are adapted to high concentrations of salt. Appropriate organizations, such as the CGIAR, may be encouraged to support and participate in such initiatives.

Nearly 97 percent of the global water resources is seawater and there is need for research on sea water farming involving the spread of agri-aqua farms. The cultivation of economically valuable halophyte and salinity tolerant fish species will help to strengthen the food and livelihood security of coastal communities. We therefore recommend the launching of a scientifically designed seawater farming for coastal area prosperity movement, along coastal areas and small islands.

3. Develop low-emissions agricultural strategies that do not compromise food security

Under a “Business as usual” scenario, an increase in food production will mechanically translate into an increase in emissions, but there are many options possible to enable a decoupling of food security and emissions. In considering mitigation policies and programs for agriculture, care should be taken to choose those that do not negatively affect food security. Fortunately, many of these options create synergies between mitigation and enhanced food security.

Considerable GHG emissions from agriculture can be mitigated by better efficiency in the use of resources (particularly land, livestock and fertilizers) and by good management practices that in many cases also increase productivity and enhance resilience. Public policies and programs should target the development and dissemination of these practices and systems.

Mitigation options must not increase vulnerability to food insecurity. Incentive-based systems that target the vulnerable while mitigating emissions and increasing climate change resilience have multiple benefits.

3 a) Reduce land use change for agriculture

Land use change from systems with extensive above-ground carbon (particularly forests) is second only to fossil fuel emissions as a source of atmospheric CO_2 and much of that conversion is into croplands and pastures. Improving crop yields from land already under cultivation is nearly always a more effective way to mitigate GHG emissions from agriculture than expanding cultivated land area. Ending most conversion of forest to cultivation should be a mitigation priority. Any new land brought under production should adhere to the good practices outlined below.

3 b) Adopt farming and grazing practices to, prevent loss of soil carbon and build carbon soil carbon banks and to prevent land degradation

Soil organic carbon content in agricultural lands is highly dependent on management practices. With well-chosen agro-ecological practices, degraded lands can be restored, contributing to food security, adaptation and to mitigation by increased carbon sinks. Urban organic wastes free from pollutants should be brought back to agricultural land to improve agricultural productivity and mitigate climate change, taking into account the direct and indirect costs of doing so. Policies and programs that increase nitrogen use efficiency have multiple benefits – reducing simultaneously farm input costs, direct and indirect GHG emissions, and off-farm damage to the environment

3 c) Improve livestock and manure management

Emissions associated with livestock agriculture are likely to grow rapidly because of population growth and diet change. Improving productivity to allow farmers to reduce substantially the GHG emissions per unit of output (meat and milk) should be a priority. The benefits of converting manure into bioenergy/biogas and fertilizers through biogas plants include lower net emissions, substitutions of emissions, improved availability of local energy sources, and higher quality fertilizers. Further research is needed in this regard.

3 d) Improve water management in rice fields

Modifying irrigation schemes can significantly reduce emissions from rice fields while saving water and without reducing yields.

3 e) Assess and compare farming systems

There is an urgent need for better assessments and comparisons of various farming systems taking into account all emissions, direct and indirect.

3 f) Manage food consumption for lower emissions in food systems

The role of diet change in reducing the demand for the most GHG intensive food types needs greater attention. Governments should promote responsible consumption, efficiencies throughout the food chain, and reduction of food waste. The private sector should be encouraged to develop products and distribution systems that result in fewer GHG emissions.

3 g) Assess the contribution of various types of biofuels to mitigation and food security

Accounting for the GHG efficiency of biofuels is very complex and compounded with many uncertainties, due to the direct and indirect use of energy in irrigation, inputs, transportation, process, especially nitrogen for the first-generation biofuels, as well as the induced loss of land carbon stocks in case of conversion of forests, wetland, carbon-rich lands in order to grow biofuel crops. Concerns have also been raised on the impact of biofuels on the other environmental challenges including biodiversity, often due to associated conversion to mono-cropping, to the increase of deforestation, threats to natural reserves, and to increased pressures on water supply and water quality problems. Efforts to assess the contribution of various types of biofuels to mitigation are important and must be continued.

3 h) Support farmers to adopt technologies with multiple benefits

Farmers need to be supported to adopt practices that enhance their resilience and food security and that also provide long-term climate benefits. Implementing these changes generally requires an enabling environment, including services and institutions to support farmers, for instance extension services. Also, even if the new practices provide better future incomes, there are barriers to their adoption: up-front costs, income foregone or additional risks during the transition period. These costs have to be covered.
Great expectations have been put in carbon finance to bring additional sources of financing, from emitters in developed countries to individual farmers in exchange of emission reduction or carbon storage. However experience has shown that these mechanisms are difficult to implement and not well suited for smallholder agriculture due to the small size of enterprises which increase transaction costs, difficulty and costs of measurement and reporting, and carbon price volatility. Amongst finance tools, market and non-market mechanisms are being explored with different governance schemes (voluntary carbon schemes, Green Fund, etc.). Whatever the type of support or incentives for improving the overall efficiencies of the food system and internalizing the externalities associated with GHG emissions and sinks, it is recommended that mechanisms take into account both the conditions of small holders and the need for prioritizing measures that improve food security while contributing to mitigation.

4. Collect information locally, share knowledge globally, and refocus research to address a more complex set of objectives

The information base available to facilitate policy and program developments to reduce the food security effects of climate change is woefully inadequate. National governments need to improve their efforts. But there is also a need for international data gathering on climate change and its effects to improve information on vulnerable communities, populations and regions.

Local lessons learned can be made much more valuable when shared. The knowledge already gained by farmers about practices that work in their conditions today could prove invaluable to farmers elsewhere in the future. But some consequences of climate change are outside the realm of recent human experience and focused, systematic data generation efforts are needed to develop effective response efforts. Because the benefits cross national borders, knowledge gathering and sharing requires global coordination as well as national programs.

A major increase in the quality and quantity of the biophysical, economic and social data available to policy makers is required. Particular challenges include (i) linking existing and future data sources using global metadata standards; (ii) making use of modern technology (ICT, remote sensing) to harvest real time data; (iv) enabling disaggregated data collection, including at the intra-household level, to identify drivers of social vulnerability to food security and challenges to mitigation and adaptation; and (v) improving the pipeline from data gathering, analysis and feeding into policy making.

4 a) <u>Collect more biophysical data</u>

Substantial genetic diversity exists in the plants and animals we use for food. But their performance under a range of agroclimatic conditions has not been systematically evaluated. Existing experimental trial data should be supplemented with collection of additional performance information and new trials set up to capture performance characteristics outside of current climate ranges. The quality of existing data about current and historical weather is mixed, with some countries doing a better job than others on collection and dissemination. More needs to be collected and much more needs to be made freely available.

4 b) <u>Monitor existing practices and performance</u>

Adaptation is a learning process. There is much that can be done to adapt agriculture to changing climate using existing knowledge about the social, economic and biophysical aspects of food production. Skills and knowledge currently appropriate for one region might be important in another region in the future. Rigorous evaluation of the effect of mitigation and adaptation interventions for their impacts on the relevant outcomes as well as on food security is needed to ensure there are no unintended negative consequences. Systematic collection and widespread dissemination of this information is essential with modern ICT providing unprecedented opportunities.

4 c) <u>Improve information about vulnerable communities/populations and regions</u>

Major shortcomings in information affect our ability to understand the consequences of climate change for vulnerable regions or groups. Successful adaptation requires greatly improved knowledge of who the vulnerable are and where they live.

4 d) <u>Improve models that facilitate understanding of climate change effects on agriculture</u>

There is a need to improve models and incorporate information about vulnerable communities, populations and regions. Climate models generate vast amounts of data about possible future outcomes but not always summarized in ways that are useful to understanding potential effects on agricultural systems and vulnerable populations. Models that link climate change outcomes to biophysical effects and then to human well-being, require much greater development. Modest investments would provide great support to policy makers everywhere.

There is a need for capacity building on the use of models and scenarios, including proper understanding of their limitations and uncertainties.

4 e) Organize regional sharing of experience and knowledge

Adaptation planning is country driven but, in regard to medium to long term needs, it is necessary to promote subregional and regional exchange of views, sharing of experience, cooperation, coordination on transboundary issues such as water, genetic resources, fisheries, transboundary pests and diseases, etc.

4 f) Refocusing research to address a more complex set of objectives

See recommendation 1 b).

5. Facilitate participation of all stakeholders in decision making and implementation

Addressing food security and climate change requires concerted and coordinated involvement and action of many actors, farmers, private sector, and public actors national and international, civil society and NGOs. It is especially challenging as they are very different, sometimes have conflicting interests and there is a need to work with a long term perspective while most of them have to consider short term outcomes first.

5 a) Promote debate on the roles of the public and private sectors in safeguarding food security in the context of climate change

The actions of all sectors of society play a role in shaping the food security and climate situation. An important question for the future is how the different sectors of the society can mobilize efforts in the same direction for both world food security and climate change and on how they can complement one another.

Climate change implies greater focus on long-term issues and on socio-economic and environmental vulnerabilities. Given controversies over the evolving roles of the public and private sector for food security in a context of climate change, it would be wise to promote greater debate on the actual effectiveness of public-private partnerships by reviewing experiences on the ground.

The participation of the communities affected, including prior and informed consultation about risks, and the direct and indirect impacts on resilience of small-scale farmers and rural communities, should be ensured.

5 b) Involve all stakeholders in public sector decision-making

The changes on the ground needed for both adaptation and mitigation will be undertaken by many actors along the marketing chain from producers to consumers. The public sector develops and implements the policy and program environment in which private sector decisions are made. Civil society is critical in its many roles from monitor of government and private sector actions, to integrator across diverse interests, and to institutional innovator. Activities to address climate change should be done with explicit attention to addressing the needs of the disadvantaged; it is especially important to focus on the role of women as agricultural decision makers and thus integral to the planning, design, and implementation of policies and programs to address climate change challenges to food security.

5 c) Encourage public-public information- and technology-sharing partnerships to share the value of public goods developed and knowledge gained locally

International cooperation between governments on adaptation and mitigation best practices, as well as sustainable technology transfer, is essential to address the impacts of climate change on food security. Regional programs on climate change and food security can be done as part of regional integration initiatives. Learning the lessons of successful national programs that can work regionally can be shared and can help countries to develop their own programs. But lessons learned in one region today might be important in other regions in the future. Institutions that can transfer learning internationally will be needed for both adaptation and mitigation.

5 d) Increase transparency and civil society participation to improve efficiency and equity

Transparency in public sector decision-making about adaptation and mitigation policies and programs is crucial to improve efficiency and equity. Participation by farmers, fisherfolk, and foresters gives them a voice on design that fosters efficient use of resources. Participation by civil society allows other groups that might be affected by climate change, either directly or through the actions of others, to be better informed about potential activities, and to steer the process towards more equitable outcomes.

Governments should ensure that all stakeholders have a voice in order to guarantee the transparency of the process, exchange information and experiences on the relevant issues related to the policies and actions on food security and climate change.

6. Recommendations for the CFS

6 a) Include climate change recommendations in the Global Strategic Framework for Food Security and Nutrition

The CFS is currently preparing a Global Strategic Framework for Food Security and Nutrition. We strongly encourage the inclusion of the recommendations provided here as key elements of this framework.

6 b) Encourage more explicit recognition of food security in UNFCCC activities

Over the past few years of the UNFCCC negotiations, the need for agricultural adaptation and mitigation has figured more prominently. At COP17 in Durban, the negotiators solicited inputs from member countries and observers on issues related to agriculture, in a view of a decision at the COP18 in Doha (December 2012). A work program of the UNFCCC Subsidiary Body for Scientific and Technological Advice, that more clearly identifies the pros and cons of various adaptation and mitigation measures and possible synergies with food security, could provide a forum both for organizing existing research and motivating new research of relevance to the negotiations. We recommend it be implemented. We also recommend more progress under the Work Program on Loss and Damage, emphasizing the impacts of adverse effects of climate change in agriculture and food security. Finally, the CFS should request UNFCCC to charge national governments with reporting on how initiatives and policies that are proposed as part of the National Climate Change Action Plans and National Adaptation Plans also address food security efforts.

Developed countries have already accepted the responsibility for financial support for adaptation activities in developing countries as part of the Copenhagen Accord and the Cancun Agreement under the UNFCCC. The CFS should endorse this position and encourage countries to design their support so that it also supports sustainable food security.

6 c) Support climate change adaptation and mitigation in international trade negotiations

The World Trade Organization has ongoing negotiations on improving the world trading regime (the Doha Round). With increasing variability in agricultural production due to climate change, and the potential for trade flows to partially compensate for climate-related shocks in agriculture, we recommend that the CFS supports inclusion of negotiating outcomes in the WTO that recognize this role. Similarly, we recommend that the CFS encourages the WTO to support trade policy reforms that facilitate rather than hinder mitigation.

6 d) Enhance the role of civil society

The CFS is unique among UN organizations in that it has an official role for civil society. We encourage the CFS to strengthen the existing channels of participation such as the CFS Advisory Group and to support more civil society activities related to the CFS, such as side events at official CFS and other UN meetings, in particular the UNFCCC conferences, to generate more publicity for, and debates on the reports published by HLPE and the decisions taken by the CFS.

6 e) Support the development of a collection sharing mechanism on international data gathering for climate change and food security

The consequences of climate change cross national boundaries. The effects can only be addressed if data gathering is coordinated internationally using commonly agreed metadata standards. Furthermore, there are great synergies to be achieved by coordinating food security data collection with that of climate change to benefit the most vulnerable regions and populations. The CFS should facilitate a dialogue on improved global data collection efforts for climate change and food security.

INTRODUCTION

In its October 2010 annual meeting, the United Nations Committee on World Food Security (CFS) requested its High Level Panel of Experts (HLPE) to conduct a study on climate change and food security, to

> "review existing assessments and initiatives on the effects of climate change on food security and nutrition, with a focus on the most affected and vulnerable regions and populations and the interface between climate change and agricultural productivity, including the challenges and opportunities of adaptation and mitigation policies and actions for food security and nutrition."

We have interpreted this charge to develop a document for national and international policymakers, the private sector and civil society that reports on the following:

- The *current* and *future* challenges to food security from the physical effects of climate change – changes in temperature and precipitation means and variability – with focus on the most affected and vulnerable regions and populations (Chapters 1 and 2).
- The state of knowledge on and need for agricultural *adaptation* to climate change, in the context of the already large challenges to food security from population and income growth in a world where many food-producing systems are already stressed and unsustainable (Chapter 3).
- Agriculture's current contributions to greenhouse gas emissions and the potential for agriculture in *mitigation* while meeting the growing demand for food (Chapter 4).
- Coordinated and coherent national and international policy strategies and actions for dealing jointly with the food security and climate change challenges (Chapter 5).

Climate change impacts food security in many different ways. A short report cannot be fully exhaustive, either about the range of food security challenges or the threats from climate change[3]. Rather, the goal of this HLPE report is to synthesize existing research findings[4] and highlight key issues to help national and international policy makers devise effective and equitable policies to combat the additional challenges to global food security from climate change.

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[3] For example, water is key to food security. Agriculture is the major user of water. Adverse changes in precipitations and temperature are among the challenges which need attention in an era of climate change. This report, focusing on food security, therefore considers some dimensions of water security as they relate to food security and agriculture. But it does not look specifically at the balance of needs of various sectors (hydraulic energy, cities, industry etc) in relation to water security and climate change.

[4] Among others, recent reports dealing with issues related to agriculture, climate change and food security have also provided useful insights (Foley *et al.*, 2011; Giovannucci *et al.,* 2012; Beddington *et al.,* 2012).

1 IMPACTS OF CLIMATE CHANGE ON FOOD AND NUTRITION SECURITY TODAY: ASSESSING VULNERABILITY

1.1 Current food security status

In 1996 the World Food Summit[5] adopted the following definition of food security:

> "Food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."

The four pillars of food security implicitly identified in the above definition are: availability,[6] access,[7] utilization[8] and stability.[9] The nutritional dimension is integral to the concept of food security (FAO, 2009a).

Certainly we have not succeeded in achieving this goal. Even the modest ambition of the hunger target of the Millennium Development goals — halving the proportion of people who suffer from hunger between 1990 and 2015 — is also unlikely to be met on a global basis, although some individual countries will achieve the target. As Tables 1 and 2 show, progress in reducing the global prevalence of undernourishment has slowed: the share of undernourished people in developing regions has remained essentially constant at about 16 percent since 2000, after declining from 20 percent in 1990 (United Nations, 2010), and it is likely to have increased during the global financial crisis that began in the late 2000s. The share of the population that is undernourished is highest in Sub-Saharan Africa followed by South Asia.[10]

Table 1. Selected poverty and food security statistics

Number of undernourished people (2006-2008)[1]:	850 million
Developed regions	*10.6 million*
Developing regions	*839.4 million*
Share of children under 5 years with underweight (2009)[1]	18 %
Number of people below the poverty line ($1.25/day) (2008)[2]	1,289 million
South Asia	*570.7* million
Sub-Saharan Africa	*386.0* million
East Asia	*284.4* million
Latin America and Caribbean	*36.9* million

Sources: 1 – FAOSTAT http://www.fao.org/economic/ess/ess-fs/fs-data/ess-fadata/en/.
2 – World Bank, Poverty and Equity Data http://povertydata.worldbank.org/poverty/home#.

5 1996 World Food Summit Plan of Action available at http://www.fao.org/wfs/index_en.htm.

6 Availability is the supply side of food security, determined by production, stocks and trade.

7 Access is influenced by incomes, markets, and prices.

8 Utilization focuses on how the body takes advantage of the various nutrients. It is influenced by care and feeding practices, food preparation, dietary diversity, and intrahousehold distribution.

9 Stability brings in the time dimension. Periodic shortfalls in food availability are a sign of food insecurity, even if current consumption is adequate.

10 At the same time, overnutrition is a growing problem in many parts of the world. Overweight affects more than 1 billion people globally, and obesity affects at least 300 million. Since 1980, obesity has more than doubled worldwide, with threefold or more increases in some areas of North America, the United Kingdom, Eastern Europe, the Middle East, the Pacific Islands, Australasia, and China (see WHO website at http://www.who.int/mediacentre/factsheets/fs311).

Looking forward, population growth accompanied by unprecedented rates of urbanization will continue through 2050. These changes will take place mostly in today's developing countries, many of whom will very likely achieve middle-income status. The outcome will be rapid growth in demand for food, both in quantity and quality. Government policies and mandates to increase the share of biofuels in energy consumption increase the challenges to our collective ability to achieve sustainable food security. With many of the resources needed for sustainable food security already stretched, the food security challenges are huge.

Table 2. Global estimates of undernourishment (hunger), 1969–2010

Period	Number of undernourished (millions)	Prevalence (percentage)
1969-71	875	33
1979-81	850	25
1990-92	848	16
1995-97	792	14
2000-02	836	14
2006-08	850	13
2009	1023*	18
2010	925*	16

Source: FAO, 2010 (for 1969-71 and 1979-81) and FAOSTAT for others (http://www.fao.org/economic/ess/ess-fs/fs-data/ess-fadata/en/). * Data for 2009 and 2010 are FAO extrapolations based on United States Department of Agriculture projections.

Climate change is already affecting food security. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC, 2007a). Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases: the average temperature rose by about 0.3°C during the first half of the 20th century, and by another 0.5°C in the second half up to the beginning of the 21st century (IPCC, 2007a). Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations (IPCC, 2007a).

As its effects become more pronounced, climate change will make the challenge of achieving food security even harder. Its effects on food production and distribution may increase poverty and inequality, with consequent effects on livelihoods and nutrition.

1.2 Vulnerability, food insecurity and climate change

One of the foci of this report is on the effects of climate change on food security[11] and nutrition, with a focus on the most affected and vulnerable regions and populations.

According to the FAO,[12] food insecurity exists when people are not able to secure access to an adequate and safe diet which constrains them from leading an active and healthy life today. In addition, those who are currently food secure may become vulnerable to food insecurity in the future.

[11] FAO, 2008 provides a useful discussion of the basic concepts of food security, including vulnerability.

[12] http://www.fao.org/hunger/en/.

People who are already poor are vulnerable to hunger because they lack the resources to meet their basic needs on a daily basis (they face *chronic food insecurity*). They are also highly vulnerable to even small shocks that will push them closer to destitution, starvation, even premature mortality. People who are not poor now but face the risk of future poverty are vulnerable to hunger if these risks materialize and they are inadequately protected (they face *transitory food insecurity*).

Vulnerability is a complex concept that needs to be considered across scales and various dimensions (Carpenter *et al.,* 2001). A rich research discussion exists around the conceptual frameworks of vulnerability and its application to environment change (see for example Cutter *et al.*, 2009; Janssen and Ostrom, 2006; Adger, 2006).

For this report, we consider vulnerability of agricultural systems, communities, households and individuals to climate change and the ways these vulnerabilities could lead to increased vulnerability to food insecurity. Vulnerability is influenced by the degree of exposure of systems, communities, households and individuals to climate change. It is typically described as having three dimensions – exposure to risks, their magnitudes, and sensitivity to them, which both determine the magnitude of impacts, and the ability to respond and adapt or resilience.

Household-level vulnerability is most often associated with threats to livelihoods. Either livelihoods are inadequate because of resource constraints and low productivity (e.g. farmers with too little land and no access to fertilizer), or livelihoods are risky and susceptible to collapse (e.g. droughts that cause harvest failure). Importantly, the majority of food producing smallholders in many countries are net buyers of food (an estimated 73% of smallholders in Ethiopia and 74% in India), which leaves them vulnerable to both production and market-related risks (de Janvry and Sadoulet, 2011). Livelihood shocks can affect individuals (illness, accidents, retrenchment), or entire communities (floods, epidemics, livestock disease) (Dercon, 2005), or entire economies (financial crises, natural disasters, conflict, widespread food price hikes) (Lustig, 2000). Households with strong and diversified assets, including social networks, are better placed to survive livelihood shocks than households with few assets and no social support systems. Vulnerability can increase over time if households face repeated shocks that steadily erode their assets. One function of social protection is to install 'safety nets' to prevent this happening (HLPE, 2012) - for example, by providing cash or food transfers or public works employment during periods of crisis and during the annual 'hungry season', as an alternative to having poor households sell their productive assets to buy food. An under-appreciated feature of vulnerability is that it is persistent and recurrent, sometimes cyclical (e.g. seasonal).

Potential impacts of climate change on food security include both direct nutritional effects (changes in consumption quantities and composition) and livelihood effects (changes in employment opportunities and cost of acquiring adequate nutrition). Climate change can affect each of these dimensions. Both biophysical and social vulnerability are critical as one considers the impact of climate change on food security. Social vulnerability examines the demographic, social, economic, and other characteristics of the population that affect their exposure to risk and their ability to respond to and cope with negative shocks. A social vulnerability lens is essential to understand why certain individuals, households, or communities experience differences in impacts even when they are in the same geographic region.

The nature of impacts. Climate change affects vulnerability to food insecurity in the first instance through its biophysical effects on crop, livestock, and farming system productivity (see Chapter 2 for more discussion). Changes in temperature and precipitation means and increased variability translate into changes in average levels and variability in food production, with follow-on effects on income for food producers and food affordability for net purchasers in rural areas and for urban consumers. Expected increases in climate variability will result in increased variability in agricultural production leading to more price and income fluctuations. Management of risk by all participants in the food system, from individuals and households to nations, will be ever more important.

The magnitude of impacts. The magnitude of impacts on systems, communities, households and individuals depends importantly on the exposure and sensitivity to climate change effects which varies by region and population. Some regions will be injured more than others by changes in temperature and precipitation means and distribution, and it is possible that some will benefit, at least initially. Effects will be felt directly in rural areas and indirectly in urban areas via higher prices and more variability. The effects are both *direct* via local changes in local precipitation and temperature and *indirect* via biophysical changes elsewhere that affect livelihoods locally, say by changing world prices. Some groups will be more affected than others either because they depend on agricultural production for their income or because they devote a greater part of their income to food.

The ability to respond. Resilience to climate change has different dimensions as the focus turns from plants and animals through agricultural systems to individuals, households, communities and countries. Individual plants and animals have relatively well-defined vulnerabilities to changes in climate, discussed in more detail below. Agricultural systems can be made more resilient by changing practices, altering planting dates and changing the mix of varieties or species. Human resilience arises from the resources at the disposal of the individual or household, physical, social or financial.

The poor are likely to be particularly vulnerable to food insecurity brought about by climate change. The well-off can afford to 'buy' food security, at least in the near term. But food insecurity occurs today even in the richest countries and it is possible that the choice of a development pathway that worsens inequality or results in degradation of the environment will make more people susceptible to food insecurity from climate change in the future (Pieter *et al.*, 2011).

The poor are often resource poor in several dimensions, not just financial. Who are the poor? As Table 1 shows, over 20 percent of the world's population are below the $1.25 a day poverty line (about 1.3 billion people). They are overwhelmingly located in two regions – Sub-Saharan Africa and South Asia, where climate change is likely to be especially pronounced (see Chapter 2) – but can be found in many parts of the world.

Today they are likely to be located in rural areas and be female and children. As Table 3 shows, even though the rate of urbanization among the poor is faster than in the general population, poverty in developing countries today is still mainly concentrated in rural areas (Ravallion *et al.*, 2007). But another study by Ravallion *et al.* (2008) finds that as urbanization continues, urban poverty rates will likely rise. Climate change could significantly increase the risk of severe undernourishment for these poor primarily through effects on food availability and expense. For the rural poor the effects on agricultural productivity add a further challenge.

Table 3. The changing face of poverty

		Number of poor (millions)			**Percent of developing world's population below each poverty line**			**Urban share of the poor** (percent)
		Urban	**Rural**	***Total***	**Urban**	**Rural**	***Total***	
$1 a day	1993	236	1 036	*1 272*	13.5	36.6	*27.8*	**18.5**
	2002	283	883	*1 165*	12.8	29.3	*22.3*	**24.2**
$2 a day	1993	683	2 215	*2 898*	39.1	78.2	*63.3*	**23.6**
	2002	746	2 097	*2 843*	33.7	69.7	*54.4*	**26.2**

Source: adapted from http://www.imf.org/external/pubs/ft/fandd/2007/09/ravalli.htm.
Data from: Ravallion *et al.*, 2007.

In addition to economic status, climate change can also deepen the fault lines of existing inequalities that operate along several social axes – gender, race, age, marital status and so on.[13] Gender is an

[13] There is fairly extensive research on the social characteristics influencing vulnerability to climate change see Cutter *et al.* (2009).

important consideration and is discussed in greater detail subsequently. Young children and older populations can also be at greater risk due to their dependency, financial or physical, on other household members. Communities that have been historically disadvantaged or marginalized are likely to be overrepresented among the poor. Even when such communities are not considered poor in the financial sense, they may still be vulnerable to food insecurity due to their lower social status. Using only one of these characterizations may fail to capture the complexity of interactions that increase vulnerability to food insecurity.

Access to food is also conditioned by power imbalances in the social and political sphere. For example, support for community-led initiatives such as food banks and state-financed food distribution systems may be reduced during times of economic hardship induced by climate change.

There is likely to be substantial overlap between the poor and vulnerable, those who are food insecure and those affected by climate change. Climate change adds to the challenges of improving their well-being. But there are many other determinants of poverty and challenges to the vulnerable. Attempts to address climate change vulnerability independently risk using resources inefficiently and losing opportunities for synergies. At the same time, climate change brings unique challenges that require new thinking about existing food security efforts. Thus, an important policy recommendation is that programs and policies to deal with climate change must be part of sustainable development efforts to reduce poverty and inequality, and enhance food security.

The threats to sustainable food security include population growth mostly in today's developing countries with growing incomes in a world where resource constraints are already limiting productivity growth in some places. Climate change adds to the challenges from other threats. All four pillars of food security are affected by changing climate means and increasing variability. These effects will be felt, and must be dealt with, throughout the systems that link producers through markets to consumers, whether local or in distant countries. Local social-environmental systems are where the immediate effects of climate change are felt and are therefore key actors in societal responses to climate change. But global, national *and* local social and political institutions will all play important roles in managing the effects of climate change on food security and need to work together to find ways to reduce risks and ensure food security and nutrition for all.

1.2.1 Food systems and climate change

An important aspect of how climate change affects food security is differences in modes of agricultural production both locally within a particular region and across the globe.

Food availability begins on millions of farms around the world. Farmers use land, their family labor and possibly that of others, and various kinds of equipment to manage the process of producing food. They choose what to produce based on the natural resources at their disposal (including soil quality and climate), the inputs they have access to (both previous investments such as irrigation systems and current inputs such as seed and animal varieties), and the market situation they face. Some portion of what they produce is transported off the farm, either by farmers themselves or traders transporting it to processors or to intermediate or final markets at home or abroad. This set of activities from farm to table is the food system.

Food systems are extremely diverse, both within individual countries and across national boundaries. Climate change will not affect all systems the same, hence the need to assess different policy and program approaches. At the same time policy choices influence the evolution of agricultural systems, which can impact climate change and food security.

Food systems differ in many dimensions. At the farm, the dimensions include the scale of farm operation, the degree to which farm output is sold, the extent to which farm operations are undertaken primarily by family and other labor or with substantial use of machinery, and the degree of mixed outputs (different crops, crop and livestock outputs, and other ecosystem services[14]), sometimes referred to as multifunctionality.[15]

Box 1. What is a small scale farm?

What we refer to as small-scale farming goes by many names with varying definitions. It is also known as small farmer, smallholder, family or peasant farmer, subsistence, and family agriculture. Participants in small-scale farming include family farmers, herders and pastoralists, landless and rural workers, forest dwellers, fisherfolk, gardeners, indigenous peoples and traditional communities (ActionAid, 2009).

Governments must translate these qualitative concepts about small-scale farming into official definitions for policy implementation. Official definitions of small scale farming vary dramatically across countries and incorporate different elements. In Asia, cultivated area is a typical measure and a common cutoff is 2 hectares. In Brazil, the official definition of a family farm (roughly equivalent to a small-scale farm) is 5-110 hectares depending on region of the country, uses predominantly family labor, and provides the bulk of the family income. In the U.S. the definition is based on sales volume, with farms having sales less than $50,000 considered small.

One common organizing approach to describing agricultural systems is a dichotomy that contrasts small scale with large scale farming. The IAASTD report (2008) states that “The two systems differ greatly in terms of resource consumption, capital intensity, access to markets and employment opportunities” (IAASTD, 2008, p. 44). A central element of scale is the agricultural area under the control of a farmer, both in its own right and because it is often correlated with other elements of a farm operation, such as use of and access to capital resources, the share of marketed output, the degree of mono- versus-multi-crop practices and information on new inputs and management techniques. Almost three quarters of all farms globally are less than 1 hectare (von Braun 2005). With some assumptions about farm size, it is possible to estimate that farms of 20 hectares or less accounted for about 25 percent of total cultivated area globally in the early 2000s. However this global average hides dramatic differences. Average farm sizes in Asia and Africa are well below 10 hectares while the average North American farm is well over 100 hectares. In Africa and Latin America, small-scale farming represents approximately 80 percent of all farms (Nagayets, 2005). In Latin America small-scale farms produce up to 67 percent of total output and create up to 77 percent of employment in the agricultural sector (FAO 2011d).[16]

Small-scale farming operations play several critical roles in addressing the needs of vulnerable populations. They “feed poor communities – including themselves” along with the majority of the world population (IAASTD, 2008, p. 22). They manage a sizeable share of the agricultural land, employ a large share of the poorer working community, provide access to food at the local and the regional level, and sometimes have less harmful environmental impacts. According to FAO (FAOSTAT, 2010), the number of people working in agriculture grew from 2.5 billion in 2000 to 2.6 billion in 2010 with the share of total population in agriculture declining from 42 percent to 38 percent. Global averages conceal great differences across countries. As a general rule, the share of the population working in

[14] The benefits people obtain from ecosystems (Alcamo *et al.*, 2003). These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

[15] The concept of multifunctionality highlights the interconnectedness of agriculture as a multi-output activity producing not only marketed outputs such as food, feed, fiber, and medicinal products, but also non-marketed outputs such as landscape amenities, ground and surface water management, and biodiversity changes (IAASTD, 2008).

[16] The sources from which these statistics are drawn do not all use the same definition of small farm.

agriculture declines as a country develops and has higher income per person. Thus small-scale farming must play a major role today in addressing the challenges of climate change. At the same time, it must be recognized that urbanization is proceeding rapidly in all parts of the world. Using the United Nation medium variant population and urbanization estimates,[17] almost 69 percent of the world's population will be living in urban areas by 2050 and the rural population will decline from 3.4 billion in 2010 to 2.9 billion in 2050. At least in some parts of the world, farm populations will decline and farm sizes eventually grow. The HLPE is preparing a study on constraints to smallholder investments, for release in 2013.

Box 2. Extreme weather in Ghana affects women disproportionately

A study in northeast Ghana shows that women subsistence farmers were disproportionately affected by drought and floods. Particularly vulnerable were single women who lacked the household labor to plant a labor-intensive crop like rice. They also could not harness the community support that married women could to help undertake house building and repairs (Glazebrook 2011).

We know too little about how crops and livestock grown and management practices change with scale to identify global patterns consistently, but it is commonly assumed that small-scale farms are more likely to engage in diversified crop and livestock agriculture, which might be more resilient to climate change. On the other hand, small-scale operations are less likely to have access to extension services, markets for new inputs and seeds, and loans to finance operations. Gaining a better understanding of the differences in farm activities, and vulnerabilities to climate change is critical, both to finding ways to improve food security and to deal with the challenges which climate change poses to agricultural productivity and stability.

1.2.2 Role of women in agricultural production

To address the direct climate change threats to agriculture, policies and programs must target all those who are involved in agricultural production. A joint report by the World Bank, the Food and Agriculture Organization of the United Nations and the International Fund for Agricultural Development (2009) estimated that women account for 60 to 90 percent of total food production. In developing countries as a whole, women constitute approximately 43 percent of the agricultural labor force, ranging from 20 percent in Latin America to 50 percent in Southeastern Asia and Sub-Saharan Africa (FAO 2011a).[18] Hence, programs that are being designed to improve agricultural production should target women as well as men. Providing women who manage agricultural operations with extension advice would seem to be a cost-effective way to deliver information about improved farming practices generally and climate change responses in particular, yet is rarely adopted in practice (IAASTD, 2008).

Beyond the issue of access to information, women are typically disadvantaged in other aspects of farming such as access to productive inputs and services and land ownership. Women are less likely to enjoy the same level of access to agricultural inputs as men (Dey-Abbas, 1997; Quisumbing, 1996; Thapa, 2008 as cited in Agarwal, 2011) and other productive inputs and services including credit, technology, equipment, extension services, fertilizers, water, and agricultural labor; all inputs needed to cope with climate change (World Bank, 2009; FAO 2011a). While there is very little systematic gender-disaggregated data on ownership of key assets such as land, the few studies that exist (see FAO 2011a for details) point to large gaps in land holdings. Among all agricultural land holders in West Asia and North Africa less than 5 percent are women while this figure is approximately 15 percent for Sub-Saharan Africa. At a regional level, Latin America has the highest average share of female agricultural holders. A recent study found that overall incidence of land ownership in the rural

[17] http://esa.un.org/unpd/wup/index.htm.

[18] These numbers would imply that labor productivity for women is much higher than for men, with little evidence to support that.

population in the state of Karnataka in India was 39 percent for men and only 9 percent for women (Swaminathan, *et al.* 2011). Evidence suggests that on average, female-headed households own smaller plots than male-headed households. Women are also constrained with regard to livestock ownership.

These gendered constraints directly affect women's farm productivity. According to FAO (2011a), developing countries can achieve productivity gains of 2.5 to 4 percent with an associated decline of 12-17 percent in undernourished people by addressing the gender gap in agriculture. While this study did not address climate change specifically, it is possible that the productivity gains would be even greater if the effects of climate change are considered.

Both efficiency and welfare benefits argue for designing policies and programs that target food security programs generally and climate-change-specific activities to women.

1.2.3 Biological effects of climate change on crops, livestock and agricultural systems[19]

Crops respond most favorably to environments similar to those they evolved in – maize in Central America, potatoes in the Andes, wheat in the Middle East, rice in South Asia – and for the climate conditions in which they evolved. Breeding efforts extend the range of environmental possibilities, and that is especially true for crops that have substantial genetic diversity or the greatest commercial demand. Considerably more research has been done on the effects of climate change on grains than on roots and tubers, horticultural crops and feed crops, and there is much more information available on its impacts in temperate climes than in the tropics, and in land-based systems than in marine-based systems.

Climate change affects plants, animals and natural systems in many ways. In general, higher average temperatures will accelerate the growth and development of plants. Most livestock species have comfort zones between 10-30°C, and at temperatures above this, animals reduce their feed intake 3-5 percent per additional degree of temperature. In addition to reducing animal production, higher temperatures negatively affect fertility. Some of the other impacts of climate change on animals are mediated through effects on the plants they eat.

Rising temperatures are not uniformly bad: they will lead to improved crop productivity in parts of the tropical highlands and high latitudes, for example, where cool temperatures are currently constraining crop growth.

Average temperature effects are important, but there are other temperature effects too. Increased night-time temperatures reduce rice yields, for example, by up to 10 percent for each 1°C increase in minimum temperature in the dry season. Increases in maximum temperatures can lead to severe yield reductions and reproductive failure in many crops. In maize, for example, each degree day spent above 30 °C can reduce yield by 1.7 percent under drought conditions. Higher temperatures are also associated with higher ozone concentrations. Ozone is harmful to all plants but soybeans, wheat, oats, green beans, peppers, and some types of cotton are particularly susceptible.

Changes in temperature and rainfall regime may have considerable impacts on agricultural productivity and on the ecosystem provisioning services provided by forests and agroforestry systems on which many people depend. There is little information currently available on the impacts of climate change on biodiversity and subsequent effects on productivity in either forestry or agroforestry systems.

[19] This section draws heavily from Thornton and Cramer (forthcoming, 2012) and summarizes its findings.

Globally, the negative effects of climate change on freshwater systems are expected to outweigh the benefits of overall increases in global precipitation due to a warming planet. The atmospheric concentration of CO_2 has risen from a pre-industrial 280 ppm to approximately 392 ppm in 2010, and was rising by about 2 ppm per year during the last decade. Many studies show that there is a CO_2-related yield increase ("CO_2 fertilization") for C_3 crops but that this effect is limited, if not insignificant, on C_4 plants such as maize and sorghum. There remains considerable uncertainty about the impact of increased CO_2 concentrations on plant growth under typical field conditions. While increased CO_2 can have a beneficial effect on yields, it might also affect negatively nutrient composition for the crop (see discussion below) and also depends on whether plant growth is limited by other factors such as water or nutrients.[20] In some crops such as bean, genetic differences in plant response to CO_2 have been found, and these could be exploited through breeding. Increased CO_2 concentrations lead directly to ocean acidification, which (together with sea-level rise and warming temperatures) is already having considerable detrimental impacts on coral reefs and the communities that depend on them for their food security.

Vegetables are generally sensitive to environmental extremes and high temperatures and limited soil moisture are the major causes of low yields in the tropics. These will be further magnified by climate change (Peña and Hughes, 2007).

Little is known in general about the impacts of climate change on the pests and diseases of crops, livestock and fish, but they could be substantial. Within some limits, insects reproduce more rapidly with higher temperatures, and are more likely to overwinter in temperate locations. Many weeds perform well under increased CO_2 concentrations.

For example, yams and cassava are crops that are known to be both well adapted to drought and heat stress (Jarvis *et al.*, 2012), but it is thought that their pest and disease susceptibility in a changing climate could severely affect their productivity and range in the future. Potato is another crop for which the pest and disease complex is very important and how these may be affected by climate change (including the problems associated with increased rainfall intensity) is not well understood.

Climate change will result in multiple stresses for animals and plants in many agricultural and aquatic systems in the coming decades. There is a great deal that is yet unknown about how stresses may combine. For example, in rice there is some evidence that a combination of heat stress and salinity stress leads to additional physiological effects over and above the effects that each stress has in isolation.

Most studies of the biological effects of climate change on crop production have focused on yield.[21] A second impact, much less studied, is how the *quality* of food and forages are affected by climate change; i.e., the composition of nutrients in the individual food items and the potential for a changing mix of foods as crops and animals respond in different ways to a changing climate. Grains have received the most attention – with both higher CO_2 levels and temperature affecting grain quality. For example, Hatfield *et al.* (2011) summarize research showing that protein content in wheat is reduced by high CO_2 levels. FACE experiments in the US reported by Ainsworth and McGrath (2010) and in China by Erda *et al.* (2005) show substantially reduced protein content and minerals such as iron and

[20] A 2006 report on the Free-Air CO_2 Enrichment (FACE) experiments of CO_2 fertilization (Long *et al.,* 2006) finds that the effects in the field are approximately 50 percent less than in experiments in enclosed containers. And another report (Zavala et al. 2008) finds that higher levels of atmospheric CO_2 increase soybean plants' susceptibility to the Japanese beetle and maize susceptibility to the western corn rootworm. Finally, a 2010 study (Bloom *et al.,* 2010) finds that higher CO_2 concentrations inhibit the assimilation of nitrate into organic nitrogen compounds. The FACE experiments are done in experimental settings with adequate nitrogen. However, when nitrogen is a limiting factor, the CO_2 fertilization effect is dramatically reduced. Ainsworth *et al.,* 2008 has described inconsistencies between the field (FACE) and laboratory (chamber) experiments, and modeling results.

[21] See http://climate.engineering.iastate.edu/Document/Grain percent20Quality.pdf for more details on climate change effects on grain quality.

zinc in non-leguminous grain crops for CO_2 concentrations that are likely to occur by mid-century. Wrigley (2006) reported that yield increase in wheat due to doubling of CO_2 comes from more grains rather than larger grains and produces lower protein content and higher starch content. The International Rice Research Institute (IRRI, 2007) reported that higher temperatures will affect rice quality traits such as chalk, amylase content, and gelatinization temperature.

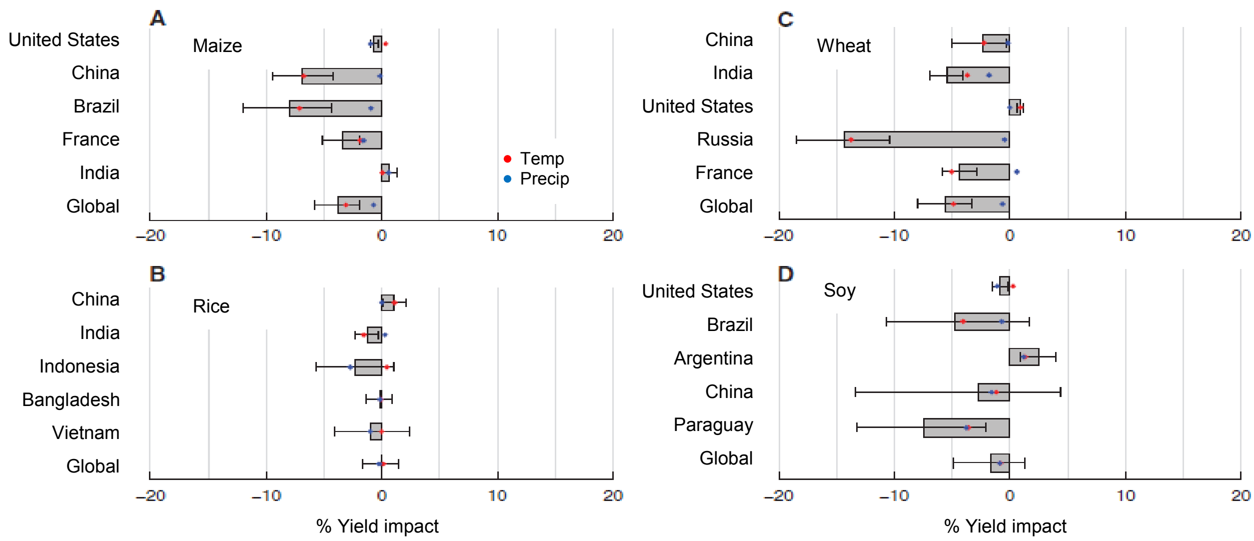
Systematic studies of the effects of changes in temperature and precipitation across the range of crops, livestock, and fish are in their infancy and more research is needed to understand the consequences and identify promising avenues for productivity and resiliency enhancing investments.

Studies are urgently needed that investigate “stress combinations” and the interactions between different abiotic and biotic stresses in key agricultural and aquaculture systems.

1.2.4 Evidence of climate change effects on agricultural production

Evidence is mounting of the links between human-induced GHG emissions, climate change, and effects on agricultural productivity. For example, recent research by David Lobell and colleagues (Lobell, *et al.*, 2011) strongly suggests that observed rising temperatures in the second half of the 20th century and early years of the 21st century, and accompanying changes in precipitation, have already had demonstrable and varying effects on agriculture across the globe. According to these findings, there are dramatic regional differences in the recent past (1980-2008) in terms of change in growing season temperature: small changes are found in North America whereas large increases are found in other parts of the world, particularly Europe and China. This translates into very different changes in yields as shown in Figure 1. Focusing on maize, the U.S. shows essentially zero effect of observed climate change on yield trends, while for China, Brazil, and France, a substantial slow of yield growth is found. However, regional crop production in some countries have benefited from higher temperatures, observations supported by northward shifts in maize area in the U.S. (Hatfield *et al.*, 2011), rice area in China (Hijmans, 2007), and wheat area in Russia (Ivanov, 2004; Ivanov and Kiryushin, 2009). Rapidly increasing GHG emissions, especially in developing countries, combined with growing evidence of negative climate change effects on agriculture, the likelihood of nonlinear effects of temperature on yields, and hints of the added burden of more frequent extreme weather events suggest an extremely serious challenge for sustainable food security.

Figure 1. Estimated net impact of climate trends for 1980–2008 on average crop yields for major producers and for global production



Grey bars show median estimate; error bars show 5% to 95% confidence. Red and blue dots show median estimate of impact for temperature trend and precipitation trend, respectively.

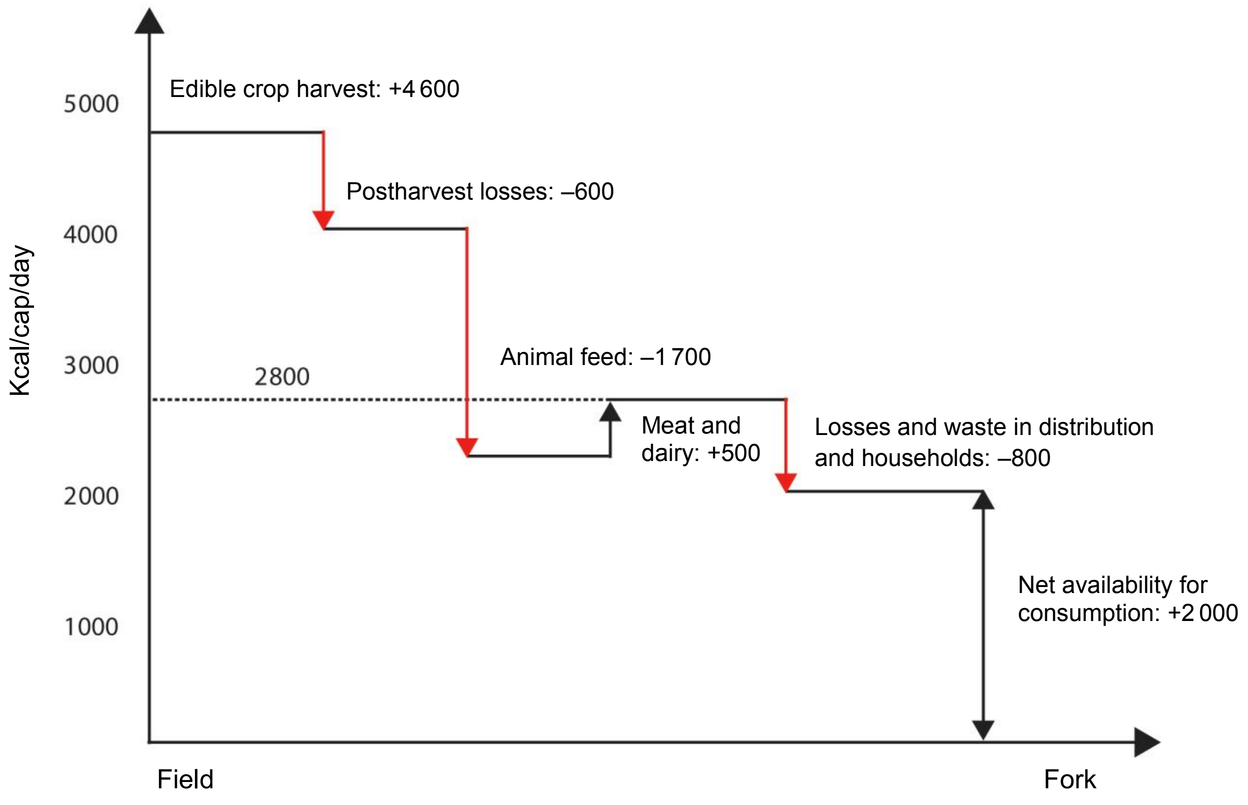
Source: Lobell *et al.* (2011).

1.2.5 Climate change effects and food security interventions from harvest to consumer

Figure 2 illustrates the potential for enhancing food security by interventions after harvest, reducing negative effects from climate change, and reducing the impact of food production on climate change. Based on an analysis by Smil (2000), harvest losses on farm, from harvest practices and poor storage, account for 13 percent of harvested output, and occur predominantly in developing countries. Higher temperatures and greater humidity from climate change will encourage more damage in stored grain from insects and fungal attacks. Animals consume another 37 percent of the harvest. Distribution losses and waste, particularly important in developed countries, account for a further 17 percent of the harvest. Higher temperatures from climate change will increase the need for refrigeration in the food distribution network.

Investments to reduce losses after harvest will also reduce agricultural GHG emissions. Policies and programs to reduce meat consumption where it is currently harmful to human health would significantly reduce feed use, making more available for direct human consumption and reducing pressure to expand agricultural areas.

Figure 2. Losses, conversions and wastes in the global food chain – from field to net household consumption



Source: adapted from Lundqvist *et al.* (2008), based on Smil (2000).

1.2.6 Climate change and livelihoods

Access to food can be affected by climate change due to the disruption of livelihoods and price volatility of staple foods. Individuals with high risk of food insecurity are largely concentrated in rural areas where food production takes place so their livelihoods will be directly affected by local effects of climate change and indirectly by effects in other parts of the world.

Box 3. Wild harvested food and climate change

According to Arnold *et al.* (2011) around one billion people, likely to be among the poorest of the poor, rely on wild harvested products for food and income. For instance a study by Nasi *et al.* (2011) provides data showing that approximately 4.5 million tons of bush meat is extracted annually from the Congo Basin forests alone. Wild animal and plant foods add not only considerable calories but also much needed protein and micronutrients. As climate change alters ecosystem functioning it is possible that these important foods for the poor will be negatively affected. It is also likely that relying on this food source may become a more important adaptation strategy during natural disasters, droughts, and floods.

Policy approaches and interventions governing access are typically focused on the household. But intra-household food allocation choices may lead to differential effects of climate change on access. “Women’s” work often includes fetching water, fuel wood collection, food preparation and caring for all household members, leaving women little time to engage in cash-generating activities. When environmental degradation caused by climate change increases the time spent on activities like water collection, it drives down further women’s ability to earn an income. Given intra-household dynamics it is conceivable that women and girls are affected more acutely during scarcity than men and boys.

Beyond quantity, determinants of the effective utilization of food include access to clean water and dietary diversity, and maternal education for child nutrition (Smith and Haddad, 2000). Climate change may increase the challenges of providing clean water on a regular basis as extreme events, both droughts and floods, put pressure on water delivery systems.

Consumption of a range of fresh fruits and vegetables and moderate amounts of protein sources (vegetable, animal or fish-based) and starchy staples is recommended by nutritionists. However, dietary trends around the world are towards more consumption of processed food products with a large proportion of sugars, fats and oils, leading to growing concerns about overnutrition and negative health consequences of obesity, even in developing countries (World Health Organization, 2011). Historically, efforts to alleviate hunger have emphasized provision of food with sufficient energy (calorific) content, and public sector research resources have been devoted to improving the productivity of the major staple crops, especially rice, wheat, and maize. These three crops currently account for 50 percent of total calorie consumption globally and with much higher shares in developing countries (FAOSTAT). Fewer research resources have been devoted to fruits and vegetables. However, fruits and vegetables are extremely valuable for dealing with micronutrient deficiencies. They also provide smallholder farmers with much higher income and more jobs per hectare than staple crops (AVRDC, 2006). The worldwide production of vegetables has doubled over the past quarter century and the value of global trade in vegetables exceeds that of cereals (AVRDC, 2006). More research is needed on the effects of climate change on fruit and vegetable productivity.

Periodic inadequate access contributes to food insecurity and results in a reduced nutritional status (FAO, 2008). Crop production is cyclic with availability during periods after harvest met either by local storage or supply from other regions, domestic or international. Access in the off-season requires availability and income to store food or purchase it.

Local prices and access stability can also be affected by climate change effects elsewhere. For example, international grain flows have long been seen as a mechanism to at least partially compensate for the increased variability that climate change will bring. The food price spikes that began in 2008 were driven in part by weather events that are likely to become more frequent with climate change. An unfortunate response in some countries was to limit the amount of grain that could be exported, exacerbating the effects on availability and raising prices in other parts of the world. The report of the HLPE on price volatility and food security (HLPE, 2011a) includes a recommendation on the important role of a transparent, accountable and rules-based trading system to manage food price volatility. This recommendation becomes ever more relevant as climate change effects become more pronounced.

The communities at greatest risk of food insecurity tend to be in low-income countries. Most measures that facilitate sustainable development with an emphasis on improving the livelihoods of the poorest sectors of society will increase general resilience and indirectly assist in climate change adaptation. Investment in agriculture and food production as part of development assistance has until recently been accorded relatively low priority. This is now changing. In the international arena, developed countries approved the L'Aquila Initiative on Global Food Security in 2009 with the objective of investing 20 billion dollars in 3 years to encourage rural development of poor countries. At the regional level, the CAADP compact (the Maputo Declaration) committed African countries to spend 10 percent of government expenditure on agriculture. Nevertheless, there have been decades of low investment in food production systems and the importance of such investments as part of a multifaceted approach to create sustainable and resilient rural livelihoods needs greater emphasis. Monitoring and evaluation of different strategies to achieve these goals are critical. The growth of large urban centres and “megacities”, especially in low-income countries, poses special issues for food security, in particular the development of resilient supply chains and means of dealing with food price volatility. More attention to urban and peri-urban agriculture as a response to addressing the food insecurity in the cities could improve food availability and access for urban populations.

1.3 Policy messages

Programs and policies to deal with climate change must be part of efforts to reduce poverty and enhance food security. Attempts to address climate change vulnerability that are undertaken independently risk using resources inefficiently and losing opportunities for synergies. At the same time, climate change brings unique challenges that require modifications to existing food security programs.

Improvements in productivity are essential to deal with food security challenges. Climate change necessitates research into crops, livestock and systems that are resilient to variability and extreme events.

Food production systems are extremely diverse, both within individual countries and across national boundaries. Climate change will not affect all systems the same, hence the need to adopt a range of policy and program approaches. Small-scale farms account for a large share of global agricultural land use and rural employment today, and often are operated by women. They are more likely to engage in mixed crop and livestock agriculture, which might be more resilient to climate change. On the other hand, small-scale operations are less likely to have access to extension services, markets for new inputs and seeds, and loans to finance operations. Policies which address the limits facing small-scale farmers, and which ensure that women have opportunities for equal access to information and resources will have important productivity, resiliency and poverty-reducing benefits for food security generally and for dealing with climate change. There are both efficiency and welfare reasons for targeting food security programs generally and climate-change-specific activities to women.

Inadequate information is available to deal effectively with many aspects of the food security challenges from climate change. We highlight two areas where more information would be especially valuable to reduce vulnerability to climate change.

- The biophysical effects of climate change on plant and animal productivity and stability of production, including the effects on pests and diseases that affect food production and post-harvest marketing system. Most information is available on the large staple crops, less on livestock (including fish), and even less on fruits and vegetables.
- How crops and livestock grown and management practices differ with scale and gender and will be affected by climate change.

2 ASSESSING IMPACTS OF CLIMATE CHANGE ON FOOD AND NUTRITION SECURITY TOMORROW: PLAUSIBLE SCENARIOS OF THE FUTURE

2.1 Introduction

Chapter one reviewed how food and nutrition security has been and is currently affected by climate change in various regions and among various groups, particularly the most vulnerable. This chapter presents perspectives on how *future* climate change might affect food and nutrition security including social, economic and biophysical outcomes for vulnerable groups in regions and food systems where climate change risks are high.

Because of the complex dynamics among climate, ecosystem change, food production, distribution, utilization; general socioeconomic development, institutional change and various dimensions of human wellbeing and poverty, scenarios are useful to explore possible future outcomes. “Scenarios are plausible and often simplified descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces and relationships.” (Millennium Ecosystem Assessment, 2005). Scenarios fall in the middle ground between facts and speculations where both complexity and uncertainty are substantial. It is often most helpful to use a variety of scenarios, constructed from ranges of plausible drivers, to better understand the range of plausible futures.

Scenario development starts with identifying potential outcomes in the future for which more understanding might help to inform better policy changes today. The climate change community has used scenarios extensively to assess the host of economic, social and institutional drivers that determine levels of human-induced GHG emissions (Nakicenovic *et al.*, 2000). Implicit (and sometimes explicit) in these scenarios are changes to the natural, economic and social systems that form the socio-ecological infrastructure critical for economic development, poverty alleviation and human wellbeing. Plausible futures for a range of non-climate variables (population, income, technology) are therefore necessary to add to climate scenarios to develop food security scenarios that include the effects of climate change.[22]

Vulnerability of food and nutrition security to climate change is a function of all the driving factors mentioned above. Biophysical changes from climate change affect food availability through supply impacts (e.g., changes in average yields and increases in variability) and the resulting challenges to livelihoods of producers. Climate change also has important implications for food distribution and access as they depend on climate-resilient road infrastructure, markets and other social and economic institutions. In addition to these supply side effects, climate change might affect utilization (demand by consumers), not only through effects on their incomes but also consumption behavior. Consequences for food stability could come from increased incidence of extreme events leading to more frequent temporary food shortages and stresses on resource availability and contributing to political unrest.

This chapter begins with a review of scenarios of the temperature and precipitation effects of climate change and their consequences for food production and availability. It then reports on recent scenario exercises that combine socioeconomic and climate change scenarios to assess the effects on other pillars of food and nutrition security and various dimensions of human well-being.

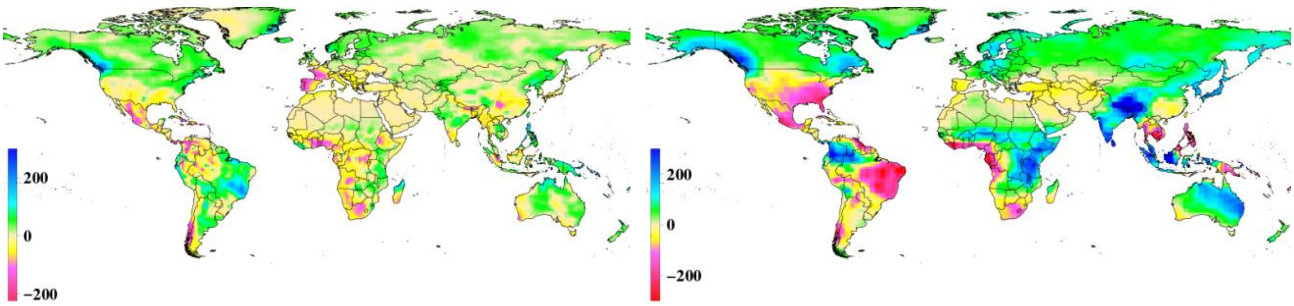
[22] Other groups have used scenarios to explore many topics, including ecosystem challenges (Millennium Ecosystem Assessment, 2005), energy futures (Shell International BV, 2008), and water scarcity (Alcamo and Gallopin, 2009).

2.2 Climate scenarios and vulnerability of food and nutrition security to climate change

Periodically, the Intergovernmental Panel on Climate Change (IPCC) issues assessment reports on the state of our understanding of climate science and interactions with the oceans, land, and human activities.[23] While the general consequences of increasing atmospheric concentrations of GHGs are becoming increasingly better known, great uncertainty remains about how climate change effects will play out in magnitudes and in specific locations. At this point there is no single emissions scenario that is viewed as most likely. Furthermore, the climate outputs from different GCMs using identical GHG emissions scenarios differ substantially, with no obvious way to choose among them.

All GCM results show generally increasing temperature and precipitation.[24] However, global averages from the GCMs conceal both substantial regional variability and changes in seasonal patterns. The divergence between GCM outcomes in predicting future precipitation trends is particularly stark. Figure 3 maps the average annual changes in precipitation between 2000 and 2050 from the CSIRO and MIROC GCMs using the A1B[25] scenario. There are large differences in the two models' predictions for many regions of the world. For example, although the MIROC GCM with the A1B emissions pathway results in substantially greater increases in average precipitation globally, there are certain regions such as the northeast part of Brazil and the eastern half of the United States, where this GCM reports a much drier future. And Eastern Africa and Bangladesh have a much wetter future. Should this scenario be realized, there would be sizeable negative effects on agricultural production in those regions.

Figure 3. Change in average annual precipitation (mm), 2000–2050, A1B IPCC scenario
Left map: CSIRO model, Right map: MIROC model.



Green/Blue show increase of precipitation. Pink/Red show decrease of precipitation.
Source: Nelson *et al.*, (2010) based on downscaled climate data available at: http://www.cgiar-csi.org/data/item/54-futureclim.

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[23] Integrated assessment models (IAMs) simulate the interactions between humans and their surroundings, including industrial activities, transportation, and agriculture and other land uses; these models estimate the emissions of the various greenhouse gases. The emissions simulation results of the IAMs are made available to the GCM models as inputs that alter atmospheric chemistry. The end result is a set of estimates of precipitation and temperature values around the globe.

[24] See Table A2.3 in Nelson *et al.* (2010) for information on regional differences in temperature and precipitation outcomes.

[25] The A1B scenario is one of several scenarios reported in the IPCC special report on emissions scenarios as part of its third assessment activities (Nakicenovic *et al.*, 2000). The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1B scenario has a balance in technological improvements across all energy sources.

The scenario uncertainties at the global level are magnified at regional and local scales where individual adaptation decisions are made. This represents a serious challenge to informed policy and decision making everywhere but especially for regions and production systems that are dependent on rainfall (dryland agriculture) and which are home to many of the world's most vulnerable people. Appropriate adaptation strategies would differ significantly depending whether one needs to deal with likely more drought or flooding episodes.

2.3 Scenario outcomes: vulnerable regions, systems and people

Climate change effects on agriculture and food security are productivity loss in the first instance. Changes in precipitation and temperature will in most locations reduce average yields and increase variability in production. In some locations, a combination of temperature and precipitation changes might result in complete loss of agricultural activity; in a few locations agriculture might become possible. Many studies have used climate scenario model outcomes in crop growth simulation models to assess potential impacts on yields (Reilly *et al.*, 2003; Parry, *et al.*, 2004; Cline, 2007; Challinor *et al.*, 2009; Nelson *et al.,* 2010) with a wide range of potential outcomes depending on crop, region, GCM and climate change scenario. Figure 4 shows how different climate scenarios can result in very different effects on yields. With identical GHG emissions pathways (the A1B emissions scenario), the MIROC GCM climate results in substantial rainfed maize yield declines between 2000 and 2050 in the U.S. corn belt and parts of Brazil and substantial yield increases in parts of India while the CSIRO GCM yield effects are less negative and less varied across the globe. Across the range of crops and climate scenarios modeled in Nelson *et al.* (2010), the yield effects range from increases in a few places to declines of as much as 30 percent. More generally, crop model outputs are likely to understate the biophysical effects of climate change because they do not account for pests and disease stresses. They however overstate climate change damages as they do not fully account for adaptation responses by agricultural producers unless coupled with socioeconomic models. Improved understanding of the potential effects of climate change (particularly uncertainties about precipitation futures) on agricultural productivity is critical to developing appropriate adaptation strategies for different regions and systems.

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007e) argues that, "Recent studies indicate that increased frequency of heat stress, droughts and floods negatively affect crop yields and livestock beyond the impacts of mean climate change, creating the possibility for surprises, with impacts that are larger, and occurring earlier, than predicted using changes in mean variables alone. This is especially the case for subsistence sectors at low latitudes. Climate variability and change also modify the risks of fires, pest and pathogen outbreaks, negatively affecting food, fiber and forestry."

2.3.1 Vulnerable regions

Studies suggest that among the regions that are likely at risk of future climate change, the arid and semi-arid areas of the tropics, particularly in the Sahel of sub-Saharan Africa, South and West Asia, North Africa, India and parts of the dry Andes in Latin America, are the most vulnerable, particularly to further drying (Swaminathan and Kesavan, 2012). "The dry areas of the developing world occupy about 3 billion hectares and are home to 2.5 billion people: 41 percent of the earth's land area and more than one-third of its population. About 16 percent of this population lives in chronic poverty." (CRP 1.1, 2011).

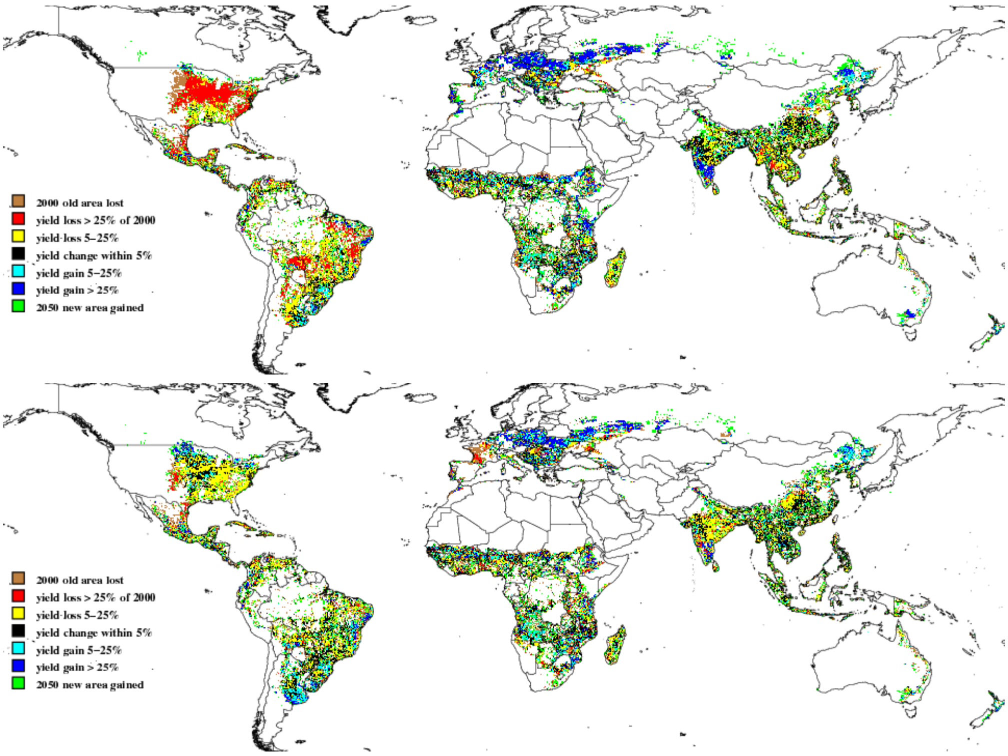
2.3.2 Vulnerable systems

Among the most vulnerable systems are pastoralists and smallholder farmers systems in dry areas with extensive holdings whose vulnerability is expected to worsen with climate change. Results from Cline (2007) suggest that India and Africa are where the highest crop productivity declines are expected. Similar results of adverse productivity effects of climate change are predicted for livestock (Nienaber and Hahn, 2007; Thornton *et al.*, 2008) and marine fisheries (A. L. Perry *et al.*, 2005). Thornton *et al.* (2008) projected highest vulnerability (both biophysical and social) to climate change in rangeland-based livestock and mixed crop-livestock rainfed arid-semiarid systems in Africa.

A continent-wide study of climate change impacts on agriculture conducted in 11 African countries covering key farming systems and agro-climatic zones suggests that specialized crop and livestock farming (mono systems), particularly under dryland in arid and semi-arid regions, are the most vulnerable to future climate damages (Hassan, 2010; Dinar *et al.*, 2008).

Coastal ecosystems, where about 40 percent of the world population lives, are at risk from flooding and sea-level rise (Agardy and Alder, 2005; Nicholls, 2004). Countries such as Vietnam, Bangladesh and Egypt where large portions of agricultural production are in low-lying coastal areas and small island nations could see significant production loss from flooding and saline intrusion. Recent assessments of impacts of climate change on the productivity of the fisheries could not agree definitively on negative or positive aggregate effects at the global level but revealed huge spatial differences. There is a general agreement that while catch potential is predicted to increase in poleward regions (Greenland, Norway, Alaska and Russia) significant decreases in primary fish productivity is predicted southwards (Indonesia, Chile, USA and China). The highest vulnerability of marine fishery production is predicted among tropical nations (Cheung *et al.*, 2010, R. I. Perry, 2010; Rice and Garcia, 2011).

Figure 4. Yield effects, rainfed maize, A1B IPCC scenario
Top map CSIRO model, bottom map MIROC model.



Red and yellow: yield loss. Dark and light blue: yield gain.
Source: Nelson *et al.*, (2010), Figures 9 and 10.

2.3.3 Farm size

In terms of farm size, situations (see 1.2.1) and trends are different between regions. There is mounting evidence that farms are becoming larger not only in the USA, Canada and Australia but in many other parts of the world, mainly as a consequence of economic growth (Hazell, 2011). Relative land abundance and recent trends in massive land acquisitions in some countries of sub-Saharan Africa seem to support the predicted likelihood of larger farms even in Sub-Saharan Africa (Deininger and Byerlee, 2011; Eastwood, 2010). At the same time, the number of small farms has been increasing in Sub-Saharan Africa (Jayne, 2012).

Climate change could increase the vulnerability of small farms because they are likely to have limited access to technologies to adapt to climate change because of weaknesses in the extension and credit systems. This will have to be considered in the framing of national agricultural development policies. And if these land transactions also result in conversion of forests and woodlands to agriculture, GHG emissions will worsen.

In this regard the recommendation of the HLPE report on land tenure and international investments in agriculture (HLPE, 2011b) is particularly relevant: governments must strengthen and secure rights to land for millions of land users who currently have uncertain tenure over their resources. The Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security,[26] recently approved, by CFS further states (paragraph 23.1) that "States should ensure that the legitimate tenure rights to land, fisheries and forests of all individuals, communities or peoples likely to be affected, with an emphasis on farmers, small-scale food producers, and vulnerable and marginalized people, are respected and protected by laws, policies, strategies and actions with the aim to prevent and respond to the effects of climate change consistent with their respective obligations, as applicable, in terms of relevant climate change framework agreements".

2.3.4 Urbanization

Urbanization will change the nature of climate change adaptation. With the expected growth in urban population and with most of the change taking place in the current developing world, supporting food and nutrition security for the urban poor and vulnerable will require special adaptation strategies (Royal Society, 2012; Satterthwaite *et al.*, 2010). In a business-as-usual scenario, this growth in urban demand will most likely be satisfied not from small family farms but rather from distant large commercialized production systems in breadbasket regions through long food supply chains (Deininger and Byerlee, 2011). Moreover, markets are predicted to become more concentrated with urbanization and the trend in dietary shifts towards more processed food and a higher share of animal protein exacerbated. These processes could worsen climate mitigation challenges if they result in replicating the current land, energy, and GHG-emissions-intensive models of agricultural production and supply and distribution chains (Bezemer and Headey, 2008; Timmer, 2009); (Royal Society, 2012; Satterthwaite, 2010). In addition to the potential of innovative urban agriculture (Redwood, 2009; Lee-Smith, 2010), recent trends in decentralized urban development; that is, smaller cities with good infrastructure within green sites (Royal Society, 2012; Satterthwaite *et al.*, 2010) could provide an alternate model that is more climate friendly.

[26] http://www.fao.org/fileadmin/user_upload/nr/land_tenure/pdf/VG_Final_May_2012.pdf.

2.3.5 Conflict

Climate change is expected to increase conflicts over access to and control of resources such as land and water. It may also exacerbate social and political volatility in regions where access to resources is restricted (e.g., water resources in west and central Asia and mobility of pastoralists in many parts of the developing world). The Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security contain important provisions to prevent and address conflicts over land (see paragraph 25).

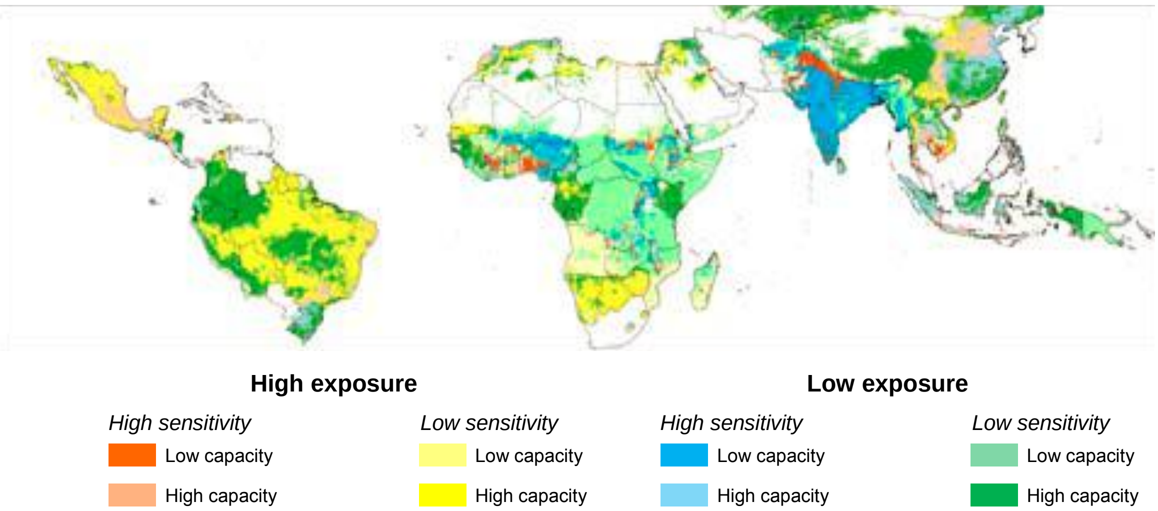
2.4 Scenarios that combine biophysical and socioeconomic outcomes

A few efforts have been undertaken to assess plausible futures. We review two here.

2.4.1 Combining current vulnerability with future availability

Some studies have attempted to construct scenarios that describe access outcomes by combining what is known about *current* vulnerability with changes in *future* availability. A recent study by Ericksen *et al.* (2011) uses this technique to construct a domain-based threshold (high and low) assessment of overall vulnerability based on three components of vulnerability – exposure, sensitivity, and coping capacity – in developing countries. For example, Figure 5 maps vulnerabilities linked to changes in length of growing period (LGP). In the most vulnerable domains, 14.2 million hectares will likely have a signifiant change in LGP with a total population affected of 401 million. They find that other effects of climate change will challenge vulnerable regions and populations in different ways.

Figure 5. Vulnerabilities linked to the changes in length of growing period (LGP)



Dark red areas are of highest vulnerability: high exposure (>5%), high sensitivity and low coping capacity. Dark green areas are of lowest vulnerability: low exposure (<5%), low sensitivity and high coping capacity.

Source: Ericksen *et al.* (2011).

2.4.2 Scenarios that combine biophysical and socioeconomic futures

A few studies have included socioeconomic as well as climate change drivers and allowed for some elements of adaptation. We report results from one of these to indicate the range of plausible outcomes. Nelson *et al.* (2010) combine a range of crop productivity scenarios based on five different climate futures with three combinations of population and GDP futures (low population-high GDP growth, high population-low GDP growth and an intermediate population-GDP growth scenario) to assess the range of plausible outcomes for food security and human well-being. This study uses both proxy (per capita income, average kilocalorie availability per day) and direct measures of food insecurity (number of malnourished children under five).

Average kilocalorie availability

In low-income developing countries today, average kilocalorie availability is only two-thirds of the availability in the richest countries. Looking out to 2050, the study finds that with high per capita income growth and no climate change, average kilocalorie availability in this group of countries reaches almost 85 percent of that in the developed countries. With the high population-low GDP growth scenario, however, average availability declines in all regions by 2050.

Number of malnourished children under five

For low-income developing countries, the number of malnourished children declines 36.6 percent under the low population-high GDP-growth scenario, but under the high population-low GDP-growth scenario the number *increases* by more than 18 percent—an increase of almost 17 million children. For middle-income developing countries, the low population-high GDP growth scenario results in a 50 percent decline in the number of malnourished children; under the high population-low GDP-growth scenario, the decline is only 10 percent.

Climate change exacerbates the challenge to reduce the number of malnourished children. Climate change increases the number of malnourished children in 2050 relative to a no-climate-change future by about 10 percent for the low population-high GDP-growth scenario and 9 percent for the high population-low GDP-growth scenario. In low-income countries, under the low population-high GDP-growth scenario, climate change increases the number of malnourished children by 9.8 percent; under the high population-low GDP-growth scenario, by 8.7 percent. These climate change effects are relatively small, as are the differences in price (and other) outcomes, because international trade flows partially compensate. For example, changes in developed country net cereal exports between 2010 and 2050 range from an increase of 5 million mt in the perfect mitigation scenario to a decline of almost 140 million mt. Trade flow changes partially offset local climate change productivity effects, allowing regions of the world with less negative effects to supply those with more negative effects. Two policy messages are clear. Broad based sustainable economic development is critical in reducing vulnerability. To deal with the uneven spatial distribution of climate change effects, the *relatively free movement of food across international borders can be an important, if partial, adaptation to climate change.* In that respect, the HLPE report on price volatility recommends that "Governments should continue to focus on building a transparent, accountable and rules-based multilateral trading system. However, these rules need to give a larger place to public policy concerns regarding food security, better account for the heterogeneity of World Trade Organization (WTO) member states and taking into account special needs of poor and vulnerable countries or social groups."

None of these global scenario efforts attempt to address distributional issues within countries and the possibility that climate change affects the vulnerable disproportionately.

2.5 Data and modeling issues

Although our ability to model the complexities of both the biophysical and socioeconomic aspects of climate change to produce plausible scenarios has advanced dramatically in the past few decades, major shortcomings affect our ability to understand the consequences of climate change for vulnerable regions and groups. While the GCMs are generally consistent in their predictions of higher temperatures globally, they differ dramatically in the precipitation outcomes. Anticipating likely climate change and planning for its consequences requires good climate and climate-impact modeling. There is an urgent need for better climate models that can be "downscaled" to smaller geographical regions, and which can better predict the consequences for agriculture. Validating and refining these models will require access to far better resources than those existing at the moment. Crop models are able to accurately reproduce crop responses to weather and temperature inputs within existing ranges, but their ability to perform in the range of future outcomes is much less certain. And they perform poorly in assessing the effects of changing pest and disease pressures that might arise from climate change.

Models of socioeconomic scenarios, especially those that include climate change effects, are in some ways more complicated than either climate or crop models. They must take into account biophysical effects and include them as part of the complex behavior of human systems. In many ways they are the weakest link in our understanding of the vulnerability of food systems to climate change.

Quantitative scenario exercises of the effects of climate change have not dealt with the consequences of increased variability from climate change. Although climate scientists are confident that increased variability will occur, based on the underlying physics of the atmosphere, the GCM outputs have not been designed to provide the necessary data on variability needed by the crop models that are used to assess climate effects on agricultural productivity. There is a critical need for transdisciplinary efforts to address this lacuna.

The studies undertaken to date tend to focus on average shifts rather than changes in variability and extreme events. Most of them do not account for adaptation, either autonomous or anticipatory. And they focus exclusively on the challenges from climate change without considering changes in socioeconomic factors (income, population, government policies and programs, etc.).

Weaknesses in all three types of models – climate, crop and socioeconomic – used to construct scenarios of the effects of climate change and other drivers on the vulnerable mean great uncertainty at global, national and local scales about policy and program responses to climate change. Significant efforts are needed to improve the functionality of these individual models as well as their interactions. In addition, the data needed to construct these models are of poor quality and data collection efforts need significant resources and wide collaboration among many agencies supported by appropriate policy actions. Platforms and mechanisms for improved linkages and communication between climate information providers (early warning agencies, meteorological services) and users (farmers, resource managers, food security programs, etc.) are necessary.

2.6 Policy messages

Plausible climate and socio-ecological change scenarios can be invaluable tools in developing appropriate response options for ensuring food security and human wellbeing in the future.

Climate change effects on the vulnerable are significant but are by no means the only threats to sustainable food security. Sustainable development efforts that lead to broad-based economic growth are essential to addressing the needs of vulnerable people and regions. Given the uncertainties in local and regional outcomes of climate change, policies and programs that are based on specific climate scenarios could potentially be counterproductive. Rather, efforts should be based on activities that provide both sustainable economic growth and increase resilience to a wide range of potential climate change threats.

The likelihood of the nations of the world being able to meet the 2°C target of maximal average temperature rise set by the UNFCCC negotiations in Cancun is diminishing with time. If negotiations for global climate policies fail, temperature rises of the order of 4°C by the end of the century, corresponding to the best estimate of the higher emissions scenarios of the IPCC, cannot be discarded.

Dryland agriculture in arid and semi-arid regions of Asia, Africa and Latin America is particularly vulnerable to the risks of climate change and variability (particularly drought). Most vulnerable in dry areas are pastoralists and smallholder farmers with extensive systems whose vulnerability is expected to worsen with climate change. Setting up drought contingency funds, as well as farm and household level storage facilities, and appropriate adaptation strategies for sustainable agriculture and building regional strategic reserves will be important policies for food security in these regions.

Coastal areas where current population densities are high and economic assets are concentrated are at significant risks of expected sea level rise and increased flooding, with small island nations at high risk. The productivity of tropical nations' fisheries is likely to be especially vulnerable to future climate change and variability.

Population growth with unprecedented rates of urbanization is predicted through 2050 with much of that growth in today's developing countries, leading to substantial growth in demand for food, both quantity and quality. Feeding a rapidly growing urban population presents a particular challenge to reducing GHG emissions as this demand will most likely be met not from small family farms but rather from high input, large production systems and energy-intensive long supply chains. Food and nutrition security for the urban poor and vulnerable will require special adaptation strategies including the potential for innovative urban agriculture and decentralized urban development.

Scenario development faces major methodological and data limitations. An important challenge is the ability of current climate models to predict how climate change effects will play out in magnitudes and in specific locations, particularly uncertainties about precipitation.

3 ADAPTATION: RESPONSE OPTIONS FOR FOOD SECURITY CHALLENGES FROM CLIMATE CHANGE

3.1 Introduction

The IPCC (2007d) defines adaptation as:

> “Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc.”

Humans have had to adapt the way they produce, process and consume food to changing circumstances since agriculture came into existence after the last ice age. The challenges (and opportunities) posed by climate change thus need to be seen in the context of the ever changing biophysical and socioeconomic environment within which the now globalised food system exists. However, the need for the food system to adapt to climate change has several unique features. First, climate change will affect the whole globe so all food production systems will need to make changes. Second, adaptation will need to occur at a time when the food system is suffering many other pressures: for example increased demand from a larger and wealthier global population, increasing competition for water, land and other inputs, and almost certainly higher (and more volatile) energy prices.

Adaptation of the food system will require complex social, economic and biophysical adjustments to food production, processing and consumption. Such changes will be most difficult for the poorest and most vulnerable regions and populations. Moreover, climate change models suggest that particularly severe effects are likely to be felt in tropical regions, especially the expected further drying of the arid tropics. Many of the poorest countries are found in these regions and hence the nations least able to adapt may be the most affected. Any hope of making substantial progress on the poverty and hunger Millennium Development Goals thus requires successful adaptation in least-developed countries. But all countries will eventually be challenged by climate change.

Climate-change adaptation starts from an assessment of risks and vulnerabilities of a specific system, of how climate change will modify them and what impact it will have on food security. There is seldom a single best way to adapt. And adaptation does not necessarily require new technologies, but is often mobilizing existing practices and resources in a different orientation. Adaptation can require substantial changes in the food system and therefore will need to build on comprehensive approaches.

Any change in agricultural and food systems has a range of consequences which all have to be considered and accounted for. Special consideration must be given to socially disadvantaged groups, gender differences and in particular the critical role of women in the food system. This must be done in a sophisticated way, for example recognizing that women are not a single homogeneous set and that there are also groups of vulnerable men. Care must be taken to anticipate the consequences of proposed adaptations on gender-specific workloads and whether they may exacerbate existing inequalities between men and women, or be used to preserve existing gender norms, both within households and communities. The opportunities of using disadvantaged groups and women as agents of change should be realized. The critical importance of institutional and social adaptation is very important to stress.

Adaptation to climate change will need to take many different forms. In this report we make a number of different distinctions (see Box 4).

Box 4. Adaptation terminology

- *General versus specific measures*. In addition to climate change, the food system will be affected by other factors that show both secular changes (e.g. increased competition for water from a larger population) as well as increasing volatility (the expectation for energy prices). General measures that make the food system more resilient to any stress will help in adaptation to climate change. But climate change will bring its own specific problems (and less frequently opportunities): in particular new patterns of weather. Food producers will need to make specific adjustments to these new conditions.

- *Reactive versus anticipatory adaptation*. Food producers can simply react to changing climate or measures can be put in place to anticipate the changes likely to occur. Though anticipation would appear to be the best strategy it is constrained by limits on our ability to predict the course of climate change, and socio-politically by the difficulties of implementing costly measures to cope with not-yet visible threats. Involvement of producers, including small scale farmers organizations and women's producers groups, directly in anticipatory planning, may increase the likelihood of successful outcomes. Improvements in early warning systems are needed to take advantage of the latest biophysical and socioeconomic modeling efforts. “Adaptive management” strategies that incorporate flexible responses to changing circumstances are somewhat intermediary.

- *Autonomous versus planned adaptation.* Communities and small scale food producers will autonomously respond to present and anticipated climate change. Local seed and grain banks provide mechanisms for the maintenance and transmission of experiential knowledge of value for autonomous adaptation. Alternatively, strategies for adaptation may be developed by government or other agencies within a planning agenda. Approaches that blend the two strategies are likely to be most efficient.

- *Recognizing the value of existing local knowledge, implementing best practices and creating new knowledge.* Much can be done to adapt to climate change using existing knowledge and practices, including the experience gained by individual farmers over many years of on-farm research on what works best in specific places, taking into account the local social, economic and environmental context. The main issues here are dissemination of existing information and knowledge, building human and social capital and putting in place the policies that support best practices. But the challenges of adapting to climate change will require new knowledge across all fields of the natural and social sciences concerned with the food system – a major new research agenda.

Climate-change adaptation will certainly require new practices and changes in the livelihood strategies of most if not all food producers as well as other actors throughout the food chain. But the changes required are more systemic and must involve farmers, retailers and intermediaries in the food chain, agri-business, the financial sector and civil society. It will require action and oversight by governments, international organizations, and civil society organizations concerned with food security and sovereignty,[27] hunger and sustainable development.

[27] Food sovereignty is defined as “the right of peoples and sovereign states to democratically determine their own agricultural and food policies” (IAASTD, 2008).

3.2 Contemporary adaptation

While the evidence that anthropogenic climate change is already occurring is increasingly strong, its effects on the food system are as yet relatively modest and difficult to disentangle from other drivers. Thus the northward shift in maize production in North America and of rice production in China may be influenced by a changing climate but also by other factors such as biofuels policies and changing diets. As the effects of climate change begin to accelerate it will be increasingly important to put in place systems to monitor and evaluate different approaches to adaptation, and to learn from and disseminate best practices.

There are, however, many lessons for responding to climate change from the way different parts of the food system have successfully adapted to other drivers of change with resulting greater resilience and strengthened food security. Adaptation should address vulnerabilities of food systems, mobilizing practices and techniques ranging from the use of the latest biotechnology techniques, precision agricultural engineering, and modern means of livestock husbandry to agroecological and agroforestry approaches that include elements such as soil organic matter enhancement (which also contributes to GHG mitigation), water management, multiple cropping or polyculture systems, use of local genetic diversity and sustainably using agricultural biodiversity (see for example, FAO, 2011b; Altieri *et al.*, 2011; IAASTD, 2008; United Nations General Assembly, 2010; Clements *et al.*, 2011). There is not space here to review this large topic but we give two brief examples in Box 5.

Box 5. Contemporary adaptation: two examples

Global warming increases the energy in the atmosphere and it is likely that the intensity of extreme events such as hurricanes and typhoons will increase (IPCC, 2012). Food producers, especially those in vulnerable low-income countries and regions, will need to adopt practices to minimise the negative consequences of more severe weather. Studies in Nicaragua have demonstrated that farmers adopting a spectrum of agroecological practices such as crop rotation, green manure, the use of natural fertilizers, cover ditches, crop diversification and reduction in burning frequency lost 18 percent less arable land, preserved 40 percent more topsoil and enhanced soil quality compared to controls after a major hurricane (Holt-Gimenéz, 2002).

Some regions have experienced major increases in soil salinization due to excessive water extraction for agriculture. This trend is likely to be exacerbated by changes in the pattern of precipitation that will occur with climate change. Also soils can become salinized as sea level rise increases the frequency of salt water incursions. Australian scientists have recently developed a variety of durum wheat that has 25 percent higher yield on saline soils (Munns *et al.,* 2012). The gene responsible was discovered in a wild relative of wheat and incorporated into the crop using non-GM techniques.

These examples show how the lessons of contemporary adaptation may be valuable for planning future responses to climate change. They show how both “low-tech” and “hi-tech” innovations can be important in meeting these challenges. Of course, for innovations to be of value to the poorest and most vulnerable communities they must be affordable and applied to relevant crops, livestock or agronomic practices. Initiatives such as the provision of water-efficient maize to vulnerable communities in Africa[28] provide an example of how this might be done (HMG, 2010; Conway, *et al.*, 2010).

[28] http://www.aatf-africa.org/wema/en/.

3.3 Increasing the general resilience of the food system

After a long period of relatively low and stable food prices, the last five years have seen marked price increases and volatility not seen since the 1970s. Their precise causes are hotly debated but secular increases in demand as well as supply-side stresses are very likely involved. As Chapter 2 has discussed, most analysts predict trends in supply and demand that if unaddressed carry the risk of severe disruption to the global food system. A series of recent reports (FAO, 2011c; Foresight, 2011; Paillard *et al.*, 2011; Oxfam, 2011) have explored these issues and asked how the global food system can be made more resilient to any perturbation including those arising from climate change.

The focus of this report and the subject of most of this chapter are the challenges to policy makers specifically arising from the need to adapt to climate change. Nevertheless it is important to consider climate-change adaptation in the broader context of building a more resilient food system. There is not space here to review this very large subject in detail but we highlight here some of the main issues and refer the reader to the reports listed above for more detailed discussion.

Different projections of likely demand for food by mid-century that extrapolate from current trends predict that globally 70 percent (FAO 2009b) more food, and up to 100 percent in some regions, needs to be produced to keep real prices within bounds that do not have severe effects on poor communities. Studies have concluded that action is needed throughout the food system: to increase supply, moderate demand from relatively-high income consumers, reduce food system waste, and improve the efficiency and governance of the food system. More food can be produced on existing farmland using existing knowledge if food producers have the resources to respond to price signals and if appropriate investments are undertaken in economic and physical infrastructure (market reform and access to markets). Increasing supply involves the better utilization of existing knowledge (in particular by revitalizing extension) as well as investment in new knowledge to improve sustainable productivity. Significant conversion of new land to food production should not be a major contributor to increased production because of its consequences for greenhouse gas emissions (Foley *et al.*, 2011; Godfray *et al.*, 2010). Restoration or improvement of degraded and partially degraded farmland ought to be a priority.

Efforts to increase food production should be sensitive to the rights and needs of farmers where these are not already well enforced. Increasing food prices are already leading to major land purchases by overseas companies and sovereign wealth funds in Africa. Though such investment may bring much needed capital into agriculture, there is a very great danger that it may lead to land dispossession and other infringements of human rights. Transparency in all major land purchases, and better developed property rights, are priorities to avoid such abuses (see also the discussion in Chapter 2). These issues are further explored in the HLPE Report 2 on land tenure and international investments in agriculture (HLPE, 2011b).

Some price volatility is inevitable in the food system but actions need to be taken to prevent markets amplifying shocks (including from weather events) and protecting vulnerable groups and communities from major price swings. Policy makers need to consider how best to regulate modern commodity trading (for details see HLPE, 2011a), what levels of information transparency in the public and private sector are optimal, and whether or not there is merit in proposals for real or virtual intervention stocks. Social protection schemes may be critical in protecting poor sectors of society in both relatively rich and poor countries (HLPE, 2012a).

Lack of sustainability in food production is a key threat to resilience and needs to be addressed by changes in the way we produce food, by moderating demand for environmental harmful food types, and in the design of national and international food system governance. Identifying and supporting food production and distribution practices that are more resource efficient *and* have fewer environmental externalities should be high priority. Considering the diversity of environmental and social settings in which food production takes place, solutions for improving sustainability will differ. No single approach will be universally applicable and a much better and sophisticated evidence base is needed to help guide the implementation of the most appropriate, context-specific measures. Below we explore specific strategies of direct relevance to climate change adaptation (and in Chapter 4 mitigation).

3.4 What can farmers do to adapt to climate change?

In addition to being a source of general stress to the food system, climate change will manifest itself in specific ways to which food producers will need to adapt (Fischer *et al.*, 2002).

As the climate changes, the average weather experienced by food producers will alter as will the frequency and distribution of more extreme events (Gornall *et al.*, 2010). Individual farmers will need to adopt a suite of measures to adapt to these changes, the details of which will be contingent on individual circumstances. Nevertheless, broad adaptation themes can be identified and food producers will need to consider the issues listed in Box 6 on adaptation options (Lobell *et al.*, 2008; FAO, 2007).

Box 6. Options for adaptation to climate change

- Plant different varieties or species of crops, or rear different breeds or species of livestock (or fish in aquaculture). Varieties or breeds with different environmental optima may be required, or those with broader environmental tolerances. The use of currently neglected or rare crops and breeds should be considered.
- In the face of greater weather variability consider increased diversification of varieties or crops to hedge against risk of individual crop failure. Make use of integrated systems involving livestock and/or aquaculture to improve resilience.
- Sow crops (including feedstocks and forage) at different times of year; alter seasonal husbandry practices to adapt to different weather patterns.
- Change irrigation practices; in many areas the major challenge of climate change will be the reduced availability of water from various causes including lower precipitation, more rain occurring in extreme events which makes water harder to capture, changes in river flow as glaciers retreat and increased competition for water in a hotter environment. These challenges may be particularly critical in some of the major “bread basket” regions upon which the food security of large population concentrations rely. Food producers will need to adopt enhanced water conservation measures, use marginal resources and make more use of rainwater harvesting and capture. In some areas, increased precipitation may allow agriculture or non-irrigated agriculture in places where previously it was not possible.
- Alter agronomic practices; changes in rainfall may favour reduced tillage to lessen water loss, similarly the incorporation of manures and compost, and other land use techniques such as cover cropping increase soil organic matter and hence improve water retention. Animal diets and stocking rates will need to respond to changing environmental conditions.
- Prepare for increased frequencies of extreme events. General water conservation measures are particularly valuable at times of drought, while strategies such as improved soil organic matter help store water after storms. Increased storm frequencies will require improved drainage and farm design to avoid soil loss and gullying. Farms in coastal areas may need to adapt to increased frequency of saltwater intrusions and in dryer areas to more frequent wildfire events.
- Adapt pest, weed and disease management strategies; different crop and livestock antagonists will respond differently to climate change, not always to the disadvantage of food producers. However, to the extent that farmers have expertise in coping with existing pests and diseases, and that the natural regulation of potential pests by their natural enemies may be disrupted by a

changing climate, food producers are on balance likely to face more rather than less challenges of this type. Similar considerations apply to the disruption of pollinator ecosystem services.

- Change post-harvest practices, for example the extent to which grain may require drying and how products are stored after harvest.
- Consider (where possible) increasing insurance cover against extreme events.
- Consider the effect of new weather patterns on the health and well-being of agricultural workers.
- Engage with other food producers to share best practice and experience so as to enhance community-based adaptation.[29]

In addition to agriculture and aquaculture, significant human protein is obtained from capture fisheries which account for just under 50 percent of the fish consumed by humans (FAO, 2009c). Climate change is likely to see the opening up of new fisheries (for example in the increasingly ice-free Arctic oceans) as well as movements of existing fisheries. Those working in capture fisheries will need to be aware of, and be able to respond to, these changes (R. I. Perry, 2010).

Finally, many people, especially in less-developed countries, use an extensive range of wild plants and animals to supplement their diets (Barucha and Pretty, 2010). These species too will be affected by climate change, in ways difficult to predict. Autonomous and reactive adaptation will occur in these communities, but policy makers should be aware that climate change may (though not necessarily will) negatively affect these important ecosystem services.

3.5 How to support food producers to adapt to climate change

Farmers and food producers alone cannot adapt successfully to climate change. They need assistance from government and from the private sector, and there is also an important role for civil society organisations. In this section, we identify a series of actions that could reduce vulnerability to climate change.

3.5.1 Undertake regular assessments of climate change risks and vulnerability

Anticipatory adaptation to climate change requires assessment of both risks and vulnerability (Howden *et al.*, 2007). Middle- and high-income countries are increasingly carrying out regular assessments but nations without this capacity need external assistance. Careful communication of the inevitable uncertainties to policy makers and more broadly is of great importance.

3.5.2 Modernize extension services

Of great importance is that food producers have access to the skills base, the human capital that is needed for climate-change adaptation. Improving the information and training available to food producers through modern revitalised extension services based on different funding models (that can involve the public, private and civil society sectors) has already been highlighted as a means of increasing general resilience. These extension services themselves must be equipped to provide the

[29] An example of knowledge sharing among producers is the Campesino a Campesino System (PCaC) that within a decade demonstrated a new working model that transformed local farming methods and peasant knowledge in new technology with the implementation of a variety of new management practices revolving around green manure, cover crops and ensured food security without expanding further land use. The system was created in Siuna, Nicaragua, but is been used in some other countries of Central America and Caribbean. PCaC created a network that shared information and strengthened governance in the region by educating the farmer on tools that the program offers to continue with the experimentation and development of the new practices that promote resilience, while comparing them to the traditional farming methods (Cuéllar and Kandel, 2005).

appropriate climate-change adaptation advice (in some cases building on existing successful models, for example in managing weather risk) taking into account the special needs of women and of disadvantaged groups. In addition to formal extension services there are initiatives such as farmer-field schools that allow best practice and knowledge to be shared among farming and other food-producing communities that can help facilitate autonomous adaptation. Though national planning for adaptation is essential, great emphasis should be placed on involving and engaging with the communities where changes actually have to occur.

3.5.3 Improve access to and understanding of the characteristics of genetic resources

Efficient adaptation will require access (both physical and legal through appropriate intellectual property rules) to genetic resources, both of existing crops, livestock and their wild relatives, as well as varieties that may be used in the future (see Blakeney (2011) for a discussion of the state of intellectual property rights regulations internationally). For example, crop genes for drought and floods tolerance should be identified and shared. Yield stability traits of species under variable conditions are particularly important areas where more understanding and research is needed.

All that is possible must be done to minimize genetic erosion in the remaining biodiversity both *in situ* and in gene banks. Food producers, public and private sector institutions, research communities, and governments need to increase cooperation and ensure dissemination, distribution and creation of knowledge and transfer of technologies to conserve and curate genetic resources in seed banks, germplasm stores and related facilities and support the adaptation to climate change. Adoption by all countries of the International Treaty on Plant Genetic Resources for Food and Agriculture, as well as urgent implementation of its articles 5 (conservation), 6 (sustainable use) and 9 (farmers' rights) would be positive steps in this regard.

To increase agricultural biodiversity, measures to develop markets for underutilized species and educate consumers about the importance of dietary diversity would help.

The Commission on Genetic Resources for Food and Agriculture[30] could consider identifying priority measures and developing a plan of action on the conservation and use of genetic resources for adaptation to climate change.

There is an on-going debate on whether the current intellectual property rights regimes support or hinder development and use of improved plant and animal varieties and agriculture biodiversity. The issue of genetic resources, including intellectual property rights and farmers' rights, is a topic the CFS may wish to recommend for an HLPE study.

3.5.4 Exploit the growing availability of information technology

One of the challenges of climate change is likely to be coping with a more variable pattern of weather. Access to weather forecasting can improve farmers' ability to cope with increased variability and extreme events provided the information can be disseminated in time to those who need it. The near-ubiquitous reach of mobile phones and related technology in even the poorest countries offers novel means of providing information and advice to food producers and in particular smallholders. Suitably resourced and designed information and communication technology (ICT) can provide this link to national meteorological services.

[30] The Secretariat of the Commission on Genetic Resources for Food and Agriculture has commissioned and prepared several background papers on climate change and genetic resources available at http://www.fao.org/nr/cgrfa/cgrfa-back/en/?no_cache=1.

3.5.5 Facilitate investment by small-holders

The consequences of climate change will become more and more apparent as time passes. Adaptation to climate change requires investments that begin before the consequences occur. In that sense adaptation requires investments, both material and immaterial (knowledge), and for food producers to have access to financial capital. In more developed countries this can be provided by the private sector, possibly supplemented by the state as part of rural support programmes. Green banks and related initiatives, depending on their precise remits, may invest in adaptation especially where linked with mitigation. There is the opportunity for adaptation to contribute to sustainable or "green" economic growth, especially if a regulatory environment is constructed that aligns responses to price signals with the improved production of public benefits. Access to capital in less developed countries is more problematic. It is a general problem that can be approached in various ways including by reprioritisation of national budgets, refocusing development assistance, or by private and civil society financial initiatives such as microfinance specifically targeted at smallholder food producers. In vulnerable areas, investment in climate-change adaptation (including in new varieties and breeds, irrigation, food storage and transport infrastructure) will require increasingly high priority. As stressed above, transparency and the protection of the rights of small-holder farmers need particular attention. It is also important to ensure that these measures attend to the special needs of women in agriculture and are non-discriminatory to vulnerable groups.

3.5.6 Explore the potential of innovative insurance schemes to manage weather risk

The nature of food production means that cash flows vary over time and are at risk when adverse weather events occur such as droughts, floods and sea-water incursions. Climate-change will increase the likelihood of such extreme events and the risk of crop and livestock loss, and will make it more important for producers to have adequate risk-coping instruments. In wealthier countries the insurance industry is in a position to enable food producers (and their customers) to hedge against uncertainty, most often in the framework of government-subsidized schemes, but in poorer countries these mechanisms are often absent or inefficient. Experiments are underway in developing countries with weather-index-based insurance programs that have identified benefits of such programs and issues in their implementation (see for example, Giné *et al.*, 2007; Giné and Yang, 2009). Research is needed into how best to provide poor food producers with financial security, for example building on programmes that pay out automatically when certain weather criteria are met, rather than needing complex loss adjustment.

But one likely consequence of climate change is that weather shocks have greater frequency and spatial extent affecting whole regions and countries, which could significantly raise the costs of weather index schemes. Innovative solutions designed specifically for these challenges such as sovereign insurance covering the state should be investigated. The increased likelihood and type of extreme events associated with climate change should be taken particular note of in disaster management planning and in designing the provision of emergency relief to people affected by severe food scarcity.

3.5.7 Develop integrated land-use policies that take a landscape approach

Efficient climate change adaptation will put a greater premium on the development of integrated land-use policies. Changes in precipitation patterns (in particular the frequency of extreme events) and in seasonal rivers flows will increase the importance of optimizing water resources management at catchment and aquifer scale. Where catchments include several countries, the legal and treaty basis to deal with trans-boundary disputes should be put in place, ideally in anticipation of the problems arising. Such agreements are important irrespective of climate change and without them strategies such as water pricing which require the identification of water rights are not possible. The inevitable uncertainties in assessing future climate (and other drivers) will require adaptive management procedures to be adopted.

As part of the development of integrated land-use policy, cost-effective civil engineering projects to increase the protection of agricultural lands from extreme events should be considered. These might involve the construction of levies and coastal defenses for small island nations and countries where significant agricultural production is close to sea level as well as interventions to capture precipitation from extreme events, but also “soft” landscape engineering such as the planting of riverine forests to improve flood control. Passive policy measures such as the preservation of forests and mangroves can be as important as active interventions. Mechanisms such as REDD (to protect forests) and other means of payment for ecosystem services should also be included among the tools to increase ecosystems and communities resilience to climate change. Though much effort has been expended to develop these tools, the political and financial underpinnings of these mechanisms require considerably more development.

Special attention will need to be paid to the most vulnerable communities everywhere, and systems put in place to assess risks as climate data accumulates and medium-scale climate modelling becomes more sophisticated. Current models suggest pastoralist communities in semi-desert environments are likely to be particularly susceptible to climate change because, for example, traditional transhumance routes may no longer be feasible.

3.5.8 Ensure people are more resilient to climate-change enhanced water availability risks

Low-level and irregular precipitation that already affects the livelihood and production of a large number of rural families is expected to be worsened in the face of climate change. The global harvest of grains, oilseeds, fruits, vegetables and other crops require an enormous quantity of water. It takes about 1000 tons of freshwater, for example, to grow one ton of wheat. Over 70% of global water supply goes to agriculture. Worldwide, 40% of the agricultural production comes from irrigated lands (Bruinsma, 2008). Future production will rely heavily on irrigation, however the freshwater supply for irrigation is definite and showing signs of vulnerability, just as we are about to become more dependent on it. Many of the major rivers and major groundwater aquifers throughout the world are suffering from overexploitation (see Box 7).

Box 7. Groundwater depletion in India

Groundwater irrigation has overtaken surface-water irrigation as the main supplier of water for India's crops. Groundwater now sustains almost 60% of the country's irrigated area. Tamil Nadu, North Gujarat, and a majority of the districts in Punjab and Haryana rely heavily on groundwater, but have limited stocks of the resource. In the western part of India, half of the wells once in use are now out of commission. This figure will increase as the groundwater table in these areas is dropping at the rate of 0.6 to 0.7 m per year. In southern India, the problem of groundwater depletion is severe in Tamil Nadu where ground water levels have dropped up to 30 meters since the 1970s. In fact, as estimated by the International Water Management Institute, if the number of groundwater-overexploited blocks continues to grow at the present rate of 5.5% per annum, by 2018 roughly 36% of India's blocks will face serious problem of groundwater depletion, affecting both food production and drinking water supply.

Access to, and uses of water in relation with food and nutrition security are multidimensional problems. Semi-arid regions need a water policy which contemplates four main dimensions: the provision of water for domestic use, the use of water for production, the use of water for rural areas and small communities, the use of water in cities.

Water has multiple uses. It was recognized as a public good by the Committee on Economic, Social and Cultural Rights (CESCR).[31] It is essential to the realization of the right to adequate food. Both supply growth and demand management should receive concurrent attention for strengthening water security for crops, farm animals, domestic needs and industry. A sustainable water security system should be developed for each agro-ecological region.

Box 8. One million rural cisterns in the semi-arid areas of Brazil

Domestic water supply is being secured in the semi arid region of Brazil through cisterns for rainwater retention. Upon a proposal by social networks and supported since its inception in 2003 by the National Water Agency, the One Million Rural Cisterns program was incorporated into the national system for food and nutrition security by the Ministry of Social Development and Fighting Hunger. It aims to support the development and dissemination of technologies of access to water to serve families and communities in state of socio-environmental vulnerability with respect to water, first of all isolated rural households in regions of water scarcity registered in the Registry for Social Programmes of the Federal Government. The program provides support to projects presented by local governments and civil society organizations. The terms of cooperation are periodically approved by the National Food and Nutrition Security (CONSEA), which also participates in the monitoring of its implementation. Between January 2003 and December 2011 more than 600 000 cisterns were build, directly benefiting 3 million people in the Brazilian Northeast in situation of vulnerability due to water scarcity. The program adopts a participatory methodology encompassing the training of the proper beneficiaries in the construction and installation of equipment and practices in the rational use and sustainable management of water for human consumption and food production. Later, the action was expanded to include access to water for food production (especially vegetables, contributing to dietary diversification) for self-consumption and for the schools, with already 11 000 units implemented. The main axes of these actions are: access to drinking water as a component of food and nutrition security; democratization of access to water, opting for decentralized access solutions, use of popular knowledge of living within the semi-arid as a reference, prioritization of the participation and control of civil society, strengthening the concept of social technology (Maluf and da Silva Rosa, 2011).

There should be a participatory water management system involving farm families, so that local communities have a stake in both water conservation and sustainable and equitable use. Participatory methodologies and communities' leading role should be part of the building up of alternative means of collecting, storing, managing and distributing good quality water in ways that respect and protect biomes, preserve natural resources and stimulate the recovering of degraded areas.

CFS and national governments should develop research and support programmes aiming at promoting universal access to good quality and sufficient water in rural areas.

3.5.9 Climate change and water in coastal areas

Nearly one third of the human population lives along the coast. Rise in sea level is likely to adversely affect both coastal agriculture and the livelihoods security of coastal communities.

According to the Fourth Assessment Report of the United National Intergovernmental Panel on Climate Change (IPCC, 2007e), it is estimated that sea level rise will be 18 to 38 cm (in a low

[31] General comment n. 15 (2002), CESCR, available at: http://www2.ohchr.org/english/issues/water/docs/CESCR_GC_15.pdf.

scenario) to 26 to 59 cm (in a high scenario) in the 21st century. Impact of such increase in sea level indicates that hundreds and thousands of square kilometres of coastal wetlands and other lowland such as fertile delta could be inundated by seawater. Salt water would advance landward and up estuaries, threatening water supply, ecosystems and agriculture. The social and economic impact of the sea level rise will be severe in many of the developing countries. Many of these countries have rapid rates of population growth, with large proportions of the populations inhabiting low-lying coastal lands. A one-meter rise in the sea level could inundate as much as 15% of the area of Bangladesh, destroy rice fields and threaten aquaculture of the Mekong delta and flood many populated atolls. In Egypt, currently nearly 20% of the population and farmlands are less than two meters above the sea level, indicating that they will also be severely affected by the rise in the sea level.

Halophytes (Box 9) are plants which need to grow in high salinity environments and can be grown in seawater farms, among mangrove plants, which are also useful to enhance capture fisheries in coastal waters (fish catch is increased by about 1 ton per hectare of mangrove per year).

Coastal saline areas could be irrigated with sea water, inland saline deserts could be irrigated with saline lake water, arid zones with brackish water, when available through irrigation.

Box 9. Halophytes

Halophytes such as *Aster tripolium* (common name: salt aster) is commonly used as a vegetable in Netherlands, Belgium and Portugal. Species belonging to *Suaeda* (common name: sea bite) are frequently served as salad in many of the European countries and Japan. Among these halophytes the most promising species is *Salicornia* (common name: Glasswort or sea asparagus). It is a leafless, succulent, annual plant that colonizes saline mud flats through prolific seed production. The seeds contain high level of oil (30%) and protein (35%), much like soybeans and other oilseed crops and the salt content is less than 3%. The oil is highly polyunsaturated. A species of glasswort, namely *Salicornia bigelovii* yields 1.7 kg of biomass and 0.2 kg of oilseed per square meter, exceeding the yields of soybeans and other oilseeds grown using freshwater irrigation. It can tolerate salinity up to 100 grams per litre. Glasswort is one of the promising halophytic crops for saltwater irrigation. Other interesting halophytes are *Atriplex* (common name: saltbush) and *Suaeda*. Both are excellent fodder crops and they can be used as part of a mixed diet for livestock.

Two different types of salted-water based farming systems are therefore of interest:
i) Halophyte farms where halophytes are grown as crops using seawater or salted water for irrigation
ii) Integrated mangrove fishery farming system which integrates mangroves, halophytes and fish.

Salted or sea water agriculture to grow halophytes has not progressed much beyond the prototype stage developed decades ago.

Anticipatory research and action will be needed for insulate coastal communities to rise the challenges from sea level and saline water intrusion. The anticipatory action plan for coastal ecological and livelihood security should include the following: (i) Mangrove bio-shields should be erected along seacoasts; (ii) Breading salinity tolerant rice and other crop varieties; (iii) Development of agro-forestry and coastal aquaculture systems of land and water management; (iv) Conservation and use of halophytes.

There is need for research on sea water farming involving the spread of agri-aqua farms. The cultivation of economically valuable halophyte and salinity tolerant fish species will help to strengthen the food and livelihood security of coastal communities. We therefore recommend the launching of scientifically designed seawater farming for coastal area prosperity movement, along coastal areas and small islands.

3.6 Climate-change adaptation in the food chain

The most direct effects of climate change are on food production itself but adaptation will also be required further along the food chain. Of course, as stressed above, measures to increase general resilience to shocks and perturbations of all nature, whose occurrence and magnitude will be further impacted by climate change, will require action throughout the food system.

3.6.1 Improve the transportation and marketing infrastructure with climate resilience as a focus

Investment in the physical infrastructure that allows food producers to be connected to markets and for large urban areas to be supplied with food is critical for general food system resilience and food security. Climate change poses some particular civil engineering challenges to infrastructure provision. In many places higher temperatures will require more resistant road surfaces and the risks of floods and storm surges will need to be considered when designing bridges, ports and related facilities (Margulis, 2010). The logistics of transporting and storing food may be affected by climate change, for example increasing the need for refrigeration or post-harvest drying.

Climate change will reduce the potential of some areas to produce food while favouring others. Similarly, the location of marine fisheries may change so that catches are landed in different ports. Though these changes are likely to occur slowly they will require adaptation in food supply networks, and possibly in the routes by which food is traded internationally.

3.6.2 Facilitate storage

The likely greater frequency of extreme events will increase the disruption of supply networks and place an increased premium on diversified sourcing. Food chain intermediaries and retailers may need access to greater reserve stocks. There is a particular challenge to ensuring continuity of supply to large cities and conurbations in less-developed countries.

3.6.3 Assess the potential for dietary changes as an adaptation to climate change

Climate change will alter the types of crops that can be grown in different areas. Where these crops are grown for markets (as opposed to consumption by the food producers themselves) the viability of this type of adaptation will depend on consumer acceptance of the new crop. For example, in some tropical countries millet is seen as a less desirable food stuff compared to maize, despite it being easier to grow in water-stressed areas. Governments may need to set up consumer awareness and education programmes to increase acceptance and explore partnerships with food processing companies. We do not yet know whether climate change will alter the spectrum of food available for different communities and whether this will have negative effects on nutrition beyond calorie availability. This will need to be monitored and opportunities for synergistic actions exploited. For example, diversifying crops to hedge against a variable climate may also increase nutritional diversity, and new varieties with multiple benefits can be developed in unified breeding programmes.

3.6.4 Approve an international trading regime that facilitates adaptation

Agricultural trade has increased markedly in the last 50 years and there have also been trends for developed countries to reduce (but not eliminate) agricultural subsidies and trade barriers, and for trade to be concentrated in a smaller number of multinational companies. Though the most recent (but not concluded) ‘Doha’ round of world trade negotiations has been avowedly “pro-poor” there is concern both about the social justice and equitability of the current and proposed global governance of food trade, as well as its lack of consideration of environmental issues which may undermine national efforts to increase sustainability. Global food trade does have an important role to play in climate change adaptation (Huang *et al.*, 2010). It is likely that we will experience an increasing frequency of extreme events with impacts felt over a greater geographical range. An efficiently functioning international trade system can allow one region to substitute for production shocks occurring in another. However, it is imperative that measures are put in place to ensure that international trade does not lead to perverse incentives that may increase environmental damage.

As a result of the food crisis of 2008, food security has become a more critical issue in agricultural trade negotiations than in the past. The notion of access to supplies is considered today as important as the traditional notion of access to markets. Current WTO provisions and rules are unclear or deficient regarding food security matters and the Doha negotiating mandate does not allow much room to make progress in addressing these concerns. Moreover, climate change will make the challenge of achieving food security much harder, and it is clear that global food trade will have an important role to play in a world facing climate change. Incorporating all these important issues in any future agricultural trade negotiations would be a step in the right direction.

3.7 Research challenges for adaptation

Much can be done to adapt the food system to climate change using existing knowledge and technology but there is also a great need for research to provide new solutions for existing and anticipated challenges. This need must be seen against recent trends of decreased investment in food system research in the public sector. The joint threats of food insecurity and climate change justify a reexamination of research priorities, as well as a reappraisal of how national and international public funded research can work best with the private sector. The call here for more and varied research should not be seen as an excuse for doing nothing now and relying on future “technological fixes”. Successful adaptation requires both action immediately using existing tools as well as investment in finding new ways to tackle very great challenges.

Particular attention must be paid to how the needs of the world’s poorest and most disadvantaged food producers can be addressed through research and knowledge creation. This will require meaningful engagement with the intended beneficiaries, and a genuine dialogue to understand their requirements, taking into account the difficulties that can exist in obtaining the views of women and disadvantaged groups.

Though research to increase yields is essential to meet broader food security goals, a continuing and accelerating refocusing of research to address a more complex set of objectives will be required to meet the challenges of climate change. Crops and other plants with new temperature optima, that have a more plastic response to variable weather, and that can use water more efficiently, or which can grow on saline soils, are examples of new breeds and varieties that may help climate change adaptation. Similarly, animal breeds that are more resilient to climate stress will be advantageous. In some circumstances new or neglected species of plants and animals will be required to maintain productivity on land which climate change has rendered marginal for agriculture. Recent advances in genetics (both GM and non-GM) allow modern plant and animal breeding to be applied to many more species than until recently was possible. Species such as sorghum, millet, cassava and the varieties of maize grown in Africa are potential candidates, as are indigenous varieties of fruit and vegetables. Involvement from the start of the farmers who currently or might grow these crops in the design of any breeding program is critical.

Agronomic practices will need to change to cope with climate change and research is required to demonstrate which strategies have greatest utility. In addition to the continuing importance of research in basic agronomy, many ideas from other approaches including conservation agriculture, permaculture, agroecology and organic farming undoubtedly have a major contribution to make to climate-change adaptation, yet their wider application is often hampered by the lack of a clear evidence base. Soil science and agricultural engineering research to develop techniques for more efficient irrigation and water retention should be a priority. Where appropriate these can include technically advanced methods such as precision agriculture but they must also involve methods aimed at farmers in low-income countries. The development of better ways to integrate different types of food production – crops, livestock, aquaculture – can lead to more efficient resource use and resilience to weather shocks.

Adaptation to climate change requires individual farmers to make informed decisions in the face of uncertain knowledge. Research in the social sciences is needed to better understand how to facilitate these changes that will ultimately benefit the farmer. There is a great need for research into how best to monitor and evaluate different social and economic interventions aimed at promoting adaptation.

The possible effects of climate change on capture fisheries is poorly understood, and research on this and how climate change should be integrated into ecosystem and adaptive management approaches to fisheries is required.

Finally, it is critically important to monitor and evaluate different adaptation strategies so as to learn from best practice. Resources for assessing progress against agronomic and social targets should be included in adaptation programmes while improving monitoring and evaluation should itself be a research target.

3.8 Policy messages

- A strong and resilient food system will be better able to withstand all perturbations including those due to climate change. Thus general food system policies designed to match supply with demand, that provide better tools to manage price volatility, that reduce waste and improve efficiency, and that encourage investments in sustainable practices will all result in a more resilient food system, better able to withstand climate change shocks.

- The communities whose food security is at greatest risk from the effects of climate change will most often be in developing countries, especially in drier regions, be the poorest sections of rich societies, and will be groups disadvantaged in some societies, for example because of gender, ethnicity or cultural reasons. Climate-change adaptation needs to be especially tailored to these groups who will often be least able to cope with the challenges. Particular attention will need to be paid to finding the financial capital for investment in adaptation, increasing the human and social capital to implement adaptation, and providing safety nets for when adaptation fails.

- Though climate change will benefit food production in a few areas initially, the net effect over all regions is ultimately likely to be very negative. There is much that can be done to adapt agriculture to changing climate using existing knowledge about the social, economic and biophysical aspects of food production – skills and knowledge currently appropriate for one region may in the future be important in another region as climate changes. Dissemination and implementation of this knowledge using modern ICT is critical. However, the magnitude and pace of the changes likely to occur will also require new knowledge and investment in the relative social and natural sciences should be a priority. But these measures ultimately will not be enough without radical changes in production, distribution and consumption patterns that can reduce GHG emissions.

- Successful adaptation of global agriculture and the food system to expected climate change will require mobilisation of the most effective practices from all modes of agriculture, realising that no single solution or set of solutions will be appropriate everywhere. Techniques drawn from conventional, agro-ecological, organic and high-technology food production will all need to be deployed. A pluralistic, evidence-based approach, sensitive to environmental and social context, and to different value systems, is essential.

- Examples of strategies for community based adaptation include setting up community-based seeds and grain banks, improve water management practices such as building infrastructure for more efficient irrigation systems and small-scale water capture, storage and use, adopting practices to conserving soil moisture, organic matter and nutrients, and using short-cycle varieties. The main issues here are dissemination of existing information and knowledge, building human and social capital and putting in place the policies that support best practices.

- There are significant time lags between the commissioning of research and the deployment of new knowledge in the field. For more “near-to-field” topics this is typically of the order of five years but for more fundamental research it can be decades. Investment in research to address tomorrow’s problems should be made today.

- Research on adaptation spans many fields of natural sciences and social science. It needs to become a priority among research funders in all sectors. Research on topics such as crop and livestock improvement, agronomy, food storage, and processing and distribution should all include the needs of adapting to new climates. Interdisciplinary research spanning the natural and social sciences is particularly important.

- Successful adaptation requires the best possible knowledge of where the most vulnerable people live. Great improvements in the quality of the biophysical, economic and social data available to policy makers are required, as well as more advanced and accessible analysis and modelling tools. Particular challenges include (i) linking existing and future data sources using global metadata standards; (ii) making use of modern technology (ICT, remote sensing) to harvest real time data; (iii) developing means of comparing and better validating the different classes of relevant models; and (iv) improving the pipeline between data gathering, analysis and feeding into policy making.

- Adapting agriculture to climate change and having national adaptation plans is globally very important. The NAPAs, submitted to the UNFCCC by the least developed countries, have highlighted agriculture and food security investments as a priority. They provide a starting point for prioritizing new national investments. Priority measures designed by LDCs in their NAPAs should be financed and implemented. Countries should build upon the experience of the NAPAs to prepare national adaptation plans.

- Finally, in the framework of UNFCCC negotiations, we recommend more progress under the Work Program on Loss and Damage, emphasizing the slow onset of impacts of adverse effects of climate change in agriculture and food security, strengthening the coverage of agriculture issues in the Nairobi Adaptation Work Programme and the Adaptation Fund and creation of a SBSTA work program on agriculture to support improvements in the knowledge base about agricultural adaptation and mitigation.

4 AGRICULTURE AND GHG EMISSIONS: MITIGATION OPTIONS WITH FOOD SECURITY SYNERGIES

4.1 Introduction

As Chapter 1 and 2 have discussed, climate change will increase the challenge of achieving food and nutrition security. But agriculture is also an important driver of GHG emissions contributing to climate change: crop and livestock agriculture was estimated to sum up roughly 15 percent of total emissions in 2005.[32] This includes around 2 percent of emissions accounted in other sectors, from production of fertilizers, herbicides, pesticides, and from energy consumption for tillage, irrigation, fertilization, and harvest.[33] Land use change, much of which is driven by expansion of agricultural area, adds another 11 to 17 percent.[34] And as Chapter 3 points out, future income and population growth will increase agricultural emissions dramatically unless low-emissions growth strategies for agriculture are found.

This chapter discusses the sources of agricultural GHG emissions and options for mitigation in agriculture. Mitigation methods can have positive or negative impacts on food security and poverty reduction; hence proper targeting is essential. Mitigation choices must be linked with adaptation and resilience and should not take place at the expense of food security. Fortunately many options that reduce emissions and enhance food security exist. Special emphasis is made on land-use policies, intensification of production to reduce deforestation, changes in consumption, and efficiency improvements to leverage synergies between adaptation and mitigation.

4.2 Agriculture's current contribution to greenhouse gas emissions

There has been a steady increase in CO_2 emissions over the latter part of the 20th century and the beginning of the 21st century (IPCC, 2007d). Two other GHGs have shown a similar upward trend: nitrous oxide (N_2O) and methane (CH_4) – with sources of emissions dominated by agricultural activities. N_2O is released from a variety of agricultural activities with nitrogen-based fertilizer as an especially important source (Park *et al.*, 2012). CH_4 is released by the digestive processes of cattle and other ruminants (both wild and domesticated), and through the decomposition of plant matter under anaerobic conditions such as in irrigated rice fields.

Agricultural activities result in GHG emissions in two ways; emissions from

- Land use change (loss of soil and biomass carbon stocks) caused by expansion of agricultural activities over other lands such as grasslands and forests. As farmers convert natural ecosystems to agriculture, the loss of vegetation above-ground results in large CO_2 emissions. In addition, the soils lose about 50 percent of the initial soil organic carbon (SOC) in the top surface layer in 25-50 years after conversion to cropland, in temperate climates and 5-10 years in the tropics (Lal, 2004) without ameliorating management practices. With past expansion of agricultural area, substantial CO_2 emissions resulted. Today, land use change driven by agricultural expansion still contributes sizeable emissions, both from above and below ground sources.

- Agricultural practices (no land-use change), from the inputs used and management choices. Direct GHG emissions from agriculture practices include CH_4 emissions from flooded rice

[32] See IPCC (2007c,d), Bellarby *et al.* (2008) and Herzog (2009) for estimates of agricultural GHG emissions.
[33] See Bellarby *et al.* (2008) with calculation based on data published by Lal (2004b).
[34] See IPCC (2007c,d) and Houghton (2010) for estimates of the global CO_2 emissions due to land-use change.

fields and livestock, N_2O emissions from the use of nitrogenous fertilizers, and CO_2 emissions from loss of soil organic carbon in croplands as a result of agricultural practices and in pastures as a result of increased grazing intensity. Unlike other sectors such as energy supply, industry, and transport, in which GHG emissions are dominated by CO_2, agricultural emissions of GHGs are dominated by CH_4 and N_2O, with CO_2 emissions being mostly *indirect* agricultural emissions, such as those linked to inputs and energy use, which in the UNFCC accounting framework are formally accounted in industry, chemicals, energy and transport, and not in the agriculture sector. Depending on farm systems and management types, such indirect CO_2 emissions can be quite significant (West and Marland, 2002).

Reducing CH_4 and N_2O emissions is especially important because of their larger global warming potential than CO_2[35], especially at shorter time scales.

However CO_2 control, such as preventing the loss of biomass and soil carbon, is also important as the average residence time of CO_2 in the atmosphere is higher than CH_4 and N_2O, therefore the release of CO_2 to the atmosphere is prone to creating warming during a longer period. Farming practices can reduce or increase the amount of carbon sequestered in a field. Net CO_2 emissions from croplands are expected in regions where agricultural management practices lead to reduction in SOC and input of organic materials cannot balance decomposition of SOC. Such management practices also lead to reduced resilience since soil organic matter holds nutrients and soil moisture, making it available over longer periods of time. Adoption of good management practices has resulted in increased soil carbon in some parts of the world (Cai, 2012). For example, in China SOC in croplands increased by about 400 Tg C during the period of 1980-2000 (Huang and Sun, 2006). A similar trend was observed in the United States (Ogle *et al.*, 2010). Hence, a first policy message is the importance of farmers adopting good management practices that can increase carbon sequestration. Many, if not all, of these practices have adaptation benefits in the form of enhanced resilience to climate change. Examples of such practices are identified below.

4.2.1 Methane emissions in agriculture

Agricultural CH_4 emissions account for more than 50 percent of CH_4 emissions from human activities (IPCC, 2007a). Agricultural CH_4 emissions today are roughly one third from flooded rice production (28-44 Tg CH_4 yr^{-1}), and two thirds from ruminants (73-94 Tg CH_4 yr^{-1}). Animal manure is another substantial source of CH_4. Its emissions vary greatly with management and duration of storage.

Monsoon Asia produces more than 90 percent of global rice production, thus accounting for an equivalent share of CH_4 emissions from the world's rice fields. Since the harvested area of irrigated rice is growing slowly, the increase in CH_4 emissions from rice fields is expected to be small.[36]

In the future, most direct increases in agricultural CH_4 emissions are likely to be ruminant-based. Ruminant numbers increased substantially in the last 50 years, particularly in East Asia, and further increase can be expected as population and income increase and diets change with more meat and milk consumed in developing countries. Growth in animal numbers means an increase in animal manure, which is another important source of CH_4.

[35] The instantaneous release of 1kg of CH_4 (resp. 1kg of N_2O) in the atmosphere is 25 times (resp. 298 times) more potent than 1kg of CO_2 to trap energy and create a cumulate greenhouse effect over a 100 years period (IPCC, 2007d).

[36] Furthermore, rice fields are converted at least partially from wetlands, which also emit CH_4, but are classified into natural emissions. Hence, the effective net emissions growth from irrigated rice could be even smaller than IPCC estimates.

4.2.2 Nitrous oxide emissions in agriculture

Nitrogen is essential to agriculture. Plants need nitrogen to grow. But this results in N_2O, a powerful GHG, being produced as an intermediate or by-product of nitrogen transformation processes. Agriculture accounts for more than 60 percent of anthropogenic N_2O emissions (IPCC, 2007a). Both chemical and organic nitrogen fertilization result in N_2O emissions. On average, about 1 percent of nitrogen applied to soil is emitted directly as N_2O (IPCC, 2007a) but rates as high as 22 percent have been reported (Denmead *et al.*, 2007). Emission rates vary by cropping systems, climate, and other variables. For example, the emissions rate from flooded rice fields is only about one third of that in uplands (IPCC, 2007a). N_2O emissions increase with precipitation (Lu *et al.*, 2006). N_2O is also produced from nitrogen lost from agricultural lands through runoff, leaching, NH_3 volatilization, and dissolved organic nitrogen, etc. These indirect emissions are estimated to be similar in magnitude to direct emissions. In addition to their effects on N_2O emissions, nitrogen-based fertilizers, particularly ammonium fertilizers, inhibit CH_4 oxidation by soils, contributing to the increase in atmospheric CH_4. Animals do not directly emit N_2O, but livestock manure is a substantial source of N_2O emissions, another reason for the importance of managing livestock to reduce emissions.

In the future, most direct increases in agricultural GHG emissions can be expected to take place in regions where crop and livestock production increases, leading to more CH_4 and N_2O emissions.

Policies and programs to manage livestock CH_4 and N_2O emissions will be particularly important.

4.3 GHG emissions from land use change

Terrestrial ecosystems, including above- and below-ground components, are a huge carbon pool[37] and there is a sizeable annual CO_2 exchange[38] between terrestrial ecosystems and the atmosphere. Therefore, a small change in carbon storage in terrestrial ecosystems or in the CO_2 exchange rate between terrestrial ecosystems and the atmosphere will result in a substantial change in the atmospheric CO_2 concentration.

The input and output of CO_2 between stable ecosystems and the atmosphere is almost balanced, but land use change disrupts this balance. Converting natural ecosystems rich in organic carbon, particularly forestlands, wetlands and peatlands, to agriculture and pasture use results in losses of carbon not only due to the removal of above ground biomass, but also reduction of soil organic carbon content. Total CO_2 emissions due to land use change were estimated to be approximately 155 Pg C during the period of 1850-2000 (Houghton, 2003), and annual emissions at approximately 1.3 Pg C/yr in the period 1950-2005, with an annual range that varies around ± 0.4 Pg C/yr of this mean (Houghton, 2010).

Land use change also influences the emissions of CH_4 and N_2O. It has been estimated that CH_4 emissions have been reduced by 10 percent due to the area reduction of wetlands (Houweling *et al.*, 2000), which is partially offset by increased CO_2 emission. Converting land to flooded rice production increases CH_4 emissions, both because water-unsaturated lands extract CH_4 from the atmosphere (estimated to be around 30 Tg CH_4 yr^{-1}) and anaerobic decomposition in flooded rice production releases CH_4. N_2O emissions also increase when natural ecosystems are converted into croplands or pasture but no reliable estimates of their magnitude exist.

The dramatic effect of land use change on GHG emissions[39] emphasizes the importance of finding agricultural development strategies that reduce the conversion of non-agricultural land to agricultural activities.

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[37] Prentice *et al.* (2001) estimated that 350-550 Pg C is stored in vegetation and Batjes (1996) that 1500-2400 Pg C in soil.

[38] Estimated to be about 120 Pg C yr^{-1}.

[39] Other negative consequences include loss of biodiversity and changes in ground and surface water availability.

4.4 Mitigation options and food security

As agricultural production is projected to increase in developing countries, so are agricultural emissions. IPCC (2007c) estimates that N_2O emissions are projected to increase by 35-60 percent to 2030 and CH_4 by 60 percent, with additional emissions from land being converted to agriculture.

Agriculture differs from all other sectors in its position in the UNFCCC negotiations on stabilization of GHGs in the atmosphere. From the start of international negotiations (Article 2 of the UNFCCC,[40] Rio de Janeiro, 1992), it was clear that the actions to mitigate climate change and stabilize atmospheric GHG were to be done "in such a time frame to ensure that food production is not threatened". Ensuring food security and food production is therefore one objective of the negotiations on climate change mitigation. This puts food security, even from the point of view of climate change policies, as a goal of the negotiations rather than as simply another topic for consideration.

Under "business as usual", an increase in food production will mechanically translate into an increase in emissions, but there are many options possible to enable a decoupling of increased food security and increased emissions. In considering mitigation policies and programs for agriculture, care should be taken to choose those that do not negatively affect food security. As with other sectors, a range of agricultural options exist to mitigate GHG emissions. Fortunately, many of these options create synergies between mitigation and enhanced food security.

The IPCC (2007c) estimates a technical mitigation potential globally of 5.5-6.0 Pg CO_2-eq yr^{-1} from agriculture by 2030. Soil carbon sequestration accounts for 89 percent of this potential, mitigation of CH_4 emissions for 9 percent, and N_2O emissions for 2 percent. The economic mitigation potential is smaller and depends both on improvements in technologies and development of improved carbon finance opportunities.

There is also a potential of 770 MtCO_2-eq/yr by 2030 that has been identified (IPCC 2007c) from reduction of fossil fuel use through improved energy efficiency in agriculture. And there are potential reductions through improved efficiency in food chains, including reduction of post-harvest losses.

Agricultural mitigation options with positive impacts on food security and environmental protection (thus contributing to adaptation) include management practices that increase soil organic carbon storage and improve nitrogen and water use efficiency (see Chapter 3). With good design, these practices can result in the double win of GHG emission mitigation and enhanced food security, with increased income and enhanced environmental protection.

In the paragraphs below we highlight important categories of activities that can mitigate GHG emissions, reduce vulnerability and also contribute to sustainable food security.

4.4.1 Reduce land use change for agriculture

Land use change from systems with extensive above-ground carbon (particularly forests) is second only to fossil fuel emissions as a source of atmospheric CO_2 and much of that conversion is into croplands and pastures. To meet growing food demand, the choices are to improve yields from land already under cultivation (intensification), expand land area cultivated (extensification) or reduce losses of food between the farm and consumer. Both intensification and extensification will increase GHGs emissions but intensification is relatively more effective in mitigating agricultural GHG emissions. For example, Burney *et al.* (2010) estimated that the net effect of higher yields has avoided emissions of up to 161 Pg C since 1961 and each dollar invested currently in agricultural yields results in 68 fewer kg C emissions relative to 1961 technology. Therefore, the focus of

[40] http://unfccc.int/essential_background/convention/background/items/1353.php.

agricultural mitigation policies and programs should be on improving productivity on existing fields and options that also enhance food security rather than expansion of croplands.

An important potential synergy is that low productivity is often associated with high poverty and food insecurity. Hence, efforts to increase productivity that are also targeted to the poor can lead to double wins.

4.4.2 Adopt farming practices that increase soil carbon in degraded soils

Soil organic carbon content in agricultural lands is highly dependent on management practices. With well-chosen agroecological practices, SOC could be restored by 50 to 66 percent of the historic carbon loss (Lal, 2004). Techniques to exploit this on-farm potential include:

- Increasing organic inputs into croplands such as crop residue incorporation and application of organic manure in appropriate ways. Urban organic waste free from pollutants should be brought back to agricultural land to improve agricultural productivity and mitigate climate change.
- Reduction of soil disturbance with practices such as low or no tillage, and reducing grazing intensity.
- Restoration of degraded croplands and grasslands with practices such as erosion control and periodic fallows.
- Re-flooding of peatlands.
- Increase in crop yields by good management of nutrients and irrigation.
- Agroforestry practices.

Importantly each of these practices can also increase productivity, often through improved soil quality and fertility, and climate change resilience.

It is important to devise public policies and programs that reduce existing disincentives and provide innovative incentives to development and dissemination of specific agricultural management practices to prevent the loss of soil carbon, build soil carbon banks and prevent degradation.

4.4.3 Improve livestock and manure management

Methane emissions from ruminants are a substantial share of anthropogenic CH_4 emissions. It does not appear to be easy to mitigate CH_4 emissions from ruminants on a per animal basis, but improving feeding practices and pasture productivity, adding feeding specific agents and dietary additives, and animal breeding would mitigate CH_4 emissions per unit of livestock product (milk and meat) (Herrero *et al.*, 2011).

There is substantial potential for mitigating CH_4 and N_2O emissions from animal manure (prevention of NH_3 volatilization, aeration of animal manure during storage, shorter periods of manure storage), or to use animal manure to produce bioenergy/biogaz and fertilizers, through biogas plants for example, leading to mitigation of methane emissions and to the partial substitution and avoidance of emissions related to energy and fertilizer production.

As population and income growth increase demand for livestock products in developing countries, policies and programs that increase animal productivity and reduce emissions per unit of product are essential to slowing emissions growth and reducing poverty among livestock holders.

4.4.4 Improve water management

Water management is a crucial factor affecting CH_4 emissions from rice fields. Avoiding water saturation when rice is not grown and shortening the duration of continuous flooding during the rice growing season are effective options for mitigating CH_4 emissions from rice fields.[41]

Irrigation management regimes that reduce CH_4 emissions increase N_2O emissions and vice versa. For example, mid-season drainage mitigates CH_4 emissions but increases N_2O emissions and in this case the cumulated effect is one of cooling, even taking into account the difference in global warming potential (GWP) of the two gases.

Box 10. Rice management changes to reduce methane emissions

IRRI is working with national research institutes and farmers in South and Southeast Asia on alternate wetting and drying practices in irrigated rice fields to reduce CH_4 emissions. The System of Rice Intensification program in India reduces the amount of flooding of irrigated rice, likely reducing CH_4 emissions as well as saving water and possibly reducing N_2O emissions.

Alternating soil moisture sharply is a driving force of N_2O emissions. Thus, avoiding unnecessary irrigation of uplands not only saves water and energy for irrigation, but also reduces N_2O emissions from uplands.

There is substantial potential for mitigating agricultural GHG emissions through appropriate water management with the added benefit of improving water use efficiency and without reducing yields. In many places, simply demonstrating these practices is sufficient to see widespread adoption.

4.4.5 Nutrient management

Nitrogen fertilization is the main factor in anthropogenic N_2O emissions (Park *et al.*, 2012). The N released to the atmosphere or in groundwater is a wasted resource from the farmer's perspective. "On average, of every 100 units of nitrogen used in global agriculture, only 17 are consumed by humans as crop, dairy or meat products. Global nitrogen-use efficiency, as measured by recovery efficiency in the first year (that is, fertilized crop nitrogen uptake – unfertilized crop N update/N applied), is generally considered to be less than 50 % under most on-farm conditions." (Reay *et al.*, 2012, p. 413). The challenge is to apply nitrogen fertilizer at the right time, in appropriate quantities, and in the right form to reduce the amount of conversion to N_2O and loss to the ecosystem with negative effects elsewhere. More efficient use also reduces the emissions associated with production of nitrogenous fertilizer. The differences in induced N_2O emissions among nitrogen sources are uncertain (Snyder *et al.*, 2009). Increasing the efficiency of use of nitrogen fertilizers through better timing and different formulations would allow reduced application rates, with lower N_2O emissions in the field, reduced indirect, fertilizer production-related CO_2 emissions and possibly increased crop yields. Proper intercropping of legumes can also be effective.

4.4.6 Crop residue management

It is estimated that 1.5 Pg of crop residues from seven major crops – corn, barley, oat, rice, wheat, sorghum, and sugar cane – are produced per year (Seungdo and Dale, 2004). Crop residues left on the surface are almost completely decomposed and released as CO_2 into the atmosphere within one year. Incorporation of wasted crop and crop residues into the soil can delay their decomposition and increase SOC storage. Any practice that moves plant material down into the soil extends the period in which carbon is sequestered. According to researchers at the French National Institute for Agricultural

[41] It is estimated that 4.1 Tg CH_4 yr^{-1} could be mitigated if fields were drained at least once during the growing season (Yan *et al.*, 2009).

Research (INRA), the mean residence time for organic carbon in the soil increases markedly with depth, with rapid turnover (days to months) near the surface and reaching from 2,000 to 10,000 years below 20 cm (Fontaine *et al.,* 2007).

An alternate use of crop residue is biochar, created when plant residues are heated in a closed container with little or no oxygen, a process called pyrolysis. The resulting carbon-rich product is very stable when incorporated into the soil. Amazonian 'terra preta', now recognized to be the result of human activities to improve soil quality, is hundreds to thousands of years old (Barrow, 2012). However, the effects of biochar on soil fertility are still being debated with experiments showing positive, negative or no benefits (see for example, Hammes *et al.*, 2008; Major *et al.*, 2011; Sparkes and Stoutjesdijk 2011; Zimmerman 2010). The benefits for soil fertility depend on soil and crop types and management, sources of the plant residues, and the specific pyrolysis technique.

4.4.7 Comparing farming systems and products

As discussed above, only part of the emissions caused by agriculture and food systems are classified in the agricultural section of the UNFCCC accounting framework. To compare practices and systems there is a need to consider all emissions generated both directly and indirectly. Often, comparisons between farming systems are flawed by preconceived ideas and partial accounting, for instance comparing systems on their energy use and taking it as a proxy for GHG emissions, without accounting for land use and methane emissions. Most of the estimations of emissions are life cycle analyses conducted on single products, mostly in industrialized countries. There are also some studies assessing the impact of intensification (understood as increased yield per hectare) which shows that the positive effect on reduced deforestation is more important than the increased emissions due to the use of synthetic fertilizers. There are not many studies comparing farming systems. A study conducted at FAO (Pierre Gerber *et al.*, 2010) on cow milk shows that the more efficient the cows (in terms of productivity, health, transformation of feed), the fewer emissions per liter of milk.

There is an urgent for a better assessment of various farming systems taking into account all emissions, direct and indirect.

4.4.8 Manage food consumption for lower emission and more efficient food systems

Food systems also generate emissions after the farm gate, especially for conservation (cold chains), transformation, transport and cooking. There are no studies that quantify emissions from the global worldwide food system (Garnett, 2011). A study in 2006 estimated that 31 percent of the EU's GHG emissions were associated with the food system (European Commission, 2006). Reduction of food losses and waste could contribute significantly to mitigate GHG emissions.

Producing animal products from vegetal and feed input involves biological processes and associated energy requirements and losses, meaning that 1 calorie of animal product requires the production upstream of more than 1 calorie of plant origin to feed the animal. Therefore the proportion of livestock products in a diet is one of the key drivers of its emissions. FAO projects that by 2050, average meat consumption per person will be 40 percent higher than in 2010 (+70 percent in developing countries, Alexandratos, 2009).

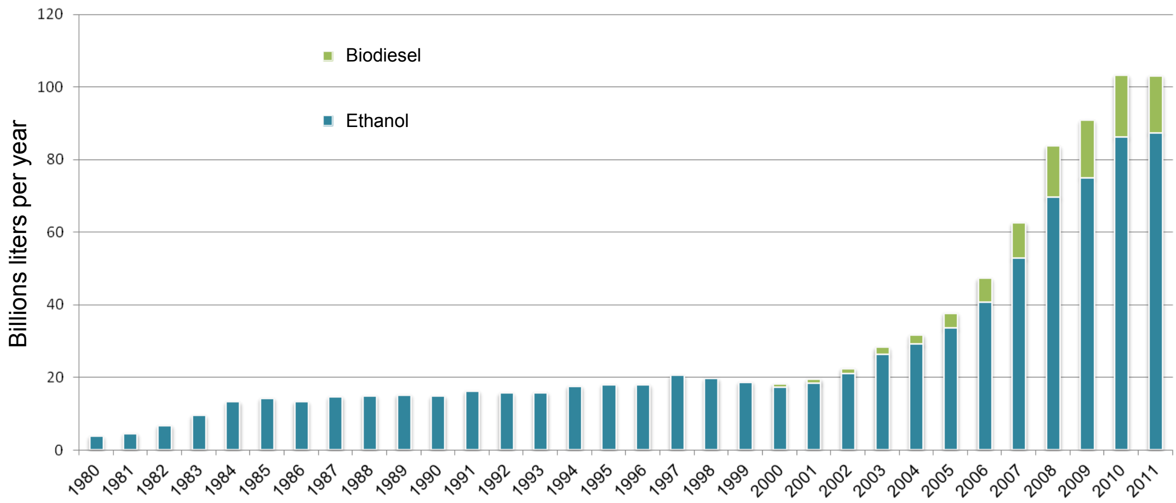
While the debate about the relative merits of diets that are entirely vegetarian versus those that include some meat products continue, there is little debate about the observation that excessive meat consumption has harmful health effects. Policies and programs that reduce excessive consumption of meat and milk and encourage more and more diverse consumption of fruits and vegetables would have both health benefits and reduce GHG emissions.

The role of diet change in reducing the demand for the most GHG intensive food types needs greater attention. Governments should promote responsible consumption, reduction of food waste and promote efficiencies throughout the food chain. The private sector should be encouraged to develop products and distribution systems that cause fewer GHG emissions.

4.4.9 Are biofuels a mitigation option?

The last decade has seen a very large increase in the amount of cropland devoted to growing crops for biofuels (both ethanol and biodiesel; see Figure 6). These so-called "first generation" biofuels are derived from carbohydrates (sugar from sugar cane and beets and starches, mainly from maize and cassava) and oils (particularly palm oil).

Figure 6. Biofuel production, 1980-2011



Source: International Energy Agency (1980-2010, estimation for 2011).

Policies to encourage the use of biofuels are motivated by two concerns – energy security and the search for more carbon-neutral energy sources. To be economically viable nearly all biofuel crops require subsidies, with Brazilian sugarcane being the main exception.

Biofuel policies have been criticized on the grounds that they can lead to increased food prices (and hence reduce food security) and that they do little to reduce and may even increase greenhouse gas emissions. The resulting higher prices encourage more production, which can come from intensification, extensification or both. It has been argued that increases in the area of land switched to biofuels were one of the underlying causes behind the higher and more volatile food prices in the last five years.

Some potential biofuels crops such as jatropha can be grown on land that is not suitable for agriculture (though possibly for pastoralism). But even in these locations, there may be indirect effects on agriculture, for example through use of water for irrigation, or depletion of groundwater and potential for loss of biodiversity.

Accounting of GHG efficiency of biofuels is very complex and compounded with many uncertainties, due to the direct and indirect use of energy in irrigation, inputs, transportation, process, especially nitrogen for the first-generation biofuels, as well as the induced loss of land carbon stocks in case of conversion of forests, wetland, carbon-rich lands in order to grow biofuel crops. Concerns have also been raised on the impact of biofuels on the other environmental challenges including biodiversity, often due to associated conversion to mono-cropping, to the increase of deforestation, threats to natural reserves, and to increase pressures on water supply and water quality problems.

The accounting calculations that have been used to demonstrate that biofuels contribute to the reduction of greenhouse emissions have been heavily questioned (e.g. Searchinger *et al.*, 2009; T. Searchinger *et al.*, 2008; Wang and Haq, 2008; Fargione *et al.,* 2008). First, the direct inputs that go into growing and processing biofuels may result in greenhouse emissions that nullify many of the advantages of fixing carbon from the atmosphere. Second the indirect land use consequences of growing biofuels can lead to substantial greenhouse emissions. This is difficult to measure as increased food prices due to biofuels in one region can lead to conversion of land to agriculture in a completely different region. Not only must the greenhouse gas emissions of land conversion be included in assessing the greenhouse gas consequences of biofuels, but also the opportunity costs of the carbon that would have been fixed in the land had they not been converted.

Thus, there is little evidence that the majority of current, first generation biofuels policies and programs are aiding either climate change mitigation or food security.

Second generation biofuels involve the use of cellulose and other plant materials that are considered waste by some. The same issues occur as with first generation biofuels, though the trade-off between land used for food and fuel may be less strong. To date the technologies have proven impossible to commercialize.

More generally, plants are not efficient converters of sunlight to useable energy. They are constrained by the radiation use efficiency limits of chlorophyll and by the fact that they can only utilize sunlight when they are alive. By contrast, today's commercially available photovoltaic cells are much more technically efficient and operate all year round (see Nelson, 2009 for more discussion of these issues).

Efforts to assess the contribution of various types of biofuels to mitigation are important and must be continued.

The HLPE will review the food security issue of biofuels in greater dealing in a new study to be released in 2013.

4.4.10 Costs and metrics to assess jointly mitigation and food security

The quality of climate is a global public good which is influenced by many different sectors in terms of emissions, and to which different countries bring different contributions.

In the face of a problem with different options, and given constraints on the amount of resources to solve it, standard economic theory recommends choosing options that are most cost-effective, with all costs accounted for (upfront costs, transaction costs, transition costs, opportunity costs, etc.).

In the context of greenhouse gas mitigation, the application of this theory implies that mitigation efforts should take place in the sectors where the mitigation costs are lowest. This theory has led to identify the agricultural sector of developing countries, and soil carbon sequestration, as one of the cheapest options worldwide (IPCC, 2007c; McKinsey&Company, 2009), a conclusion however strongly put in question by two facts:

- first, to be of use, the assessment of costs must encompass all the costs (upfront costs, transaction costs, transition costs, opportunity costs...). The current lack of reliable data of sufficient geographic and systemic coverage for agricultural mitigation costs and the weak robustness of existing mitigation costs curves in agriculture should lead to great prudence in the use of current results as an indication of “optimal” climate policies.

- second, when there is the need to pursue two global public objectives at the same time (climate change and food security), the least cost option of meeting one is not necessarily the least cost option of meeting the other. The joint consideration of climate change and of food security imposes to reframe the basic economic problem as such: Reduce emissions at the lowest “food security cost”; Improve food security worldwide at the lowest “climatic cost”.

Fortunately, there exist mitigation solutions that reduce vulnerability to food insecurity. But a potential for conflict arises if mitigation solutions negatively affect food security.

In practical terms, this translates into a questioning on the appropriate metrics to measure mitigation efforts in agriculture that are compatible with reducing vulnerability to food insecurity. As we have seen, under “business as usual”, an increase in food production will mechanically translate into an increase in emissions, the challenge being to find ways to achieve a decoupling between increased food security and increased emissions. One pertinent metric to assess emissions reductions in agriculture with a food security perspective would consist in measuring them in terms of improvements in projected efficiency rather than absolute reductions in GHG emissions. Projected efficiency, in a business as usual scenario, would need to be assessed taking into account country and region specific needs to maintain food security and guarantee the right to food, while also taking into account the impact of climate change. Mitigation actions would be assessed as a deviation from this baseline, for example by efficiency gains in food production and food chains, by reduced expansion of agriculture onto forested areas or wetlands or by the restoration of degraded land (increased carbon stock, improved vegetation coverage).

4.4.11 Supporting farmers for change

Farmers need to be supported to adopt practices that enhance their resilience and food security and that also provide long-term climate benefits. Implementing these changes generally requires an enabling environment, including services and institutions to support farmers, for instance extension services. Also, even if the new practices provide better future incomes, there are barriers to their adoption: up-front costs, income foregone or additional risks during the transition period. These costs have to be covered. Great expectations have been put in carbon finance to bring additional sources of financing, however experience has shown that these mechanisms are not well suited for agriculture due to the small size of enterprises which increases transaction costs, difficulty and costs of measurement and reporting, and carbon price volatility. Amongst finance tools, non-market mechanisms are also being explored (voluntary carbon schemes, Green Fund, etc.) with different governance schemes. Whatever the type of support or incentives for improving the overall efficiencies of the food system and internalizing the externalities associated with GHG emissions and sinks, it is recommended that mechanisms take into account both the conditions of small holders and the need for prioritizing measures that improve food security while contributing to mitigation.

4.5 Policy recommendations

Agriculture differs from all other sectors in its position in the UNFCCC negotiations on stabilization of GHGs in the atmosphere. From the start of international negotiations in Rio de Janeiro in 1992 (Article 2 of the UNFCCC[42]), it was clear that the actions to mitigate climate change and stabilize atmospheric GHG were to be done “in such a time frame to ensure that food production is not threatened”. Ensuring food security and food production is therefore one objective of the negotiations on climate change mitigation. This puts food security, even from the point of view of climate change policies, as a goal of the negotiations rather than as simply another topic for consideration.

[42] http://unfccc.int/essential_background/convention/background/items/1353.php.

Low-emissions strategies for agriculture are needed in developed and developing countries. Meeting any of the emissions goals to keep global temperatures within safe bounds will require *both* reductions in emissions from developed countries and reductions in emissions growth in developing countries. Mitigation activities should be undertaken where the costs per unit of GHG mitigated, both financial and in terms of sustainable food security, are lowest and the benefits the highest. The assessment of costs should take into account both direct and indirect emissions. This might result in some mitigation activities being undertaken in countries with relatively low historical or current emissions. Care should be taken that such activities do not have negative consequences for food security. Incentive-based systems that target the vulnerable while mitigating emissions and increasing climate change resilience have multiple benefits.

While emissions per person are currently low in developing countries, they are likely to grow rapidly unless development strategies that include low-emission systems, practices and technologies for agriculture are followed. These are likely to be much less costly to implement as part of general development efforts today than done later and independently. National public policies that support mitigation in agriculture are an essential element of ensuring globally efficient mitigation activities. It is also important to support these changes by the creation of policies and financial incentives, including market- and non-market-based mechanisms adapted to the needs of agriculture and particularly of small holders and to design global trade and aid policies that support adaptation and mitigation.

Considerable GHG emissions from agriculture can be mitigated by good management practices that in many cases also increase productivity and enhance resilience. Public policies and programs should target the development and dissemination of these win-win outcomes first. Improving crop yields from land already under cultivation is often a more effective way to mitigate GHGs emissions from agriculture than expanding cultivated land area. Ending most conversion of land to agriculture should be a mitigation priority. Emissions associated with livestock agriculture are likely to grow rapidly because of population growth and diet change. Research on systems, practices and technologies that raise productivity and allow farmers to reduce substantially the GHG emissions per unit of output (meat and milk) should be a priority.

Throughout this chapter, we have identified policy recommendations on appropriate development of agricultural mitigation that also enhance food security. We summarize these here. Developing countries' agricultural and land use change emissions will likely grow rapidly unless low-emissions strategies that also contribute to sustainable food security are actively pursued. Agriculture is unique in that some practices can capture CO_2 and sequester carbon above and below-ground. GHG emissions from agriculture can be mitigated by good management practices and most of these practices can also increase productivity and resilience to climate change. It is important to devise national and international policies and programs that reduce existing disincentives and provide innovative incentives to development and dissemination of specific practices of relevance to those in charge of farm operations.

The dramatic effect of land use change on GHG emissions emphasizes the importance of finding agricultural development strategies that reduce the conversion of non-agricultural land to agricultural activities. The focus of agricultural mitigation policies and programs should be on improving productivity on existing fields and searching for options that also enhance food security rather than expansion of croplands. It is important to devise public policies and programs that reduce existing disincentives and provide innovative incentives to development and dissemination of specific practices of agricultural management that increase soil organic carbon in degraded soils.

There is a substantial potential for mitigating agricultural GHG emissions through appropriate water management especially in rice production with the added benefit of improving water use efficiency.

Increasing the efficiency of use of nitrogen fertilizers would allow reduced application rates, with lower N_2O emissions and possibly increased crop yields. Policies and programs that increase nitrogen use efficiency have multiple benefits – reducing simultaneously application rates and farm input costs, direct and indirect GHG emissions, and off-farm damage to the environment. Further research is needed into less energy intensive ways of manufacturing artificial fertilizers and into means of reducing greenhouse gas emissions from animal waste and wetland rice.

As population and income growth increase demand for livestock products, policies and programs that increase animal productivity and reduce emissions per unit of product are essential. Reducing emissions from animal waste will also be critical.

The potential role of diet change in reducing the demand for the most GHG intensive food types needs greater attention. Policies and programs that reduce consumption of livestock products and encourage more and more diverse consumption of fruits and vegetables in developed countries would contribute both to improved health outcomes and lower GHG emissions. Reduction of food losses and waste could contribute significantly to mitigate GHG emissions. The private sector should be encouraged to develop products and food systems that cause less GHG emissions.

There is little evidence that the majority of current biofuels policies and programs are aiding either climate change mitigation or food security.

5 COORDINATION AND COHERENCE OF FOOD SECURITY AND CLIMATE CHANGE POLICIES AND ACTIONS

It is not possible to provide detailed policy recommendations for specific countries, regions, or groups. Actions that are entirely appropriate in some locations and countries would be completely inappropriate in others. We start with a set of four general policy principles and then a series of policy messages to provide guidance for developing nationally-relevant policies and programs and that can also assist international activities.

5.1 Four principles for policies and action

Four principles should guide the design of policies and programs to reduce the negative effects of climate change on food security and to shape development strategies to support agriculture's contribution to greenhouse gas mitigation.

Integrate food security and climate change efforts. Policies and programs designed to respond to climate change should be complementary to, not independent of, those needed for sustainable food security. Climate change is one of a range of threats to food security and interventions designed to increase general food system resilience are highly likely to contribute to climate change adaptation. Efforts to increase expenditure just on adaptation would be better directed toward increasing overall expenditures on sustainable food security with particular attention being paid to the unique and uncertain threats from climate change that require action today (public, private and other sectors).

Collect information locally and share knowledge globally. Climate change adaptation and mitigation activities in agriculture are implemented on millions of farms and undertaken by people who are often the most vulnerable. Local lessons learned can be made much more valuable when shared. The knowledge already gained by farmers about practices that work in their conditions today could prove invaluable to farmers elsewhere in the future. But some consequences of climate change are outside the realm of recent human experience and focused, systematic data generation efforts are needed to develop effective response efforts. Because the benefits cross national borders, knowledge gathering and sharing require global coordination as well as national programs.

Involve all stakeholders in decision-making. The changes on the ground needed for both adaptation and mitigation will be undertaken by many actors along the marketing chain from producers to consumers. The public sector develops and implements the policy and program environment in which private sector decisions are made. Civil society is critical in its many roles from monitor of government and private sector actions to integrator across diverse interests to institutional innovator. Both public-public and public-private partnerships are essential to address all elements of the coming challenges to food security from climate change in equitable and efficient ways. This will require greater transparency and new roles for all elements of society, including the private sector and civil society.

Focus on the needs and contributions of the disadvantaged. Finally, activities to address climate change should be done with explicit attention to addressing the needs of the disadvantaged. This principle applies to all who are vulnerable to climate change, but it is especially important to focus on the role of women as agricultural decision-makers and thus integral to the planning, design, and implementation of policies and programs to address climate change challenges to food security. Too often in development discussions, women are perceived as beneficiaries and not as resource persons. It is essential to promote women's leadership and participation in decision–making on food security generally and specifically as adaptation and mitigation needs are addressed. At the same time, a nuanced view of gender must recognize that women are not a homogenous constituency. Gender inequities are conditioned by class and various cultural and other socio-economic factors.

The development and strengthening of capacity (human, infrastructural and institutional) for climate change is required at all levels of society, across sectors (agriculture, health and education) and across the local and global food system.

Keeping pace with this knowledge development will require responsive knowledge management and dissemination systems and will need providing a range of meaningful information and knowledge to various players in the food system.

The capacity to adopt new technologies and practices is also required. Reaching the most vulnerable and marginalized communities will require careful attention. Physical and institutional infrastructure is required for monitoring and evaluating climate change and mitigating and managing the effects at levels ranging from the farm to global governance.

Responsive information collection, management and dissemination systems, using appropriate media tools, should be established that reach those who need it the most.

5.2 Transparent, fair and efficient partnerships for climate sensitive agricultural research and development

Addressing food security and climate change requires concerted and coordinated involvement and action of many actors, farmers, private sector, and public actors national and international, civil society and NGOs. It is especially challenging as they are very different, sometimes have conflicting objectives and there is a need to work on a long term perspective while most of them have to consider first a short term outcome. This requires the involvement of all stakeholders. Adaptation efforts should build approaches that prioritize vulnerable communities.

5.2.1 Promote debate on the roles of the public and private sectors in safeguarding food security in the context of climate change

The quality of the climate is widely recognized to be a public good. Similarly, global food security is increasingly recognized as a public good. The actions of the public and private sector and CSOs and farmers are shaping the provision of these goods. Therefore an important question for the future is how to mobilize efforts in the same direction and on how they can complement one another.

The issue of public-private partnerships, which has already been actively promoted in sectors such as infrastructure and health, is increasingly presented as an essential part of the solution to problems of agricultural development. In relation to climate change, public private partnerships are being promoted to secure access of small holders to markets (Beddington *et al.*, 2012) and to hedge against climatic uncertainties such as insurance schemes co-funded by the private sector.

The role of the private sector is being promoted in all areas of agriculture – from research to extension to production and distribution. The argument is that since the public sector is unable to invest sufficiently in all these services, the private sector has to step in.

This view is challenged by groups, including many developing country governments and civil society actors, which see an important role for the public sector and question the ability and effectiveness of the private sector to provide public goods. Critics of public-private partnerships maintain that it is not possible to reconcile the profit-seeking interests of the private sector with objectives such as decreasing hunger and poverty. In addition, government funds could be used to subsidize private sector interests. These partnerships could lead to unexpected negative externalities or public funds might be used for positive externalities that may not materialize.

Given these controversies it would be wise to promote greater debate on the actual effectiveness of public-private partnerships by reviewing experiences on the ground. Climate change is changing the perspectives on how to look at food security. Climate change is one of the factors that might change how we approach these partnerships by putting greater focus on long-term issues and on vulnerabilities. The public sector is more able to balance the short and long-term interests of society, and to address the needs of vulnerable groups more than the private sector which seeks short-term benefits.

The participation of the communities affected, including previous and informed consultation about risks, and the direct and indirect impacts on resilience of small-scale farmers and rural communities, should be ensured.

5.2.2 Cooperate for research

The joint threats of food insecurity and climate change justify a reappraisal of how national and international public funded research can work best with the private sector. This need must be seen against recent trends of decreased investment in food system research in the public sector, but research by the private sector is focused on a limited number of crops and regions. New public sector research should emphasize those crops, animals, and systems that are important for food security but receive less private sector attention. It is essential that public sector research and extension efforts associate the private sector and civil society.

Particular attention must be paid to how the needs of the world's poorest and most disadvantaged food producers can be addressed through research and knowledge creation. This will require meaningful engagement with the intended beneficiaries, and a genuine dialogue to understand their requirements, taking into account the difficulties that can exist in obtaining the views of women and disadvantaged groups.

5.2.3 Cooperate for extension

In many parts of the world, in countries of all development status, extension services are currently not fit for purpose to deliver the varied knowledge skills that farmers require to adapt to climate change and contribute to mitigation. Modern revitalized extension services, often funded from both public and private sector resources are urgently needed to face these challenges. To make sure that productivity and resilience enhancing technologies are adopted, extension programs should target those who make the management decisions. A 21st century extension service should work closely with research, the private sector and civil society, also including farmer-to-farmer networks of information and knowledge sharing, to increase skills in raising yields sustainably and in dealing with the challenges of climate change.

5.2.4 Capacity building

Assessing vulnerabilities to climate change (including proper apprehension of uncertainties and time scales) and devising ways to increase efficiency and resilience of food systems in order to both adapt to climate change and contribute to its mitigation requires specific capacity building focusing on the needs of decision makers and stakeholders at local and national levels.

In many countries, the physical, institutional, social, biological, and human capacity to deal with climate change and food security challenges is not adequate. Also essential is investment in human capital, particularly education and health infrastructure to build resilience to food insecurity and be aware of and respond effectively to climate change risks.

Information for adaptation and mitigation is an essential element in building resilience and the capacity of populations and nations to anticipate and manage climate change. Knowledge systems with regard to climate change are dynamic and emerging as more information and research becomes available. Governments and other actors need to strengthen their capacity for responsive and innovative information collection, management and dissemination systems, which can reach everyone, with particular focus on the most vulnerable groups.

Deliberate efforts to build these capacities are urgently needed.

5.3 Increase the base of evidence for policy-making

5.3.1 More, better and coordinated data collection

An evidence-based approach, sensitive to environmental and social context, and to different value systems, is essential. Successful adaptation of global agriculture and the food system to climate change, and successful food security-compatible mitigation will require mobilization of the most effective practices from all modes of agriculture, realizing that no single solution or set of solutions will be appropriate everywhere. Techniques drawn from conventional, agro-ecological, organic and high-technology food production will all need to be evaluated for their location-specific appropriateness.

The information base available to facilitate policy and program developments to reduce the food security effects of climate change is woefully inadequate. National governments need to improve their efforts. But there is also a need for international data gathering on climate change and its effects to improve information on vulnerable communities, populations and regions.

A major increase in the quality and quantity of the biophysical, economic and social data available to policy makers is required. Particular challenges include (i) linking existing and future data sources using global metadata standards; (ii) making use of modern technology (ICT, remote sensing) to harvest real time data; (iii) developing means of evaluating the different classes of climate change models; (iv) enabling disaggregated data collection, including at the intra-household level, to identify drivers of social vulnerability to food security and challenges to mitigation and adaptation; and
(v) improving the pipeline between data gathering, analysis and feeding into policy making.

Collect more biophysical data. Substantial genetic diversity exists in the plants and animals we use for food. But their performance under a range of agroclimatic conditions has not been systematically evaluated. Existing experimental trial data should be supplemented with collection of additional performance information, including on neglected crops, and new trials set up to capture performance characteristics outside of current climate ranges. The quality of existing data about current and historical weather is mixed, with some countries doing a better job than others on collection and dissemination. More needs to be collected and much more needs to be made freely available.

Improve information about vulnerable communities/populations and regions. Successful adaptation requires greatly improved knowledge of who the vulnerable are and where they live. More advanced means of mapping vulnerability and its components of risk, sensitivity and capacity to respond should be a priority.

Integrate data collection across all dimensions of climate change and food security. National and international meteorological, statistical and data services will need strengthening and full advantage taken of modern technological advances including remote sensing and ICT. There are a wealth of recent initiatives designed to collect environmental, land use, and human geographic data at small, medium and large spatial scales. It is essential that these be linked together through the adoption of common metadata standards to maximize all possible synergies

Improve models that facilitate understanding of climate change effects on agriculture; support capacity building in their use. Climate models generate vast amounts of data about possible future outcomes but not always summarized in ways that are useful to understanding potential effects on agricultural systems. Models that link climate change outcomes to biophysical effects and then to human well-being require much greater development. Modest investments would provide great support to policy makers everywhere.

5.3.2 Assess interventions and monitor performance

Adaptation is a learning process. There is much that can be done to adapt agriculture to changing climate using existing knowledge about the social, economic and biophysical aspects of food production. Skills and knowledge currently appropriate for one region might be important in another region in the future. But m*onitoring existing practices and performance is important.* Rigorous evaluation of the effect of mitigation and adaptation interventions for their impacts on the relevant outcomes as well as on food security is needed to ensure there are no unintended negative consequences. Systematic collection and widespread dissemination of this information is essential with modern ICT providing unprecedented opportunities.

Adaptation to climate change requires individual farmers to make informed decisions in the face of uncertain knowledge. Research in the social sciences is needed to better understand how to facilitate these changes that will ultimately benefit the farmer. There is a great need for research into how best to monitor and evaluate different social and economic interventions aimed at promoting adaptation.

5.3.3 Refocus research to address a more complex set of objectives

The joint threats of food insecurity and climate change justify a reexamination of research priorities.

Anticipatory and participatory research must be promoted to strengthen the coping capacity of farm families. Research on agriculture must fully integrate climate adaptation aspects. Such research is required to maintain productivity growth in the face of more frequent extreme events, to adjust to differing responses of crops, livestock, and management systems to changes in temperature and precipitation, and to deal with the off-farm effects of climate change. Research on topics such as crop and livestock improvement, agronomy and food storage, processing and distribution should all include the need to adapt to new climates. As maintaining crop and livestock genetic diversity is important to facilitate improved yields and efficiency under new environmental conditions, there is also a need for more research on the effects of climate change on neglected crops, particularly on fruit and vegetable productivity.

Studies are urgently needed that investigate “stress combinations” and the interactions between different abiotic and biotic stresses in key agricultural and aquaculture systems.

Research on mitigation practices must take into account their impact on food security

Research should pay special attention to the conditions and limits facing today’s small-scale farmers. They account for a large share of global agricultural land use, food production in some regions, and rural employment today, and often are operated by women. They are more likely to engage in mixed crop and livestock agriculture.

National Adaptation Programs of Actions (NAPAs) submitted to the UNFCCC by the least developed countries have often highlighted agriculture and food security investments for research and extension and provide a starting point for prioritizing new national investments. There is an urgent need to undertake these investments quickly, because improvements take time to develop and deliver to farmers.

5.4 Climate change negotiations and agriculture

The United Nations Framework Convention on Climate Change (UNFCCC) was set up at the first United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. Its original objective was to stabilize GHG emissions at a level that would prevent dangerous impacts on human well-being and in such a time frame that "ensures that food production is not threatened" (Article 2). Agriculture and food security did not receive much attention in the initial years of the UNFCCC agenda in spite of significant impacts of climate change on agriculture and food security, and the contribution of agricultural GHG emissions. More focus on agriculture began with the Nairobi Work Program (NWP) formally launched in 2005 on impacts, vulnerability and adaptation. More recently, many countries have included agriculture and food security projects in their National Adaptation Programs of Action (NAPAs). Cropland and grazing land management are Land Use and Land-Use Change and Forestry (LULUCF) activities that Annex I Parties may choose to include as part of Kyoto Protocol emission reduction obligations, but very few of them have done so.[43]

As part of the negotiations to achieve a binding global agreement that began in the Bali meeting of the UNFCCC annual conference of parties in 2007, agriculture has become more prominent. Significant controversy has arisen over whether agriculture can be addressed on its own, or whether a general framework for cooperative sectoral approaches needs to be agreed upon before any specific sectoral initiatives are undertaken.[44]

The parties discussed the specific contributions of agriculture to GHG mitigation with the release of a technical paper in 2008 regarding challenges and opportunities for mitigation in the agricultural sector for the Working Group on Long-term Cooperative Action (AWG-LCA) and in a workshop held in 2009. No official discussions have been held on agricultural adaptation. A drafting group was created under the AWG-LCA to prepare text for agriculture requesting a SBSTA work program[45] on agriculture under the Convention's Article 4.1(c).[46] The draft was not approved during Conference of the Parties (COP) 15, Copenhagen in 2009 nor at COP 16 in Cancun in 2010. The negotiators at COP 17 in Durban agreed to consider issues related to agriculture at the inter-sessional meeting in Bonn in May 2012 "with the aim of exchanging views and the Conference of the Parties adopting a decision on this matter at its eighteenth session," still under the framing of Article 4.1(c).

Support for a SBSTA work program on agriculture has come from some observers to the UNFCCC negotiations. For example, FAO has sent various submissions[47] stressing the specificity of agriculture and the importance of properly addressing food security and agriculture and other observers have also argued for a work program that includes both adaptation and mitigation. The Cancun Adaptation Framework, approved at the COP 16, included agriculture and food security as an element of various streams of work, including the second phase of the NWP and the newly initiated Program on Loss and

[43] UNFCCC Decision 16/CMP.1, available at http://unfccc.int/resource/docs/2005/cmp1/eng/08a03.pdf.

[44] A paragraph on trade is reported to be one of the major items of disagreement hindering approval of a framework for sectoral approaches.

[45] The Subsidiary Body for Scientific and Technological Advice (SBSTA) "[…] is one of two permanent subsidiary bodies to the Convention established by the COP/CMP. It supports the work of the COP and the CMP through the provision of timely information and advice on scientific and technological matters as they relate to the Convention or the Kyoto Protocol. [...] The SBSTA plays an important role as the link between the scientific information provided by expert sources such as the IPCC on the one hand, and the policy-oriented needs of the COP on the other. It works closely with the IPCC, sometimes requesting specific information or reports from it, and also collaborates with other relevant international organizations that share the common objective of sustainable development." (http://unfccc.int/bodies/body/6399.php). The Nairobi Work Programme is an example of a SBSTA work program.

[46] Bali Action Plan 1(b)(iv) reads: "Cooperative sectoral approaches and sector-specific actions, in order to enhance implementation of Article 4, paragraph 1(c) of the Convention".

[47] See http://unfccc.int/resource/docs/2010/smsn/igo/081.pdf, http://unfccc.int/resource/docs/2011/smsn/igo/121.pdf and http://unfccc.int/resource/docs/2012/smsn/igo/73.pdf.

Damage, specifically in relation to slow onset temperature rise.[48] Agriculture will continue to be addressed under the Adaptation Framework and ongoing programs such as the Nairobi Work Program and the Work Program on Loss and Damage. It will also be an essential element of discussions under four newly established work programs under the Kyoto Protocol as well as the SBSTA work program on REDD+, as countries will consider the role of agriculture as a driver of deforestation.[49] However, as discussed in Chapters 2-4, there remain significant technical and scientific uncertainties about the needs for adaptation in agriculture and the possibilities for mitigation, especially focused in reducing the contributions of agricultural emissions globally.

5.5 Recommendations for the CFS

Include climate change recommendations in the Global Strategic Framework for Food Security. The CFS is currently preparing a Global Strategic Framework for Food Security. We strongly encourage the inclusion of the recommendations provided here as key elements of this framework.

Encourage more explicit recognition of food security in UNFCCC activities. Over the past few years of the UNFCCC negotiations, the need for agricultural adaptation and mitigation has figured more prominently. In Durban, the negotiators solicited inputs from member countries and observers on issues related to agriculture. A SBSTA work program on agriculture that more clearly identifies the pros and cons of various adaptation and mitigation measures and possible synergies with food security could provide a forum both for organizing existing research and motivating new research of relevance to the negotiations. We recommend it be implemented. We also recommend more progress under the Work Program on Loss and Damage, emphasizing the impacts of adverse effects of climate change on agriculture and food security. Finally, the CFS should request UNFCCC to charge national governments with reporting on how initiatives and policies that are introduced as part of the National Climate Change Action Plans and National Adaptation Plans also address food security efforts.

Developed countries have already accepted the responsibility for financial support for adaptation activities in developing countries as part of the Copenhagen Accord and the Cancun Agreement under the UNFCCC. The CFS should endorse this position and encourage countries to design their support so that it also supports sustainable food security.

Support climate change adaptation and mitigation in international trade negotiations. The World Trade Organization has ongoing negotiations on improving the world trading regime (the Doha Round). With increasing variability in agricultural production due to climate change, and the potential for trade flows to partially compensate for climate-related shocks in agriculture, we recommend that the CFS support inclusion of negotiating outcomes in the WTO that recognize this role. Similarly, we recommend that the CFS encourage the WTO to support trade policy reforms that facilitate rather than hinder mitigation.

Enhance the role of civil society. The CFS is unique among UN organizations in that it has an official role for civil society. We encourage the CFS to strengthen the existing channels of participation such as the CFS Advisory Group and to support more civil society activities related to the CFS, such as side events at official CFS and other UN meetings, in particular the UNFCCC conferences, to generate more publicity for and debates on the reports published by the HLPE and the decisions taken by the CFS.

Support the development of a collection sharing mechanism on international data gathering for climate change and food security. The consequences of climate change cross national boundaries. The effects can only be addressed if data gathering is coordinated internationally using commonly agreed metadata

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[48] See UNFCCC Decision 1/CP.16, available at http://unfccc.int/resource/docs/2005/cmp1/eng/08a03.pdf.

[49] See Decision 2/CMP.7 at http://unfccc.int/meetings/durban_nov_2011/session/6250/php/view/decisions.php. and Decision 1/CP.16 at http://unfccc.int/meetings/cancun_nov_2010/session/6254/php/view/decisions.php.

standards. Furthermore, there are great synergies to be achieved by coordinating food security data collection with that of climate change to benefit the most vulnerable regions and populations. The CFS should facilitate a dialogue on global data collection efforts for climate change and food security.

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The HLPE also acknowledges the important feedback received from the anonymous peer-reviewers on a pre-final draft of this report.

APPENDIX

A1. The HLPE project cycle

The HLPE has been created in 2009 as part of the reform of the Committee on World Food Security (CFS) to assess and analyze the current state of food security and nutrition and its underlying causes; provide scientific and knowledge-based analysis and advice on specific policy-relevant issues, utilizing existing high quality research, data and technical studies; Identify emerging issues, and help members prioritize future actions and attentions on key focal areas.

The HLPE receives its mandate from CFS and reports to it. It produces its reports, recommendations and advice independently from governmental positions, in order to inform and nourish the debate with comprehensive analysis and advice.

The HLPE has a two-tier structure:

- A Steering Committee composed of 15 internationally recognized experts in a variety of food security and nutrition related fields, appointed by the Bureau of CFS. HLPE Steering Committee members participate in their individual capacities, and not as representatives of their respective governments, institutions or organizations.
- Project Teams acting on a project specific basis, selected and managed by the Steering Committee to analyze/report on specific issues.

To ensure the scientific legitimacy and credibility of the process, as well as its transparency and openness to all forms of knowledge, the HLPE operates with very specific rules, agreed by the CFS.

The reports are produced by time-bound and topic-bound Project Teams, selected and appointed by the Steering Committee, following its guidance and under its oversight.

The project cycle for the reports, in spite of its being extremely time constrained, includes clearly defined stages separating the elaboration of the political question and request by the CFS, its scientific formulation by the Steering Committee, the work of a time bound and topic bound project team, external open consultations to enrich the knowledge base, an external scientific review (Figure 7).

The process promotes a scientific dialogue between the Steering Committee and the Project Team throughout the project cycle, with the experts in the HLPE Roster, and all concerned and interested knowledge-holders worldwide, thriving for the involvement of diverse scientific points of view.

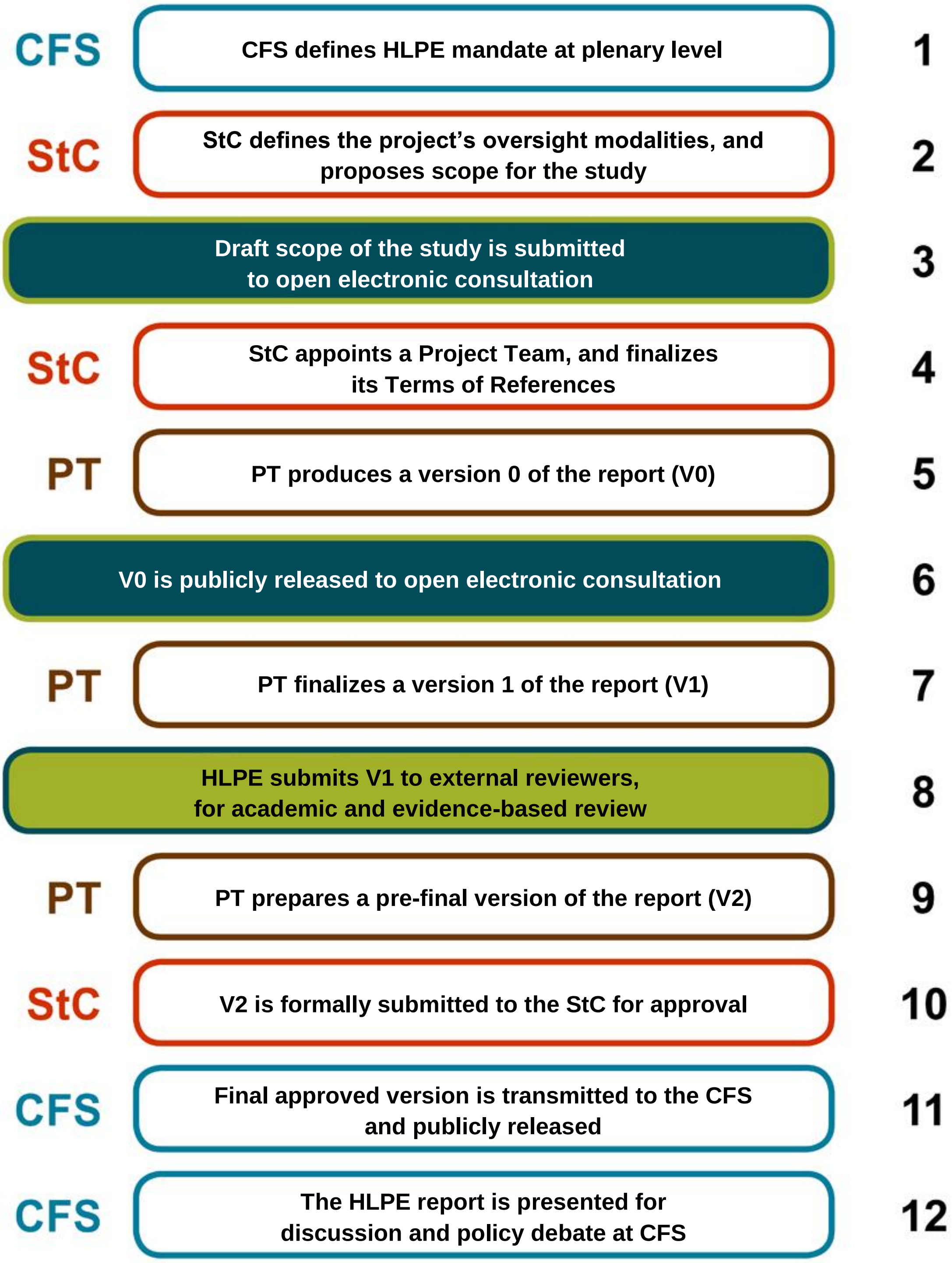
This is why the HLPE runs two external consultations per report: first, on the scope of the study; second, on a first draft (V0). This provides an opportunity to open the process to the input of all experts interested and towards the experts HLPE roster (there are currently 1200 of them), as well as to all concerned stakeholders. The input provided, including social knowledge, is then considered by the Project Team and enriches the knowledge base.

The draft report is submitted to independent evidence-based review. It is then finalized and discussed, leading to its approval by the Steering Committee during a face-to-face meeting.

The report approved by the Steering Committee is transmitted to the CFS, made public, and serves to inform discussions and debates in CFS.

All information regarding the HLPE, its process, former reports is available at the HLPE website: www.fao.org/cfs/cfs-hlpe.

Figure 7. HLPE project cycle



CFS Committee on World Food Security
HLPE High Level Panel of Experts on Food Security and Nutrition
StC HLPE Steering Committee
PT HLPE Project Team

Source: HLPE, 2012b.

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CFS
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