CLIMATE CHANGE AND FOOD SECURITY:

A FRAMEWORK DOCUMENT

INTERDEPARTMENTAL WORKING GROUP ON CLIMATE CHANGE

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FOREWORD

Climate change will affect all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability. It will have an impact on human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term, resulting from more frequent and more intense extreme weather events, and long term, caused by changing temperatures and precipitation patterns,

People who are already vulnerable and food insecure are likely to be the first affected. Agriculture-based livelihood systems that are already vulnerable to food insecurity face immediate risk of increased crop failure, new patterns of pests and diseases, lack of appropriate seeds and planting material, and loss of livestock. People living on the coasts and floodplains and in mountains, drylands and the Arctic are most at risk.

As an indirect effect, low-income people everywhere, but particularly in urban areas, will be at risk of food insecurity owing to loss of assets and lack of adequate insurance coverage. This may also lead to shifting vulnerabilities in both developing and developed countries.

Food systems will also be affected through possible internal and international migration, resource- based conflicts and civil unrest triggered by climate change and its impacts.

Agriculture, forestry and fisheries will not only be affected by climate change, but also contribute to it through emitting greenhouse gases. They also hold part of the remedy, however; they can contribute to climate change mitigation through reducing greenhouse gas emissions by changing agricultural practices.

At the same time, it is necessary to strengthen the resilience of rural people and to help them cope with this additional threat to food security. Particularly in the agriculture sector, climate change adaptation can go hand-in-hand with mitigation. Climate change adaptation and mitigation measures need to be integrated into the overall development approaches and agenda.

This document provides background information on the interrelationship between climate change and food security, and ways to deal with the new threat. It also shows the opportunities for the agriculture sector to adapt, as well as describing how it can contribute to mitigating the climate challenge.

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SUMMARY

Until recently, most assessments of the impact of climate change on the food and agriculture sector have focused on the implications for production and global supply of food, with less consideration of other components of the food chain. This paper takes a broader view and explores the multiple effects that global warming and climate change could have on food systems and food security. It also suggests strategies for mitigating and adapting to climate change in several key policy domains of importance for food security.

Defining terms and conceptualizing relationships

Food security is the outcome of food system processes all along the food chain. Climate change will affect food security through its impacts on all components of global, national and local food systems.

Climate change is real, and its first impacts are already being felt. It will first affect the people and food systems that are already vulnerable, but over time the geographic distribution of risk and vulnerability is likely to shift. Certain livelihood groups need immediate support, but everbody is at risk.

Managing risk

Risk exists when there is uncertainty about the future outcomes of ongoing processes or about the occurrence of future events. Adaptation is about reducing and responding to the risks climate change poses to people's lives and livelihoods.

Reducing uncertainty by improving the information base, and devising innovative schemes for insuring against climate change hazards will both be important for successful adaptation. Adaptive management can be a particularly valuable tool for devising strategies that respond to the unique risks to which different ecosystems and livelihood groups are exposed.

Strengthening resilience

Strengthening resilience involves adopting practices that enable vulnerable people to protect existing livelihood systems, diversify their sources of income, change their livelihood strategies or migrate, if this is the best option.

Changing consumption patterns and food preparation practices may be sufficient to protect food security in many circumstances. Both market forces and voluntary choices influence individual decisions about what food to eat and how to maintain good health under a changing climate.

Safeguarding food security in the face of climate change also implies avoiding the disruptions or declines in global and local food supplies that could result from changes in temperature and precipitation regimes and new patterns of pests and diseases.

Raised productivity from improved agricultural water management will be crucial to ensuring global food supply and global food security. Sustainable livestock management practices for adaptation and associated mitigation should also be given high priority. Conservation agriculture can make a significant difference to efficiency of water use, soil quality, capacity to withstand extreme events, and carbon sequestration. Promoting agrobiodiversity is particularly important for local adaptation and resilience.

Meeting the growing demand for energy is a prerequisite for continued growth and development. Bioenergy is likely to play an increasingly important role, but its use should not undermine food security.

Mitigating climate change

Mitigating climate change means reducing greenhouse gas emissions and sequestering or storing carbon in the short term, and – of even greater importance – making development

choices that will reduce risk by curbing emissions over the long term. Although the entire food system is a source of greenhouse gas emissions, primary production is by far the most important component. Incentives are needed to persuade crop and livestock producers, agro-industries and ecosystem managers to adopt good practices for mitigating climate change.

The way forward

In the food and agriculture sector, adaptation and mitigation often go hand in hand, so adopting an integrated strategic approach represents the best way forward.

Several funds within the United Nations system finance specific activities aimed at reducing greenhouse gas emissions and increasing resilience to the negative impacts of climate change. Because many mitigation actions that would have high payoffs also represent good options for adaptation within the food and agriculture sectors of low-income developing countries, it may be possible to obtain additional resources from bilateral and multilateral aid agencies, which are becoming increasingly interested in investing development resources in adaptive responses to climate change.

The ultimate goal of FAO's climate change work is to inform and promote local dialogue about what the impacts of climate change are likely to be and what options exist for reducing vulnerability, and to provide local communities with site-specific solutions.

ACRONYMS

CBD	United Nations Convention on Biological Diversity
CCFS	climate change and food security
CDM	Clean Development Mechanism
CER	certified emissions reduction
CIESIN	Center for International Earth Science Information Network
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
COP	Conference of the Parties
DRC	Democratic Republic of the Congo
ECV	essential climate variable
EPA	Environmental Protection Agency (United States)
ESAC	Comparative Agricultural Development Service (FAO)
ESSP	Earth System Science Partnership
ETFRN	European Tropical Forestry Research Network
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FIVIMS	Food Insecurity and Vulnerability Information and Mapping System
FSIEWS	Food Security Information and Early Warning System
GCOS	Global Climate Observing System
GECAFS	Global Environmental Change and Food Systems (project)
GEF	Global Environment Facility
GHG	greenhouse gas
GIPB	Global Partnership Initiative for Plant Breeding Capacity Building
ICSU	International Council for Science
IDWG	Interdepartmental Working Group
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IFRC-RCS	International Federation of Red Cross and Red Crescent Societies
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
ILO	International Labour Organization
INI	International Nitrogen Initiative
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
LDC	least-developed country
LDCF	Least Developed Countries Fund (UNFCCC)
MDG	Millennium Development Goal
NAPA	National Adaptation Programme of Action (UNFCCC)
NFP	National Forest Programme
NGO	non-governmental organization
NPFS	National Programme for Food Security
NRC	Environment, Climate Change and Bioenergy Division (FAO)
NRCB	Climate Change and Bioenergy Unit (FAO)
NRCE	Environmental Assessment and Management Unit (FAO)
NWP	Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change
RICMS	Rice Integrated Crop Management Systems
RPFS	Regional Programme for Food Security
SARD	sustainable agriculture and rural development

SBSTA	Subsidiary Body for Scientific and Technical Advice (UNFCCC)
SCCF	Special Climate Change Fund (UNFCCC)
SEI	Stockholm Environment Institute
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNDPI	United Nations Department of Public Information
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
UK DEFRA	United Kingdom Department for Environment, Food and Rural Affairs
WCRP	World Climate Research Programme
WFS	World Food Summit
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute

INTRODUCTION

Mean global temperatures have been increasing since about 1850, mainly owing to the accumulation of greenhouse gases in the atmosphere. The main causes are the burning of fossil fuels (coal, oil and gas) to meet increasing energy demand, and the spread of intensive agriculture to meet increasing food demand, which is often accompanied by deforestation. The process of global warming shows no signs of abating and is expected to bring about long-term changes in weather conditions.

These changes will have serious impacts on the four dimensions of food security: food availability, food accessibility, food utilization and food system stability. Effects are already being felt in global food markets, and are likely to be particularly significant in specific rural locations where crops fail and yields decline. Impacts will be felt in both rural and urban locations where supply chains are disrupted, market prices increase, assets and livelihood opportunities are lost, purchasing power falls, human health is endangered, and affected people are unable to cope.

Until about 200 years ago, climate was a critical determinant for food security. Since the advent of the industrial revolution, however, humanity's ability to control the forces of nature and manage its own environment has grown enormously. As long as the economic returns justify the costs, people can now create artificial microclimates, breed plants and animals with desired characteristics, enhance soil quality, and control the flow of water.

Advances in storage, preservation and transport technologies have made food processing and packaging a new area of economic activity. This has allowed food distributors and retailers to develop long-distance marketing chains that move produce and packaged foods throughout the world at high speed and relatively low cost. Where supermarkets with a large variety of standard-quality produce, available year-round, compete with small shops selling high-quality but only seasonally available local produce, the supermarkets generally win out.[1]

The consumer demand that has driven the commercialization and integration of the global food chain derives from the mass conversion of farmers into wage-earning workers and middle-level managers, which is another consequence of the industrial revolution. Today, food insecurity persists primarily in those parts of the world where industrial agriculture, long-distance marketing chains and diversified non-agricultural livelihood opportunities are not economically significant.

At the global level, therefore, food system performance today depends more on climate than it did 200 years ago; the possible impacts of climate change on food security have tended to be viewed with most concern in locations where rainfed agriculture is still the primary source of food and income.

However, this viewpoint is short-sighted. It does not take account of the other potentially significant impacts that climate change could have on the global food system, and particularly on market prices. These impacts include those on the water and energy used in food processing, cold storage, transport and intensive production, and those on food itself, reflecting higher market values for land and water and, possibly, payments to farmers for environmental services.

Rising sea levels and increasing incidence of extreme events pose new risks for the assets of people living in affected zones, threatening livelihoods and increasing vulnerability to future food insecurity in all parts of the globe. Such changes could result in a geographic redistribution of vulnerability and a relocalization of responsibility for food security – prospects that need to be considered in the formulation of adaptation strategies for people who are currently vulnerable or could become so within the foreseeable future.

[1] For two recent discussions of the modernization processes that have transformed food systems in the past half century, see FAO, 2004b: 18–19; and Ericksen, 2006.

The potential impacts of climate change on food security must therefore be viewed within the larger framework of changing earth system dynamics and observable changes in multiple socio-economic and environmental variables. This paper seeks to illuminate the potential impacts, both the fairly certain and the highly uncertain, at least at the local level.

Chapter 1 defines key terms and conceptual relationships and discusses possible impacts of climate change on food system performance and food security outcomes. Chapters 2 and 3 provide detail about adaptation and mitigation options for the food and agriculture sector, and Chapter 4 describes the institutional setting for acting to mitigate and adapt to climate change, and draws conclusions for follow-up action by FAO and the international community.

1. DEFINING TERMS AND CONCEPTUALIZING RELATIONSHIPS

FOOD SYSTEMS AND FOOD SECURITY

Food security

In May 2007, at the 33rd Session of the Committee on World Food Security, FAO issued a statement to reaffirm its vision of a food-secure world:

"FAO's vision of a world without hunger is one in which most people are able, by themselves, to obtain the food they need for an active and healthy life, and where social safety nets ensure that those who lack resources still get enough to eat." (FAO, 2007f)

This vision has its roots in the definition of food security adopted at the World Food Summit (WFS) in November 1996: "Food security exists when all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996).

In the year and a half following WFS, the Inter-Agency Working Group that established the Food Insecurity and Vulnerability Information and Mapping System (FIVIMS) elaborated a conceptual framework that gave operational meaning to this definition (Figure 1). FAO reaffirmed this view in its first published assessment of the implications of climate change for food security, contained in its 2015 to 2030 projections for world agriculture.

FAO stressed that "food security depends more on socio-economic conditions than on agroclimatic ones, and on access to food rather than the production or physical availability of food". It stated that, to evaluate the potential impacts of climate change on food security, "it is not enough to assess the impacts on domestic production in food-insecure countries. One also needs to (i) assess climate change impacts on foreign exchange earnings; (ii) determine the ability of food-surplus countries to increase their commercial exports or food aid; and (iii) analyse how the incomes of the poor will be affected by climate change" (FAO, 2003b: 365–366).

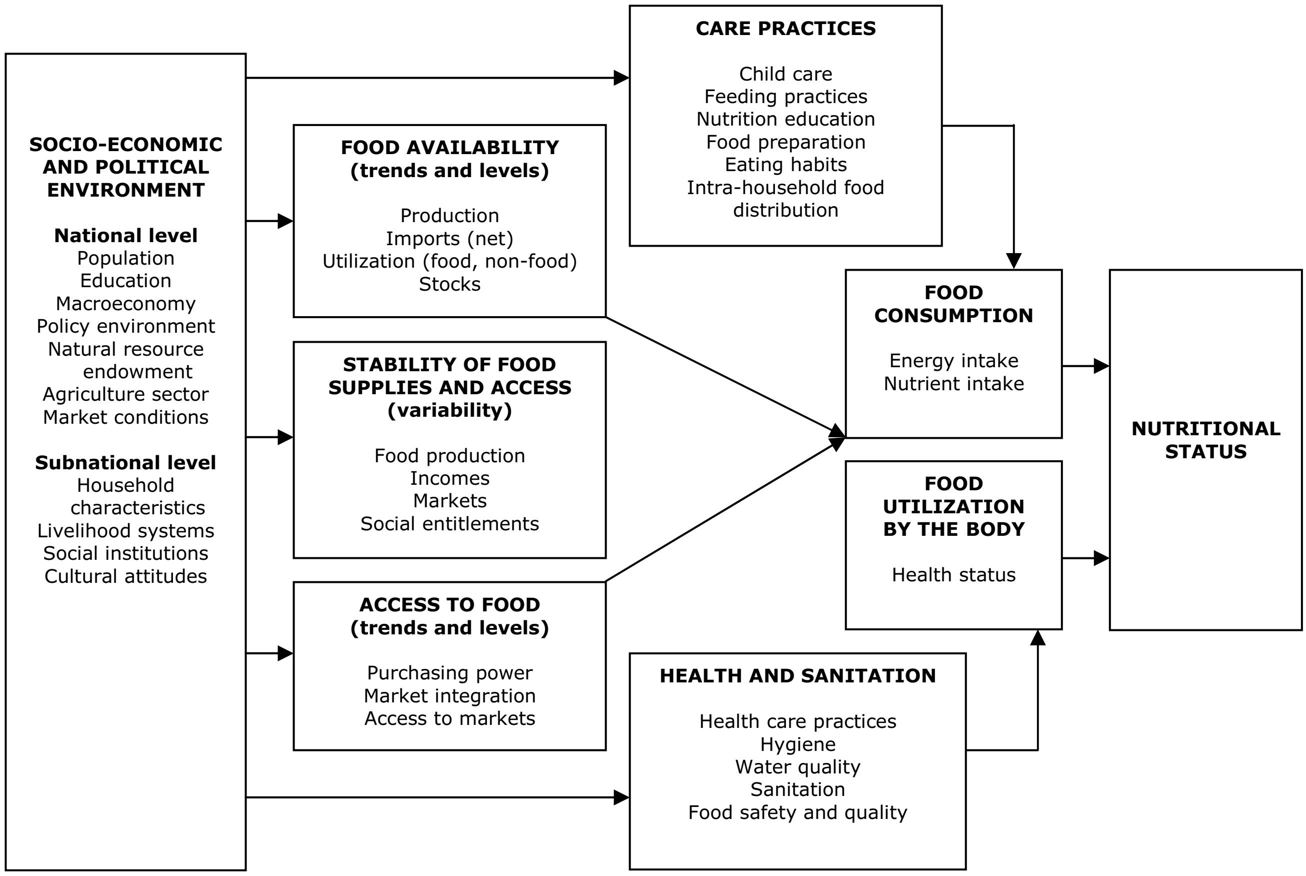
Food system

Definitions of food security identify the outcomes of food security and are useful for formulating policies and deciding on actions, but the processes that lead to desired outcomes also matter. Most current definitions of food security therefore include references to processes as well as outcomes. Recent work describing the functioning of food systems has helped to show both desired food security goals and what needs to happen to bring these about.

Between 1999 and 2003, a series of expert consultations, convened by the Global Environmental Change and Food Systems (GECAFS) project with FAO's participation, developed a version of the FIVIMS framework that further clarifies how a variety of processes along a food chain need to occur in order to bring about food security. Taken together, these processes constitute the food system, and the performance of the food system determines whether or not food security is achieved. GECAFS gives the following definition and graphical representation (Figure 2):

"Food systems encompass (i) activities related to the production, processing, distribution, preparation and consumption of food; and (ii) the outcomes of these activities contributing to food security (food availability, with elements related to production, distribution and exchange; food access, with elements related to affordability, allocation and preference; and food use, with elements related to nutritional value, social value and food safety). The outcomes also contribute to environmental and other securities (e.g. income). Interactions between and within biogeophysical and human environments influence both the activities and the outcomes." (GECAFS Online)

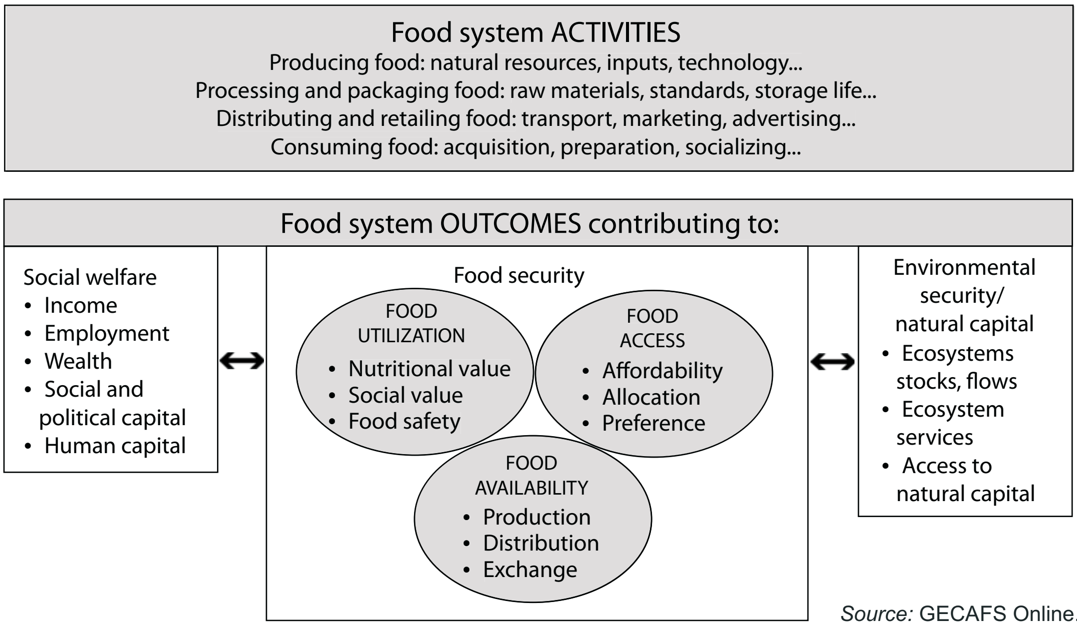
Figure 1. Conceptual framework of possible causes of low food consumption and poor nutritional status



Source: FAO, 2000c.

Another study expresses the complexity of food systems and their link to food security as follows: "Dynamic interactions between and within the biogeophysical and human environments lead to the production, processing, preparation and consumption of food, resulting in food systems that underpin food security" *(*Gregory, Ingram and Brklacich, 2005).

Figure 2. Food system activities and food security outcomes



Source: GECAFS Online.

Food chain

The sum of all the processes in a food system is sometimes referred to as a food chain, and often given catchy slogans such as “from plough to plate” or “from farm to fork”. The main conceptual difference between a food system and a food chain is that the system is holistic, comprising a set of simultaneously interacting processes, whereas the chain is linear, containing a sequence of activities that need to occur for people to obtain food.

The concept of the food system is useful for scientists investigating cause and effect relationships and feedback loops, and is important for the technical analyses that underpin policy recommendations. However, when communicating the findings of such investigations it is often easier to use the concept of the food chain.

The section on Food security and climate change: a conceptual framework (p. 10) presents a simplified description of the dynamics of potential climate change impacts and feedback loops in a holistic food system. The implications are discussed linearly, however, by looking at projected changes for each of five of the most important climate variables for food systems, and at the potential impacts of each of these changes on each food system process.

A food system comprises multiple food chains operating at the global, national and local levels. Some of these chains are very short and not very complex, while others circle the globe in an intricate web of interconnecting processes and links. One simple chain, which is important for food security in many households practising rainfed agriculture, begins with a staple cereal crop produced in a farmer’s field, moves with the harvested grain through a local mill and back to the farmer’s home as bags of flour, and finishes in the cooking pot and on the household members’ plates.

This same household probably also participates in a more complex food chain to obtain salt, which is locally available in only a few places, but is used worldwide as a preservative and seasoning. Part of the meagre cash income of even the poorest farming households is often set aside to purchase salt from passing traders or local stalls.

A household’s food system comprises all the food chains it participates in to meet its consumption requirements and dietary preferences, and all the interactions and feedback loops that connect the different parts of these chains. The example of a simple two-commodity food system (grain and salt) shows that it is very unlikely that a household can achieve food security without some cash expenditure. All households need sources of livelihood that give them sufficient purchasing power to buy the food that they need but cannot or do not produce for their own consumption.

Climate is a particularly important driver of food system performance at the farm end of the food chain, affecting the quantities and types of food produced and the adequacy of production-related income. Extreme weather events can damage or destroy transport and distribution infrastructure and affect other non-agricultural parts of the food system adversely.

However, the impacts of climate change are likely to trigger adaptive responses that influence the environmental and socio-economic drivers of food system performance in positive as well as negative ways. This paper is concerned with the projected balance of these various impacts on food system performance and food security outcomes at the local and global levels.

CLIMATE AND CLIMATE CHANGE[2]

Climate and its measurement

Climate refers to the characteristic conditions of the earth's lower surface atmosphere at a specific location; weather refers to the day-to-day fluctuations in these conditions at the same location. The variables that are commonly used by meteorologists to measure daily weather phenomena are air temperature, precipitation (e.g., rain, sleet, snow and hail), atmospheric pressure and humidity, wind, and sunshine and cloud cover.

When these weather phenomena are measured systematically at a specific location over several years, a record of observations is accumulated from which averages, ranges, maximums and minimums for each variable can be computed, along with the frequency and duration of more extreme events.

The World Meteorological Organization (WMO) requires the calculation of averages for consecutive periods of 30 years, with the latest being from 1961 to 1990. Such a period is long enough to eliminate year-to-year variations. The averages are used in the study of climate change, and as a base with which current conditions can be compared (UK Met Office Online).

Climate can be described at different scales. Global climate is the average temperature of the earth's surface and the atmosphere in contact with it, and is measured by analysing thousands of temperature records collected from stations all over the world, both on land and at sea. Most current projections of climate change refer to global climate, but climate can also be described at other scales, based on records for weather variables collected from stations in the zones concerned. Zonal climates include the following:

- *Latitudinal climates* are temperature regimes determined by the location north or south of the equator. They include polar climate, temperate climate, sub-tropical climate and tropical climate.
- *Regional climates* are patterns of weather that affect a significant geographical area and that can be identified by special features that distinguish them from other climate patterns. The main factors determining regional climate are: (i) differences in temperature caused by distance from the equator and seasonal changes in the angle of the sun's rays as the earth rotates; (ii) planetary distribution of land and sea masses; and (iii) the worldwide system of winds, called the general circulation, which arises as a result of temperature difference between the equator and the poles. Examples of regional climates are maritime climate, continental climate, monsoon climate, Mediterranean climate, Sahelian climate and desert climate.
- *Local climates* have influence over very small geographical areas, of only a few kilometres or tens of kilometres across. They include land and sea breezes, the orographic lifting of air masses and formation of clouds on the windward side of mountains, and the heat island effects of cities. Under certain conditions, local climatic effects may predominate over the more general pattern of regional or latitudinal climate. If the area involved is very small, such as in a flower bed or a shady grove, it may be referred to as a microclimate. Microclimates can also be

[2] Unless otherwise noted, definitions and explanations contained in this section are drawn from UK DEFRA, 2005. Annex I gives standard, internationally agreed terminology from the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC).

created artificially, as in hothouses, museum displays or storage environments where temperature and humidity are controlled.

Climate system

The climate system is highly complex. Under the influence of the sun's radiation, it determines the earth's climate (WMO, 1992) and consists of:

- the atmosphere: gaseous matter above the earth's surface;
- the hydrosphere: liquid water on or below the earth's surface;
- the cryosphere: snow and ice on or below the earth's surface;
- the lithosphere: earth's land surface (e.g., rock, soil and sediment);
- the biosphere: earth's plants and animal life, including humans.

Although climate *per se* relates only to the varying states of the earth's atmosphere, the other parts of the climate system also have significant roles in forming climate, through their interactions with the atmosphere (Figure 3).

The Global Climate Observing System (GCOS) has developed a list of variables essential for monitoring changes in the climate system. The list includes atmospheric, oceanic and terrestrial phenomena, and covers all the spheres of the climate system (Annex I).

Figure 3. The formation of climate

Sun's radiation

interacting with

The climate system				
Biosphere (all living organisms, including humans)	Lithosphere (soil, rock, sediment)	Atmosphere (air, water vapour, other gaseous matter)	Hydrosphere (liquid water)	Cryosphere (snow, ice permafrost)

produces

Atmospheric conditions
(surface air temperature, precipitation, humidity/atmospheric pressure, cloud cover/ hours of sunshine, wind velocity and direction)

Weather	**Climate**
(daily atmospheric conditions in a specific location)	(average atmospheric conditions – means and variability – over 3 decades in a specific location)

at different scales

Global climate	**Latitudinal climates**	**Regional climates**	**Local and microclimates**

Source: FAO/NRCB.

GCOS was established by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

GCOS and its partners provide vital and continuous support to the United Nations Framework Convention on Climate Change (UNFCCC), the World Climate Research

Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC). The reporting system on essential climate variables provides information to (GCOS Online a):

- characterize the state of the global climate system and its variability;
- monitor the forcing of the climate system, by both natural and anthropogenic causes;
- support attributions of climate change causes;
- support predictions of global climate change;
- enable projection of global climate change information to the regional and local scales;
- enable characterization of extreme events that are important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

Climate variability and climate change

There is no internationally agreed definition of the term "climate change" (see Annex II for internationally agreed terminology on climate and climate change). Climate change can refer to: (i) long-term changes in average weather conditions (WMO usage); (ii) all changes in the climate system, including the drivers of change, the changes themselves and their effects (GCOS usage); or (iii) only human-induced changes in the climate system (UNFCCC usage).

There is also no agreement on how to define the term "climate variability". Climate has been in a constant state of change throughout the earth's 4.5 billion-year history, but most of these changes occur on astronomical or geological time scales, and are too slow to be observed on a human scale. Natural climate variation on these scales is sometimes referred to as "climate variability", as distinct from human-induced climate change. UNFCCC has adopted this usage (e.g., UNFCCC, 1992). For meteorologists and climatologists, however, climate variability refers only to the year-to-year variations of atmospheric conditions around a mean state (WMO, 1992).

To assess climate change and food security, FAO prefers to use a comprehensive definition of climate change that encompasses changes in long-term averages for all the essential climate variables. For many of these variables, however, the observational record is too short to clarify whether recent changes represent true shifts in long-term means (climate change), or are simply anomalies around a stable mean (climate variability).

Effects of global warming on the climate system

Global warming is the immediate consequence of increased greenhouse gas emissions with no offsetting increases in carbon storage on earth. This paper is concerned mainly with the projected effects of the current episode of human-induced global warming on the climate system, now and for the next several decades, as these are the effects that will both cause additional stresses and create new opportunities for food systems, with consequent implications for food security.

The linear depiction shown in Figure 4 is a rough approximation of how the interactive dynamics of global warming, climate system response and changes in weather patterns may work in different parts of the globe.

Acclimatization, adaptation and mitigation

Acclimatization is essentially adaptation that occurs spontaneously through self-directed efforts. Adaptation to climate change involves deliberate adjustments in natural or human systems and behaviours to reduce the risks to people's lives and livelihoods. Mitigation of climate change involves actions to reduce greenhouse gas emissions and sequester or store carbon in the short term, and development choices that will lead to low emissions in the long term.

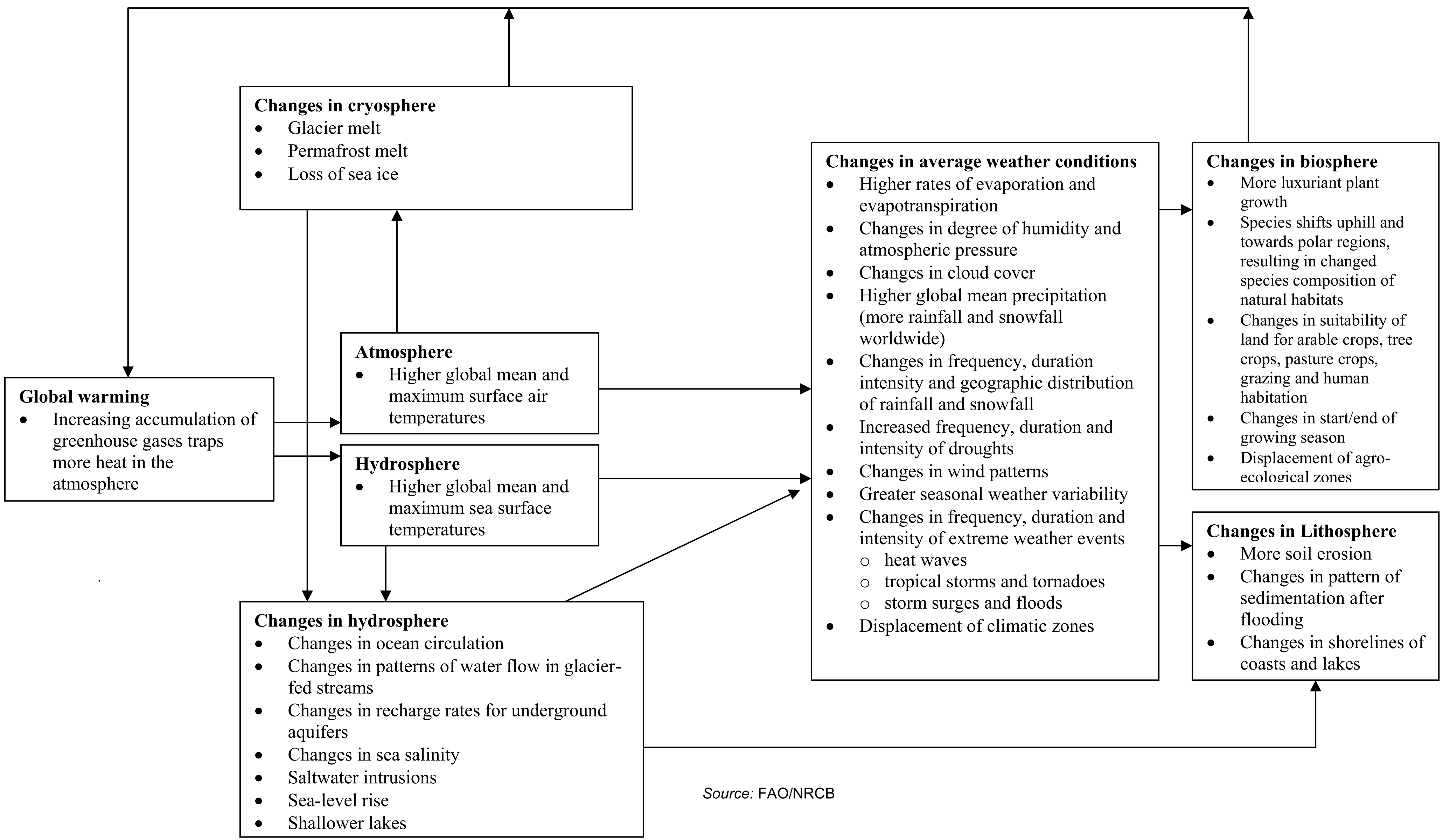
Acclimatization is a powerful and effective adaptation strategy. In simple terms, it means getting used to climate change and learning to live comfortably with it. All living organisms, including humans, adapt and develop in response to changes in climate and habitat. Some adaptations may be biological – for example, human physiology may become more heat-tolerant as global temperatures rise – but many are likely to involve changes in perceptions and mental attitudes that reinforce new, more adapted responses to extreme events.

CLIMATE CHANGE AND FOOD SECURITY

Agriculture, climate and food security

Agriculture is important for food security in two ways: it produces the food people eat; and (perhaps even more important) it provides the primary source of livelihood for 36 percent of the world's total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50 percent, and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture (ILO, 2007). If agricultural production in the low-income developing countries of Asia and Africa is adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and their vulnerability to food insecurity increased.

Figure 4. Global warming and changes in the climate system



Source: FAO/NRCB

Agriculture, forestry and fisheries are all sensitive to climate. Their production processes are therefore likely to be affected by climate change. In general, impacts are expected to be positive in temperate regions and negative in tropical ones, but there is still uncertainly about how projected changes will play out at the local level, and potential impacts may be altered by the adoption of risk management measures and adaptation strategies that strengthen preparedness and resilience.

The food security implications of changes in agricultural production patterns and performance are of two kinds:

- Impacts on the production of food will affect food supply at the global and local levels. Globally, higher yields in temperate regions could offset lower yields in tropical regions. However, in many low-income countries with limited financial capacity to trade and high dependence on their own production to cover food requirements, it may not be possible to offset declines in local supply without increasing reliance on food aid.
- Impacts on all forms of agricultural production will affect livelihoods and access to food. Producer groups that are less able to deal with climate change, such as the rural poor in developing countries, risk having their safety and welfare compromised.

Other food system processes, such as food processing, distribution, acquisition, preparation and consumption, are as important for food security as food and agricultural production are. Technological advances and the development of long-distance marketing chains that move produce and packaged foods throughout the world at high speed and relatively low cost have made overall food system performance far less dependent on climate than it was 200 years ago.

However, as the frequency and intensity of severe weather increase, there is a growing risk of storm damage to transport and distribution infrastructure, with consequent disruption of food supply chains. The rising cost of energy and the need to reduce fossil fuel usage along the food chain have led to a new calculus – "food miles", which should be kept as low as possible to reduce emissions. These factors could result in more local responsibility for food security, which needs to be considered in the formulation of adaptation strategies for people who are currently vulnerable or who could become so within the foreseeable future.

Food security and climate change: a conceptual framework

Food systems exist in the biosphere, along with all other manifestations of human activity. As shown in Figure 4, some of the significant changes in the biosphere that are expected to result from global warming will occur in the more distant future, as a consequence of changes in average weather conditions. In Figure 4, the most likely scenarios of climate change indicate that increases in weather variability and the incidence of extreme weather events will be particularly significant now and in the immediate future.

The projected increases in mean temperatures and precipitation will not manifest through constant gradual changes, but will instead be experienced as increased frequency, duration and intensity of hot spells and precipitation events. Whereas the annual occurrence of hot days, and maximum temperatures are expected to increase in all parts of the globe, the mean global increase in precipitation is not expected to be uniformly distributed around the world. In general, it is projected that wet regions will become wetter and dry regions dryer.

For this analysis, a conceptual framework on climate change and food security interactions was developed to highlight the variables defining the food and climate systems. The climate change and food security (CCFS) framework (Figure 5 and Table 1) shows how climate change affects food security outcomes for the four components of food security – food availability, food accessibility, food utilization and food system stability – in various direct and indirect ways.

Climate change variables influence biophysical factors, such as plant and animal growth, water cycles, biodiversity and nutrient cycling, and the ways in which these are managed through agricultural practices and land use for food production. However, climate variables also have an impact on physical/human capital – such as roads, storage and marketing infrastructure, houses, productive assets, electricity grids, and human health – which indirectly changes the economic and socio-political factors that govern food access and utilization and can threaten the stability of food systems.

All of these impacts manifest themselves in the ways in which food system activities are carried out. The framework illustrates how adaptive adjustments to food system activities will be needed all along the food chain to cope with the impacts of climate change.

The climate change variables considered in the CCFS framework are:

- the CO_2 fertilization effect of increased greenhouse gas concentrations in the atmosphere;
- increasing mean, maximum and minimum temperatures;
- gradual changes in precipitation:
  - increase in the frequency, duration and intensity of dry spells and droughts;
  - changes in the timing, duration, intensity and geographic location of rain and snowfall;
- increase in the frequency and intensity of storms and floods;
- greater seasonal weather variability and changes in start/end of growing seasons.

This paper does not discuss in detail the wider set of factors/driving forces that govern food system activities and food security, such as demographic developments, changes in economic systems and trade flows, science and technology developments or shifts in cultural practices; a wide range of literature is available on each of these. Instead, the paper focuses on disentangling the pathways of climate change impacts on food system activities and food security outcomes.

Evidence indicates that more frequent and more intense extreme weather events (droughts, heat and cold waves, heavy storms, floods), rising sea levels and increasing irregularities in seasonal rainfall patterns (including flooding) are already having immediate impacts on not only food production, but also food distribution infrastructure, incidence of food emergencies, livelihood assets and human health in both rural and urban areas.

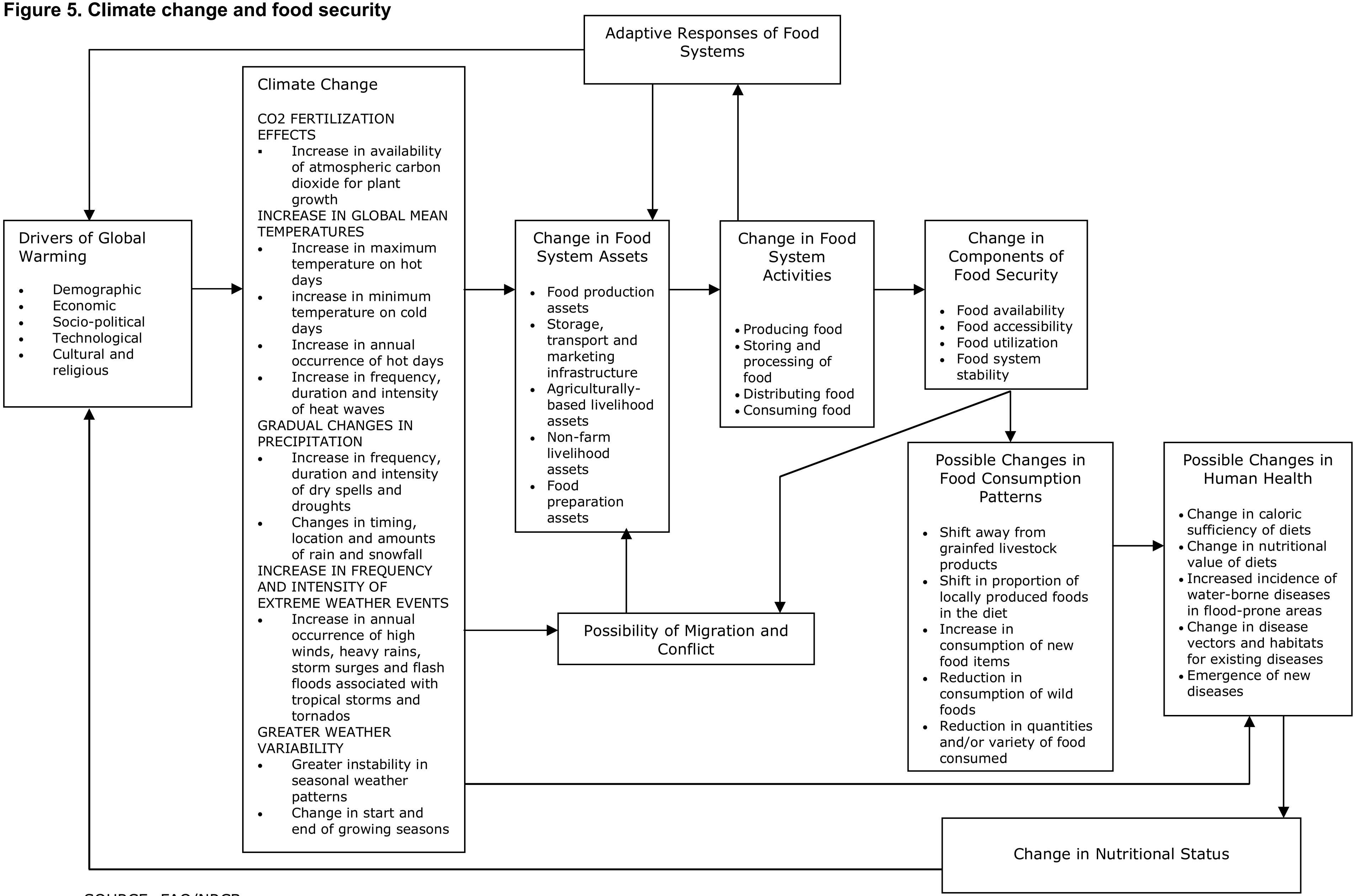
In addition, less immediate impacts are expected to result from gradual changes in mean temperatures and rainfall. These will affect the suitability of land for different types of crops and pasture; the health and productivity of forests; the distribution, productivity and community composition of marine resources; the incidence and vectors of different types of pests and diseases; the biodiversity and ecosystem functioning of natural habitats; and the availability of good-quality water for crop, livestock and inland fish production. Arable land is likely to be lost owing to increased aridity (and associated salinity), groundwater depletion and sea-level rise. Food systems will be affected by internal and international migration, resource-based conflicts and civil unrest triggered by climate change.

Vulnerability to climate change

Uncertainty and risk: Risk exists when there is uncertainty about the future outcomes of ongoing processes or about the occurrence of future events. The more certain an outcome is, the less risk there is, because certainty allows informed choices and preparation to deal with the impacts of hazardous processes or events.

Global climate change projections have a solid scientific basis, and there is growing certainty that extreme weather events are going to increase in frequency and intensity. This makes it highly likely that asset losses attributable to weather-related disasters will increase. Whether these losses involve productive assets, personal possessions or even loss of life, the livelihoods and food security status of millions of people in disaster-prone areas will be adversely affected.

Figure 5. Climate change and food security



SOURCE: FAO/NRCB.
Figure produced for this report.

Table 1
Potential impacts of climate change on food systems and food security, and possible adaptive responses

A. CO2 fertilization effects				
Impact on food system assets	**Impact on food system activities**	**Impact on food security outcomes**	**Impact on other human well-being outcomes**	**Possible adaptive responses**
Production assets: ▪ Increase in availability of atmospheric carbon dioxide for plant growth	***Producing food:*** ▪ More luxuriant biomass ▪ Higher yields of food and cash crops, mainly in temperate regions	***Food availability (production, distribution, exchange):*** ▪ Increased food production in major exporting countries would contribute to global food supply but diversion of land from food to more economically attractive cash crops could negate this benefit ***Food accessibility (allocation, affordability, preference):*** ▪ Increases in food production would limit price increases on world markets, but diversion of productive assets to other cash crops could cause food prices to rise	***Livelihoods:*** ▪ Increased income from improved food and cash crop performance would benefit commercial farmers in developed countries but not in developing countries	***Policies and regulations:*** ▪ Avoidance of subsidies or other monetary or non-monetary incentives for diversion of food production assets to other uses

B. Increase in global mean temperatures				
Impact on food system assets	**Impact on food system activities**	**Impact on food security outcomes**	**Impact on other human well-being outcomes**	**Possible adaptive responses**
Production assets: ▪ Trend changes in suitability of land for crop and livestock production ▪ Gradual loss of biodiversity ▪ Trend changes in vectors and natural habitats of plant and animal pests and diseases ***Storage, transport and marketing infrastructure:*** ▪ Strain on electricity grids, air conditioning and cold storage capacity	***Producing food:*** ▪ Immediate crop and livestock losses due to heat and water stress ▪ Lower yields from dairy animals ▪ Reduced labour productivity due to heat stress ▪ Trend impacts uncertain, conditional on location, availability of water and adoption of new cropping patterns by farmers ***Storing and processing of food:*** ▪ Upgrade in cooling and storage facilities required to maintain food quality at higher temperatures ▪ Increasing energy requirements for cooling ***Consuming food:*** ▪ Higher intake of liquids ▪ Lower intake of cooked food ▪ Perishable products have shorter shelf life ▪ More need for refrigeration ▪ Heat stress may negatively affect people's ability to access food (no energy to shop or do productive work)	***Food availability (production, distribution, exchange)*:** ▪ Reduced production of food crops and livestock products in affected areas ▪ Local losses could have temporary effect on local markets, ▪ Reduction in global supplies likely to cause market prices to rise ***Food accessibility (allocation, affordability, preference):*** ▪ Impacts on incomes, prices and affordability uncertain ▪ Changes in preference uncertain ***Food utilization (nutritional value, social value, food safety)*:** ▪ Risk of dehydration ▪ Risk of ill health from eating food that is spoiled ▪ Ability of body to process food reduced due to heat stress or diseases ***Food system stability:*** ▪ Higher cost for storing grain and perishable products	***Livelihoods:*** ▪ Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity ***Social values and behaviours:*** ▪ Acceptance of a greater degree of risk and uncertainty as a natural condition of life ***National and global economies:*** ▪ Reorientation of public and private sector investments towards mitigating and adapting to climate change	***Policies and regulations*** ▪ Greater reliance on weather-related insurance ▪ Development of risk management frameworks ***Farming, forestry and fishery practices*** ▪ Trend changes in cropping patterns ▪ Development and dissemination of more heat-tolerant varieties and species ***Food processing, distribution and marketing practices*** ▪ Greater use of alternative fuels for generating electricity ***Food preparation practices*** ▪ Greater use of alternative fuels for home cooking

C.1. Gradual changes in precipitation (increase in the frequency, duration and intensity of dry spells and droughts)				
Impact on food system assets	**Impact on food system activities**	**Impact on food security outcomes**	**Impact on other human well-being outcomes**	**Possible adaptive responses**
Production assets ▪ Loss of perennial crops and vegetative cover for grazing and fuel wood due to water stress and increasing fire hazard ▪ Loss of livestock due to water stress and lack of feed ▪ Loss of productive assets due to hardship sales ▪ Loss of buildings, equipment and vehicles and other productive assets due to fire ▪ Changes in rates of soil moisture retention and aquifer recharge ▪ Trend changes in suitability of land for crop and livestock production ▪ Gradual loss of biodiversity ▪ Trend changes in vectors and natural habitats of plant and animal pests and diseases ***Food preparation assets*** ▪ Lack of water for cooking ▪ Lack of vegetation for fuel	***Producing food:*** ▪ Immediate crop and livestock losses due to water stress ▪ Trend declines in yields ▪ Change in irrigation requirements ***Storing/processing of food:*** ▪ Less need for chemicals to preserve stored grain ▪ Scarcity of water for food processing ***Distributing food:*** ▪ Easier movement of vehicles on dry land ***Consuming food:*** ▪ May not be possible to continue growing preferred foods ▪ May be necessary to purchase a larger proportion of foods consumed ▪ Diet may become less varied and / or less nutritious	***Food availability (production, distribution, exchange)*:** ▪ Declines in production ▪ Wild foods less available ▪ Pressure on grain reserves ▪ Decrease in food exports / increase in food imports ▪ Increased need for food aid ***Food accessibility (allocation, affordability, preference):*** ▪ Local increase in food prices in drought-affected areas ▪ Loss of farm income and non-farm employment ▪ Preferred foods not available or too costly ***Food utilization:*** ▪ Risk of dehydration ▪ Ability of body to process food reduced due to diseases ▪ Dietary adjustments with different nutritional content ***Food system stability:*** ▪ Greater instability of food supply, food prices and agriculturally-based incomes	***Livelihoods:*** ▪ Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education ▪ Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity ***Social values and behaviours:*** ▪ Food scarcity strains ability to meet reciprocal food-sharing obligations ***National and global economies:*** ▪ Strain on national budgets and aid resources due to increased need for food safety nets	***Policies and regulations:*** ▪ Greater reliance on weather-related insurance ▪ Development of risk management frameworks ***Infrastructure investments*** ▪ New investment in irrigation for intensive agriculture where water resources permit ***Farming, forestry and fishery practices*** ▪ Trend changes in cropping patterns ▪ Development and dissemination of more drought-tolerant varieties and species ▪ Use of moisture-retaining land management practices ▪ Use of recycled wastewater for irrigation ***Food processing practices:*** ▪ Use of recycled wastewater ▪ Use of dry processing and packaging methods ***Food preparation practices*** ▪ Use of dry cooking methods

C.2. Gradual changes in precipitation (changes in timing, location and amounts of rain and snowfall)				
Impact on food system assets	**Impact on food system activities**	**Impact on food security outcomes**	**Impact on other human well-being outcomes**	**Possible adaptive responses**
Production assets ▪ Changes in rates of soil moisture retention and aquifer recharge ▪ Increase in proportion of global population exposed to water scarcities ▪ Changes in locations where investment in irrigation is economically feasible ▪ Trend changes in suitability of land for crop and livestock production ▪ Trend changes in vectors and natural habitats of plant and animal pests and diseases	***Producing food:*** ▪ Trend impacts on yields uncertain, conditional on location, availability of water and adoption of new cropping patterns by farmers ***Consuming food:*** ▪ Changes in consumption patterns may occur, in response to changes in relative prices	***Food availability (production, distribution, exchange)*:** ▪ Some local losses virtually certain, but their likely geographic distribution is not known ▪ Likely impact on global supplies, trade and world market prices is not known ***Food accessibility (allocation, affordability, preference):*** ▪ Full-cost pricing for water may cause food prices to rise ***Food system stability:*** ▪ Greater instability of food supply, food prices and agriculturally-based incomes is likely	***Livelihoods:*** ▪ Changes in geographic distribution of vulnerability ***Social values and behaviours:*** ▪ Acceptance of a greater degree of risk and uncertainty as a natural condition of life ***National and global economies:*** ▪ Reorientation of public and private sector investments towards mitigating and adapting to climate change	***Policies and regulations:*** ▪ More aggressive support for efficient water management policies and water use regulations ▪ Full-cost pricing for water ***Infrastructure investments:*** ▪ New investment in irrigation for expanding intensive agriculture where available water resources permit ***Farming, forestry and fishery practices*** ▪ Use of moisture-retaining land management practices ▪ Use of recycled wastewater for irrigation ***Food processing practices:*** ▪ Use of recycled wastewater for plant hygiene ***Food safety and preventive healthcare practices:*** ▪ Use of recycled wastewater for home hygiene

D. Impacts of increase in the frequency and intensity of extreme weather events

(increase in annual occurrence of high winds, heavy rains, storm surges, flash floods and rising water levels associated with tornados, tropical storms, and prolonged heavy rains)

Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive options
Production assets: ▪ Damage to standing crops ▪ Animals stranded ▪ Increase in water-borne livestock diseases ▪ Damage to buildings and equipment ▪ Loss of stored crops ***Storage, transport and marketing infrastructure:*** ▪ Damage to roads, bridges, storage structures, processing plants and electricity grids ***Non-farm livelihood assets:*** ▪ Damage to trade goods ***Food preparation assets:*** ▪ Loss of household food supplies	***Producing food:*** ▪ Possibility of lower yields in flooded agricultural areas ▪ Increased soil erosion reducing future yields ***Processing food:*** ▪ Pollution of water supply used in processing food ***Distributing food*:** ▪ Disruptions in food supply chains and increase in marketing and distribution costs ***Consuming food:*** ▪ Reliance on emergency rations ▪ Possibility that preferred foods will be less available in emergency situations and food variety will decrease ▪ Increased health risks from water-borne diseases may negatively affect people's ability to access food (no energy to shop or do productive work)	***Food availability (production, distribution, exchange):*** ▪ Possible decrease in surplus production in flooded agricultural areas ▪ Increased need for emergency distribution of food rations ***Food accessibility (allocation, affordability, preference):*** ▪ Possible increase in food prices ▪ Possible loss of farm income and non-farm employment, depending on extent of asset loss ***Food utilization (nutritional value, social value, food safety):*** ▪ Food safety is compromised by water pollution and damage to stored food ▪ Ability of body to process food reduced due to diseases	***Livelihoods:*** ▪ Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education ▪ Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity ▪ Changes in geographic distribution of vulnerability ***Social values and behaviours:*** ▪ Acceptance of a greater degree of risk and uncertainty as a natural condition of life ***National and global economies:*** ▪ Reorientation of public and private sector investments towards mitigating and adapting to climate change	***Policies and regulations:*** ▪ Development of weather-related insurance schemes for storms and floods ▪ Development of risk management frameworks ▪ Support for resettlement schemes in low-risk areas ***Infrastructure investments:*** ▪ New investment in flood embankments ▪ Use of wind resistant technologies on new and existing structures ▪ Establishment of emergency shelters on high ground ***Farming, forestry and fishery practices*** ▪ Use of practices that create more dense root mass to hold soil in place ▪ Development and dissemination of more flood-tolerant varieties and species ***Food safety and preventive healthcare practices*** ▪ Provision for emergency water supplies

E. Impacts of greater weather variability				
Impact on food system assets	**Impact on food system activities**	**Impact on food security Outcomes**	**Impact on other human well-being outcomes**	**Possible adaptive options**
Production assets: ▪ Change in frequency and extent of pests and diseases	***Producing food:*** ▪ Increasing uncertainty ▪ Changing yields ▪ Changing land use patterns ▪ Viability of production systems may be undermined	***Food availability*:** ▪ Some local losses virtually certain, but their likely geographic distribution is not known ▪ Likely impact on global supplies, trade and world market prices is not known ***Food accessibility:*** ▪ Reduced yields may lead to loss of farm income, but this depends on market conditions ***Food system stability:*** ▪ Greater instability of food supply, food prices and agriculturally-based incomes is likely	***Livelihoods:*** ▪ Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education ▪ Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity ▪ Changes in geographic distribution of vulnerability ***Social values and behaviours:*** ▪ Acceptance of a greater degree of risk and uncertainty as a natural condition of life ***National and global economies:*** ▪ Reorientation of public and private sector investments towards mitigating and adapting to climate change	***Policies and regulations*** ▪ Greater reliance on weather-related insurance ▪ Development of risk management frameworks ***Farming, forestry and fishery practices*** ▪ Trend changes in cropping patterns ▪ Changes in water management regimes

Source: FAO/IDWG on Climate Change. Table produced for this report.

An average of 500 weather-related disasters are now taking place each year, compared with 120 in the 1980s; the number of floods has increased sixfold over the same period (Oxfam, 2007). Population increases, especially in coastal areas, where most of the world's population now lives, mean that more and more people will be affected by catastrophic weather events.

The international aid community has developed an immediate response capacity that can limit loss of life, but there is a growing risk that its ability to assist affected people in replacing lost assets and recovering livelihoods following climate-related natural disasters will be overwhelmed. Increasing weather-related losses are causing private sector insurers to restrict the types of natural disasters or catastrophic events that can be insured, and it is not clear whether public sector safety net programmes will be able to fill the subsequent gaps.

Although the areas that are vulnerable to extreme weather events are generally known, there is still a lack of reliable information about how future changes in temperature and precipitation regimes will affect specific locations. Further scientific work can reduce the current knowledge gap, but these aspects of climate change are likely to remain uncertain for the foreseeable future, making investments in agriculture and other weather-dependent livelihoods inherently more risky.

The limited risk absorption capacity of poor people means that they are unlikely to be able to cope with the added risk imposed by climate change. These people will be exposed to greater variability in and uncertainties about food system performance, and their livelihood sources will become more vulnerable.

Food system vulnerability: *Overview:* A food system is vulnerable when one or more of the four components of food security – food availability, food accessibility, food utilization and food system stability – is uncertain and insecure.

Food availability is determined by the physical quantities of food that are produced, stored, processed, distributed and exchanged. FAO calculates national food balance sheets that include all these elements. Food availability is the net amount remaining after production, stocks and imports have been summed and exports deducted for each item included in the food balance sheet. Adequacy is assessed through comparison of availability with the estimated consumption requirement for each food item.

This approach takes into account the importance of international trade and domestic production in assuring that a country's food supply is sufficient. The same approach can also be used to determine the adequacy of a household's food supply, with domestic markets playing the balancing role.

High market prices for food are usually a reflection of inadequate availability; persistently high prices force poor people to reduce consumption below the minimum required for a healthy and active life, and may lead to food riots and social unrest. Growing scarcities of water, land and fuel are likely to put increasing pressure on food prices, even without climate change. Where these scarcities are compounded by the results of climate change, the introduction of mitigation practices that create land-use competition and the attribution of market value to environmental services to mitigate climate change, they have the potential to cause significant changes in relative prices for different food items, and an overall increase in the cost of an average food basket for the consumer, with accompanying increases in price volatility.

Food accessibility is a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires to obtain access to food (A. Sen, 1989, cited in FAO, 2003a). Until the 1970s, food security was linked mainly to national food production and global trade (Devereux and Maxwell, 2001), but since then the concept has expanded to include households' and individuals' access to food.

The mere presence of an adequate supply does not ensure that a person can obtain and consume food – that person must first have access to the food through his/her entitlements. The enjoyment of entitlements that determine people's access to food depends on allocation mechanisms, affordability, and cultural and personal preferences for particular food products.

Increased risk exposure resulting from climate change will reduce people's access to entitlements and undermine their food security.

Food utilization refers to the use of food and how a person is able to secure essential nutrients from the food consumed. It encompasses the nutritional value of the diet, including its composition and methods of preparation; the social values of foods, which dictate what kinds of food should be served and eaten at different times of the year and on different occasions; and the quality and safety of the food supply, which can cause loss of nutrients in the food and the spread of food-borne diseases if not of a sufficient standard. Climatic conditions are likely to bring both negative and positive changes in dietary patterns and new challenges for food safety, which may affect nutritional status in various ways.

Food system stability is determined by the temporal availability of, and access to, food. In long-distance food chains, storage, processing, distribution and marketing processes contain in-built mechanisms that have protected the global food system from instability in recent times. However, if projected increases in weather variability materialize, they are likely to lead to increases in the frequency and magnitude of food emergencies for which neither the global food system nor affected local food systems are adequately prepared.

Potential impacts of climate change on food availability: *Production* of food and other agricultural commodities may keep pace with aggregate demand, but there are likely to be significant changes in local cropping patterns and farming practices. There has been a lot of research on the impacts that climate change might have on agricultural production, particularly cultivated crops. Some 50 percent of total crop production comes from forest and mountain ecosystems, including all tree crops, while crops cultivated on open, arable flat land account for only 13 percent of annual global crop production. Production from both rainfed and irrigated agriculture in dryland ecosystems accounts for approximately 25 percent, and rice produced in coastal ecosystems for about 12 percent (Millennium Ecosystem Assessment, 2005).

The evaluation of climate change impacts on agricultural production, food supply and agriculture-based livelihoods must take into account the characteristics of the agro-ecosystem where particular climate-induced changes in biochemical processes are occurring, in order to determine the extent to which such changes will be positive, negative or neutral in their effects.

The so-called "greenhouse fertilization effect" will produce local beneficial effects where higher levels of atmospheric CO_2 stimulate plant growth. This is expected to occur primarily in temperate zones, with yields expected to increase by 10 to 25 percent for crops with a lower rate of photosynthetic efficiency (C3 crops), and by 0 to 10 percent for those with a higher rate of photosynthetic efficiency (C4 crops), assuming that CO_2 levels in the atmosphere reach 550 parts per million (IPCC, 2007c); these effects are not likely to influence projections of world food supply, however (Tubiello *et al.,* 2007). Mature forests are also not expected to be affected, although the growth of young tree stands will be enhanced (Norby *et al.,* 2005).

The impacts of mean temperature increase will be experienced differently, depending on location (Leff, Ramankutty and Foley, 2004). For example, moderate warming (increases of 1 to 3 ºC in mean temperature) is expected to benefit crop and pasture yields in temperate regions, while in tropical and seasonally dry regions, it is likely to have negative impacts, particularly for cereal crops. Warming of more than 3 ºC is expected to have negative affects on production in all regions (IPCC, 2007c). The supply of meat and other livestock products will be influenced by crop production trends, as feed crops account for roughly 25 percent of the world's cropland.

For climate variables such as rainfall, soil moisture, temperature and radiation, crops have thresholds beyond which growth and yield are compromised (Porter and Semenov, 2005). For example, cereals and fruit tree yields can be damaged by a few days of temperatures above or below a certain threshold (Wheeler *et al.,* 2000). In the European heat wave of 2003, when temperatures were 6 ºC above long-term means, crop yields dropped significantly, such as by 36 percent for maize in Italy, and by 25 percent for fruit and 30 percent for forage in France (IPCC, 2007c). Increased intensity and frequency of storms, altered hydrological cycles, and precipitation variance also have long-term implications on the viability of current world agro-ecosystems and future food availability.

Wild foods are particularly important to households that struggle to produce food or secure an income. A change in the geographic distribution of wild foods resulting from changing rainfall and temperatures could therefore have an impact on the availability of food. Changes in climatic conditions have led to significant declines in the provision of wild foods by a variety of ecosystems, and further impacts can be expected as the world climate continues to change. For the 5 000 plant species examined in a sub-Saharan African study (Levin and Pershing, 2005), it is predicted that 81 to 97 percent of the suitable habitats will decrease in size or shift owing to climate change. By 2085, between 25 and 42 percent of the species' habitats are expected to be lost altogether. The implications of these changes are expected to be particularly great among communities that use the plants as food or medicine.

Constraints on water availability are a growing concern, which climate change will exacerbate. Conflicts over water resources will have implications for both food production and people's access to food in conflict zones (Gleick, 1993). Prolonged and repeated droughts can cause loss of productive assets, which undermines the sustainability of livelihood systems based on rainfed agriculture. For example, drought and deforestation can increase fire danger, with consequent loss of the vegetative cover needed for grazing and fuelwood (Laurence and Williamson, 2001). In Africa, droughts can have severe impacts on livestock. Table 2 illustrates how droughts increased livestock mortality in selected African countries between 1980 and 1999.

Storage, processing and distribution: Food production varies spatially, so food needs to be distributed between regions. The major agricultural production regions are characterized by relatively stable climatic conditions, but many food-insecure regions have highly variable climates. The main grain production regions have a largely continental climate, with dry or at least cold weather conditions during harvest time, which allows the bulk handling of harvested grain without special infrastructure for protection or immediate treatment.

TABLE 2

Impacts of droughts on livestock numbers in selected African countries, 1981 to 1999

Date	Location	Livestock losses	Source
1981–1984	Botswana	20 percent of national herd	FAO, 1984 cited in Toulmin, 1986
1982–1984	Niger	62 percent of national cattle herd	Toulmin, 1986
1983–1984	Ethiopia (Borana Plateau)	45–90 percent of calves, 45 percent of cows, 22 percent of mature males	Coppock, 1994
1991	Northern Kenya	28 percent of cattle; 18 percent of sheep and goats	Surtech, 1993 cited in Barton and Morton, 2001
1991–1993	Ethiopia (Borana)	42 percent of cattle	Desta and Coppock, 2002
1993	Namibia	22 percent of cattle; 41 percent of goats and sheep	Devereux and Tapscott, 1995
1995–1997	Greater Horn of Africa (average of 9 pastoral areas)	20 percent of cattle; 20 percent of sheep and goats	Ndikumana et al., 2000
1995–1997	Southern Ethiopia	46 percent of cattle; 41 percent of sheep and goats	Ndikumana et al., 2000
1998–1999	Ethiopia (Borana)	62 percent of cattle	Shibru, 2001 cited in Desta and Coppock, 2002

Source: IPCC, 2007a.

Depending on the prevailing temperature regime, however, a change in climatic conditions through increased temperatures or unstable, moist weather conditions could result in grain being harvested with more than the 12 to 14 percent moisture required for stable storage. Because of the amounts of grain and general lack of drying facilities in these regions, this could create hazards for food safety, or even cause complete crop losses, resulting from contamination with microorganisms and their metabolic products. It could lead to a rise in food prices if stockists have to invest in new storage technologies to avoid the problem.

Distribution depends on the reliability of import capacity, the presence of food stocks and – when necessary – access to food aid (Maxwell and Slater, 2003). These factors in turn often depend on the ability to store food. Storage is affected by strategies at the national level and by physical infrastructure at the local level. Transport infrastructure limits food distribution in many developing countries. Where infrastructure is affected by climate, through either heat stress on roads or increased frequency of flood events that destroy infrastructure, there are impacts on food distribution, influencing people's access to markets to sell or purchase food (Abdulai and CroleRees, 2001).

Exchange of food takes place at all levels – individual, household, community, regional, national and global. At the lowest levels, exchanges usually take the form of reciprocal hospitality, gift-giving or barter, and serve as an important mechanism for coping with supply fluctuations. If changing climatic conditions bring about trend declines in local production, the capacity of affected households to engage in these traditional forms of exchange is likely to decline.

Trade remains the main mechanism for exchange in today's global economy. Although most food trade takes place within national borders, global trade is the balancing mechanism that keeps exchange flowing smoothly (Stevens, Devereux and Kennan, 2003). The relatively low cost of ocean compared with overland transport makes it economically advantageous for most countries to rely on international food trade to smooth out fluctuations in domestic food supply. Where trade is heavily regulated, as in southern Africa, farmers' behaviour illustrates this principle. After a food crisis such as that in southern Africa in 2002, even if recovery programmes lead to a bumper harvest of maize, in some countries the maize may not find its way into national grain markets, as announced or anticipated producer prices and market regulations could encourage farmers to channel their surplus outside formal markets (Mano, Isaacson and Dardel, 2003: iv).

FAO projects that the impact of climate change on global crop production will be slight up to 2030. After that year, however, widespread declines in the extent and potential productivity of cropland could occur, with some of the severest impacts likely to be felt in the currently food-insecure areas of sub-Saharan Africa, which have with the least ability to adapt to climate change or to compensate through greater food imports (Fischer *et al.,* 2001, cited in FAO, 2003b: 358).

Although the projections suggest that normal carryover stocks, food aid and international trade should be able to cope with the localized food shortages that are likely to result from crop losses due to severe droughts or floods, this is now being questioned in view of the price boom that the world has experienced since 2006. According to FAO, the global food price index rose by 9 percent in 2006 and by 37 percent in 2007. The price boom has been accompanied by much higher price volatility than in the past, especially in the cereals and oilseeds sectors, reflecting reduced inventories, strong relationships between agricultural commodity and other markets, and the prevalence of greater market uncertainty in general.

This has triggered a widespread concern about food price inflation, which is fuelling debates about the future direction of agricultural commodity prices in importing and exporting countries, be they rich or poor, and giving rise to fears that a world food crisis similar in magnitude to those of the early 1970s and 1980s may be imminent, with little prospect for a quick rebound as the effects of climate change take their toll.

Potential impacts of climate change on food access: *Allocation*: Food is allocated through markets and non-market distribution mechanisms. Factors that determine whether people will have access to sufficient food through markets are considered in the following section on affordability. These factors include income-generating capacity, amount of remuneration received for products and goods sold or labour and services rendered, and the ratio of the cost of a minimum daily food basket to the average daily income.

Non-market mechanisms include production for own consumption, food preparation and allocation practices within the household, and public or charitable food distribution schemes. For rural people who produce a substantial part of their own food, climate change impacts on food production may reduce availability to the point that allocation choices have to be made within the household. A family might reduce the daily amount of food consumed equally among all household members, or allocate food preferentially to certain members, often the able-bodied male adults, who are assumed to need it the most to stay fit and continue working to maintain the family.

Non-farming low-income rural and urban households whose incomes fall below the poverty line because of climate change impacts will face similar choices. Urbanization is increasing rapidly worldwide, and a growing proportion of the expanding urban population is poor (Ruel *et al.,* 1998). Allocation issues resulting from climate change are therefore likely to become more and more significant in urban areas over time.

Where urban gardens are available, they provide horticultural produce for home use and local sale, but urban land-use restrictions and the rising cost of water and land restrain their potential for expansion. Urban agriculture has a limited ability to contribute to the welfare of poor people in developing countries because the bulk of their staple food requirements still need to be transported from rural areas (Ellis and Sumberg, 1998).

Political and social power relationships are key factors influencing allocation decisions in times of scarcity. If agricultural production declines and households find alternative livelihood activities, social processes and reciprocal relations in which locally produced food is given to other family members in exchange for their support may change or disappear altogether.

Public and charitable food distribution schemes reallocate food to the most needy, but are subject to public perceptions about who needs help, and social values about what kind of help it is incumbent on more wealthy segments of society to provide. If climate change creates other more urgent claims on public resources, support for food distribution schemes may decline, with consequent increases in the incidence of food insecurity, hunger and famine-related deaths.

Affordability. In many countries, the ratio of the cost of a minimum daily food basket to the average daily income is used as a measure of poverty (World Bank PovertyNet, 2008). When this ratio falls below a certain threshold, it signifies that food is affordable and people are not impoverished; when it exceeds the established threshold, food is not affordable and people are having difficulty obtaining enough to eat. This criterion is an indicator of chronic poverty, and can also be used to determine when people have fallen into temporary food insecurity, owing to reduced food supply and increased prices, to a sudden fall in household income or to both.

Income-generating capacity and the remuneration received for products and goods sold or labour and services rendered are the primary determinants of average daily income. The incomes of all farming households depend on what they obtain from selling some or all of their crops and animals each year. Commercial farmers are usually protected by insurance, but small-scale farmers in developing countries are not, and their incomes can decline sharply if there is a market glut, or if their own crops fail and they have nothing to sell when prices are high.

Most food is not produced by individual households but acquired through buying, trading and borrowing (Du Toit and Ziervogel, 2004). Climate impacts on income-earning opportunities can affect the ability to buy food, and a change in climate or climate extremes may affect the availability of certain food products, which may influence their price. High prices may make certain foods unaffordable and can have an impact on individuals' nutrition and health.

Changes in the demand for seasonal agricultural labour, caused by changes in production practices in response to climate change, can affect income-generating capacity positively or negatively. Mechanization may decrease the need for seasonal labour in many places, and labour demands are often reduced when crops fail, mostly owing to such factors as drought, flood, frost or pest outbreaks, which can be influenced by climate. On the other hand, some adaptation options increase the demand for seasonal agricultural labour.

Local food prices in most parts of the world are strongly influenced by global market conditions, but there may be short-term fluctuations linked to variation in national yields, which are influenced by climate, among other factors. An increase in food prices has a real income effect, with low-income households often suffering most, as they tend to devote larger shares of their incomes to food than higher-income households do (Thomsen and Metz, 1998).

When they cannot afford food, households adjust by eating less of their preferred foods or reducing total quantities consumed as food prices increase. Given the growing number of people who depend on the market for their food supply, food prices are critical to consumers' food security and must be watched.

Food often travels very long distances (Pretty *et al.,* 2005), and this has implications for costs. Increasing fuel costs could lead to more expensive food and increased food insecurity. The growing market for biofuels is expected to have implications for food security, because crops grown as feedstock for liquid biofuels can replace food crops, which then have to be sourced elsewhere, at higher cost.

Preference: Food preferences determine the kinds of food households will attempt to obtain. Changing climatic conditions may affect both the physical and the economic availability of certain preferred food items, which might make it impossible to meet some preferences. Changes in availability and relative prices for major food items may result in people either changing their food basket, or spending a greater percentage of their income on food when prices of preferred food items increase.

In southern Africa, for example, many households eat maize as the staple crop, but when there is less rainfall, sorghum fares better, and people could consume more of it. Many people prefer maize to sorghum, however, so continue to plant maize despite poor yields, and would rather buy maize than eat sorghum, when necessary.

The extent to which food preferences change in response to changes in the relative prices of grain-fed beef compared with other sources of animal protein will be an important determinant of food security in the medium term. Increased prices for grain-fed beef are foreseeable, because of the increasing competition for land for intensive feedgrain production, the increasing scarcity of water and rising fuel costs (FAO, 2007c). If preferences shift to other sources of animal protein, the livestock sector's demands on resources that are likely to be under stress as a consequence of climate change may be contained. If not, continued growth in demand for grain-fed beef, from wealthier segments of the world's population, could trigger across-the-board increases in food prices, which would have serious adverse impacts on food security for urban and rural poor.

Potential impacts of climate change on food utilization: *Nutritional value*: Food insecurity is usually associated with malnutrition, because the diets of people who are unable to satisfy all of their food needs usually contain a high proportion of staple foods and lack the variety needed to satisfy nutritional requirements. Declines in the availability of wild foods, and limits on small-scale horticultural production due to scarcity of water or labour resulting from climate change could affect nutritional status adversely. In general, however, the main impact of climate change on nutrition is likely to be felt indirectly, through its effects on income and capacity to purchase a diversity of foods.

The physiological utilization of foods consumed also affects nutritional status, and this – in turn – is affected by illness. Climate change will cause new patterns of pests and diseases to emerge, affecting plants, animals and humans, and posing new risks for food security, food safety and human health. Increased incidence of water-borne diseases in flood-prone areas, changes in vectors for climate-responsive pests and diseases, and emergence of new diseases could affect both the food chain and people's physiological capacity to obtain necessary nutrients from the foods consumed. Vector changes are a virtual certainty for pests and diseases that flourish only at specific temperatures and under specific humidity and irrigation management regimes. These will expose crops, livestock, fish and humans to new risks to which they have not yet adapted. They will also place new pressures on care givers within the home, who are often women, and will challenge health care institutions to respond to new parameters.

Malaria in particular is expected to change its distribution as a result of climate change (IPCC, 2007a). In coastal areas, more people may be exposed to vector- and water-borne diseases through flooding linked to sea-level rise. Health risks can also be linked to changes in diseases from either increased or decreased precipitation, lowering people's capacity to utilize food effectively and often resulting in the need for improved nutritional intake (IPCC, 2007a).

Where vector changes for pests and diseases can be predicted, varieties and breeds that are resistant to the likely new arrivals can be introduced as an adaptive measure. A recent upsurge in the appearance of new viruses may also be climate-related, although this link is not certain. Viruses such as avian flu, ebola, HIV/AIDS and SARS have various implications for food security, including risk to the livelihoods of small-scale poultry operations in the case of avian flu, and the extra nutritional requirements of affected people in the case of HIV-AIDS.

The social and cultural values of foods consumed will also be affected by the availability and affordability of food. The social values of foods are important determinants of food preferences, with foods that are accorded high value being preferred, and those accorded low value being avoided. In many traditional cultures, feasts involving the preparation of specific foods mark important seasonal occasions, rites of passage and celebratory events.

The increased cost or absolute unavailability of these foods could force cultures to abandon their traditional practices, with unforeseeable secondary impacts on the cohesiveness and sustainability of the cultures themselves. In many cultures, the reciprocal giving of gifts or sharing of food is common. It is often regarded as a social obligation to feed guests, even when they have dropped in unexpectedly. In conditions of chronic food scarcity, households' ability to honour these obligations is breaking down, and this trend is likely to be reinforced in locations where the impacts of climate change contribute to increasing incidence of food shortages.

Food safety may be compromised in various ways. Increasing temperature may cause food quality to deteriorate, unless there is increased investment in cooling and refrigeration equipment or more reliance on rapid processing of perishable foods to extend their shelf-life. Decreased water availability has implications for food processing and preparation practices, particularly in the subtropics, where a switch to dry processing and cooking methods may be required. Changes in land use, driven by changes in precipitation or increased temperatures, will alter how people spend their time. In some areas, children might have to prepare food, while parents work in the field, increasing the risk that good hygiene practices may not be followed.

Potential impacts of climate change on food system stability: *Stability of supply*: Many crops have annual cycles, and yields fluctuate with climate variability, particularly rainfall and temperature. Maintaining the continuity of food supply when production is seasonal is therefore challenging. Droughts and floods are a particular threat to food stability and could bring about both chronic and transitory food insecurity. Both are expected to become more frequent, more intense and less predictable as a consequence of climate change. In rural areas that depend on rainfed agriculture for an important part of their local food supply, changes in the amount and timing of rainfall within the season and an increase in weather variability are likely to aggravate the precariousness of local food systems.

Stability of access: As already noted, the affordability of food is determined by the relationship between household income and the cost of a typical food basket. Global food markets may exhibit greater price volatility, jeopardizing the stability of returns to farmers and the access to purchased food of both farming and non-farming poor people.

Food emergencies: Increasing instability of supply, attributable to the consequences of climate change, will most likely lead to increases in the frequency and magnitude of food emergencies with which the global food system is ill-equipped to cope. An increase in human conflict, caused in part by migration and resource competition attributable to changing climatic conditions, would also be destabilizing for food systems at all levels. Climate change might exacerbate conflict in numerous ways, although links between climate change and conflict should be presented with care. Increasing incidence of drought may force people to migrate from one area to another, giving rise to conflict over access to resources in the receiving area. Resource scarcity can also trigger conflict and could be driven by global environmental change.

Grain reserves are used in emergency-prone areas to compensate for crop losses and support food relief programmes for displaced people and refugees. Higher temperatures and humidity associated with climate change may require increased expenditure to preserve stored grain, which will limit countries' ability to maintain reserves of sufficient size to respond adequately to large-scale natural or human-incurred disasters.

Livelihood vulnerability

The livelihoods perspective is often used as a means of investigating a range of sectors and how they affect individual livelihoods. Viewing food security from a livelihoods perspective makes it possible to assess the different components of food security holistically at the household level.

Livelihoods can be defined as the bundle of different types of assets, abilities and activities that enable a person or household to survive (FAO, 2003a). These assets include physical assets such as infrastructure and household items; financial assets such as stocks of money, savings and pensions; natural assets such as natural resources; social assets, which are based on the cohesiveness of people and societies; and human assets, which depend on the status of individuals and can involve education and skill. These assets change over time and are different for different households and communities. The amounts of these assets that a household or community possesses or can easily gain access to are key determinants of sustainability and resilience.

Marginal groups include those with few resources and little access to power, which can constrain people's capacity to adapt to climate changes that could have a negative impact on them. It is usually people's few productive assets that are at greatest risk from the impacts of climate change. Physical assets can be damaged or destroyed, financial losses can be incurred, natural assets can be degraded and social assets can be undermined.

The change in seasonality attributed to climate change can lead to certain food products becoming more scarce at certain times of year. Such seasonal variations in food supply, along with vulnerabilities to flooding and fire, can make livelihoods more vulnerable at certain times of the year. Although these impacts might appear indirect, they are important because many marginal livelihood groups are close to the poverty margin, and food is a key component of their existence.

Agriculture is often at the heart of the livelihood strategies of these marginal groups; agricultural employment, whether farming their own land or working on that of others, is key to their survival. In many areas, the challenges of rural livelihoods drive urban migration. As the number of poor and vulnerable people living in urban slums grows, the availability of non-farm employment opportunities and the access of urban dwellers to adequate food from the market will become increasingly important drivers of food security.

A recent International Labour Organization study (ILO, 2005) suggests that there will be significant differences between middle- and low-income countries in the ways in which climate change affects agriculture-based livelihoods. Table 3 shows regional differences in the share of agriculture in total employment and changes in these shares over the past decade. In middle-income countries, a commercialization process appears to be bringing about declines in unpaid on-farm family labour and increases in wage employment.

TABLE 3
Employment in agriculture as share of total employment, by region

Region	1996	2006
Developed economies and EU	6.2	4.2
Central and southeastern Europe (non-EU) and CIS	27.2	20.3
East Asia	48.5	40.9
Southeast Asia and the Pacific	51.0	45.4
South Asia	59.7	49.4
Latin America and the Caribbean	23.1	19.6
North Africa	36.5	34.0
Sub-Saharan Africa	74.4	65.9
Middle East	21.2	18.1
World	41.9	36.1

EU = European Union.
CIS = Commonwealth of Independent States.
Source: ILO, 2007.

In low-income countries, however, wage work is declining, while self-cultivation and mixed contractual forms increase. This means that while the adverse impacts of climate change on agricultural production in middle-income countries are more likely to be felt as loss of employment opportunities, reduction in wage earnings and loss of purchasing power for agricultural wage workers, in low-income countries they are likely to be felt as declines in own production for household consumption by smallholder farming households.

Livelihood groups that warrant special attention in the context of climate change include:[3]

- low-income groups in drought- and flood-prone areas with poor food distribution infrastructure and limited access to emergency response;
- low- to middle-income groups in flood-prone areas that may lose homes, stored food, personal possessions and means of obtaining their livelihood, particularly when water rises very quickly and with great force, as in sea surges or flash floods;
- farmers whose land becomes submerged or damaged by sea-level rise or saltwater intrusions;
- producers of crops that may not be sustainable under changing temperature and rainfall regimes;
- producers of crops at risk from high winds;
- poor livestock keepers in drylands where changes in rainfall patterns will affect forage availability and quality;
- managers of forest ecosystems that provide forest products and environmental services;
- fishers whose infrastructure for fishing activities, such as port and landing facilities, storage facilities, fish ponds and processing areas, becomes submerged or damaged by sea-level rise, flooding or extreme weather events;
- fishing communities that depend heavily on coral reefs for food and protection from natural disasters;
- fishers/aquafarmers who suffer diminishing catches from shifts in fish distribution and the productivity of aquatic ecosystems, caused by changes in ocean currents or increased discharge of freshwater into oceans.

Within these livelihood groups, producers at different points of the food chain, such as fishers versus fish cleaners, would have different vulnerabilities and access to coping

[3] This expanded list has been developed from a shorter list contained in FAO, 2003b: 368.

mechanisms. Producers of different types of crops, such as crops for sale versus those for home consumption, may face different risks and management options (e.g., access to irrigation water or seeds). Gender and age differences will also affect the degree of risk faced by individuals within a vulnerable group.

Agriculture-based livelihood systems that are already vulnerable to climate change face immediate risk of increased crop failure, loss of livestock and fish stocks, increasing water scarcities and destruction of productive assets. These systems include small-scale rainfed farming, pastoralism, inland and coastal fishing/aquaculture communities, and forest-based systems. Rural people inhabiting coasts, floodplains, mountains, drylands and the Arctic are most at risk. The urban poor, particularly in coastal cities and floodplain settlements, also face increasing risks. Among those at risk, pre-existing socio-economic discriminations are likely to be aggravated, causing nutritional status to deteriorate among women, young children and elderly, ill and disabled people.

Over time, the geographic distribution of risk and vulnerability is likely to shift. Future vulnerability is likely to affect not only farmers, fishers, herders and forest-dependent people, but also low-income city dwellers, in both developed and developing countries, whose sources of livelihood and access to food may be at risk from the impact of extreme weather events and variable food prices, and who lack adequate insurance coverage. Some agriculture-based livelihoods may benefit from the effects of climate change, while others will be undermined.

The livelihood status of agricultural workers will also change if centres of agricultural production shift or methods of production become less labour-intensive in response to climate change. All wage earners face new health risks that could cause declines in their productivity and earning power. Climate change will also affect people differently depending on such factors as landownership, asset holdings, marketable skills, gender, age and health status.

Fishing is frequently integral to mixed livelihood strategies, in which people take advantage of seasonal stock availability or resort to fishing when other forms of food production and income generation fall short. Fishing is often related to extreme poverty and may serve as a vital safety net for people with limited livelihood alternatives and extreme vulnerability to changes in their environment. However, the viability of fishing as a sustainable livelihood is threatened by climate change.

Fishing communities that depend on inland fishery resources are likely to be particularly vulnerable to climate change; access to water resources and arrangements with other sectors for sharing and reuse will become a key to future sustainability. Climate change is also likely to have substantial and far-reaching impacts on coastal fisheries and fishing communities. Major physical impacts of climate change on the marine system will be changes in ocean currents, a rise in average temperature, sharpening of gradient structures, and large and rapid increases of freshwater discharge; these often trigger an increase in chemical nutrients, typically compounds containing nitrogen or phosphorus, resulting in lack of oxygen and severe reductions in water quality and in fish and other animal populations (eutrophication).

Biological responses to these changes are expected to be rachet-like, i.e., once a threshold is reached, the situation shifts from one phase to another. Fishing is essentially a hunting activity, so its success or failure depends heavily on the vagaries of nature. Climate change is creating more anomalies, both failures and bonanzas, among multiple species, as well as drastic shifts in the areas where small, migrating fish are found. Coastal peoples and communities that depend on fishing in locations where a rise in sea level makes relocation inevitable will require extra support, as they must not only migrate, but in many instances also find new, unfamiliar ways of earning a living (FAO, 2007b).

All IPCC emission scenarios assume that economies for the world as a whole will continue to grow, albeit at different rates and sometimes with significant regional differences, depending on the scenario (IPCC, 2000). However, it is also possible that the impact of climate change will actually curtail economic growth.

If global financial markets are not able to keep pace with continued high losses from extreme weather events, and large numbers of individual households in developed and emerging developing countries experience uncompensated declines in the value of their personal assets and income-generating capacity, global economic recession and a deterioration in the food security situation at all levels is also a possibility, putting everybody at risk.

2. PROTECTING FOOD SECURITY THROUGH ADAPTATION TO CLIMATE CHANGE

FAO'S STRATEGIC APPROACH

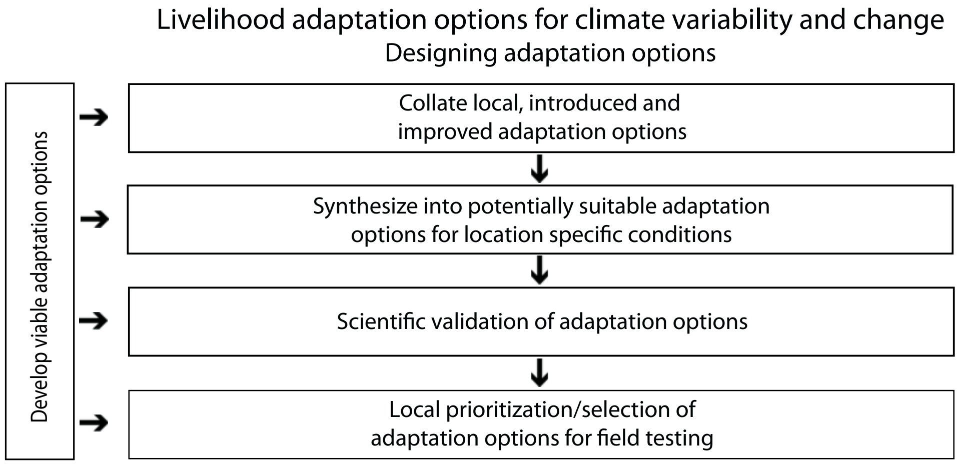
IPCC defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC Online, 2001). It involves learning to manage new risks and strengthening resilience in the face of change. Risk management focuses on preparing to deal with shocks. Change management focuses on modifying behaviours over the medium-to-long term to avoid disruptions or declines in global and local food supplies due to changes in temperature and precipitation regimes, and to protect ecosystems through providing environmental services. The following practices for adapting to climate change in the food and agriculture sector are described in this chapter:

- Protecting local food supplies, assets and livelihoods against the effects of increasing weather variability and increased frequency and intensity of extreme events, through:
  - general risk management;
  - management of risks specific to different ecosystems – marine, coastal, inland water and floodplain, forest, dryland, island, mountain, polar, cultivated;
  - research and dissemination of crop varieties and breeds adapted to changing climatic conditions;
  - introducing tree crops to provide food, fodder and energy and enhance cash incomes.
- Avoiding disruptions or declines in global and local food supplies due to changes in temperature and precipitation regimes, through:
  - more efficient agricultural water management in general;
  - more efficient management of irrigation water on rice paddies;
  - improved management of cultivated land;
  - improved livestock management;
  - use of new, more energy-efficient technologies by agro-industries.
- Protecting ecosystems, through provision of such environmental services as:
  - use of degraded or marginal lands for productive planted forests or other cellulose biomass for alternative fuels;
  - Clean Development Mechanism (CDM) carbon sink tree plantings;
  - watershed protection;
  - prevention of land degradation;
  - protection of coastal areas from cyclones and other coastal hazards;
  - preservation of mangroves and their contribution to coastal fisheries;
  - biodiversity conservation.

Figures 6 and 7 set out the steps recommended by FAO for selecting adaptation options and designing strategies to operationalize them. FAO has defined the following elements in a framework for climate change adaptation (FAO, 2007a):

- legal and institutional elements;
- policy and planning elements;
- livelihood elements;
- cropping, livestock, forestry, fisheries and integrated farming system elements;
- ecosystem elements;
- linking climate change adaptation processes with technologies that promote carbon sequestration and substitutes for fossil fuels.

Figure 6. Steps for selecting adaptation options



Source: FAO, 2006a.

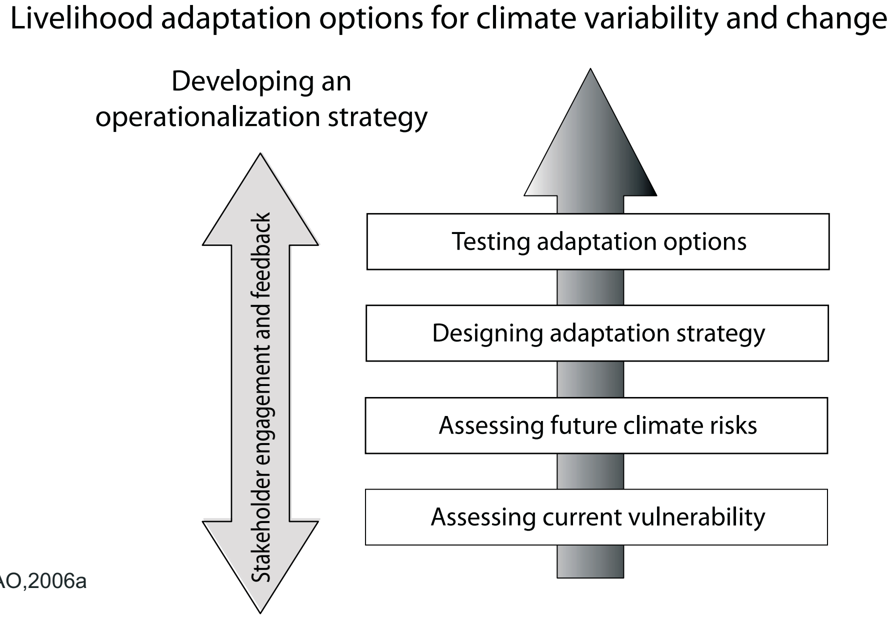
FAO stresses the importance of addressing impacts and responses across sectors and scales and of establishing institutional mechanisms for upscaling adaptation measures. Figure 8 illustrates the range of tools available for obtaining information about current and future climate impacts at different scales – from climate forecasts for farm-level decision-making to impact assessments based on climate change scenarios. Figure 9 shows how these tools can be used to inform multistakeholder coordination processes that seek to mainstream climate change adaptation into sustainable development approaches.

LIVING WITH UNCERTAINTY AND MANAGING NEW RISKS

Adapting to climate change involves managing risk by improving the quality of information and its use, providing insurance against climate change risk, adopting known good practices to strengthen the resilience of vulnerable livelihood systems, and finding new institutional and technological solutions.

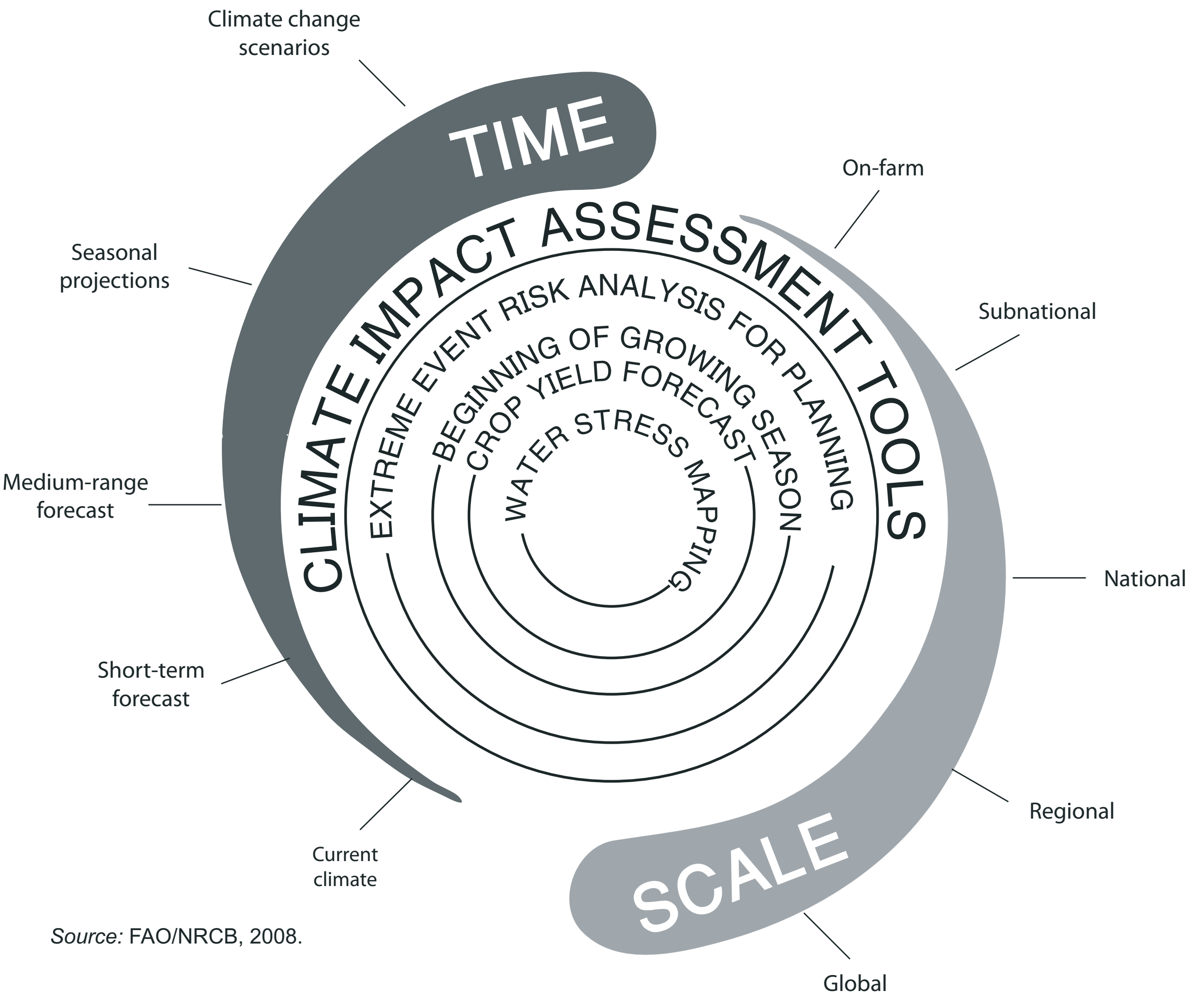
People in the insurance business make a clear distinction between certain and uncertain risks: a risk is certain if the probabilities of specific states occurring in the future are precisely known, and uncertain if these probabilities are not precisely known (Kunreuther and Michel-Kerjan, 2006).

Figure 7. Steps for designing a strategy to implement the adaptation options selected



Source: FAO,2006a

Figure 8. Methods and tools for assessing climate change impacts for different time periods and at various scales



Source: FAO/NRCB, 2008.

In the field of climate change, there is still much uncertainty about the probabilities of various possible changes occurring in specific locations. This can be dealt with by investing in improved information to reduce the degree of local uncertainty, or by spreading the uncertain risk through some form of global insurance scheme.

Knowledge about the future will always be uncertain, but the current high degree of uncertainty about potential local impacts of climate change could be reduced through improving the science. Other priorities include recognizing the need for decision-making in the face of uncertainty, bridging the gap between scientific and traditional perceptions of climate change, and promoting the adoption of practices that are consistent with the precautionary approach and adaptive management principles and that will strengthen the resilience and sustainability of vulnerable livelihood systems.

Climate-related risks affect everybody in one way or another, so innovative insurance schemes such as a global reinsurance fund for climate change damage, or expanded local coverage of weather-based insurance are likely to be needed. No risk management policy or programme will work unless those at risk feel that it addresses their needs, so adequate provisions must be made to allow the most vulnerable to participate in deciding which actions to take to strengthen their resilience.

The state of the art for these approaches and the implications of each for protecting food security in the face of climate change are explored in the following sections.

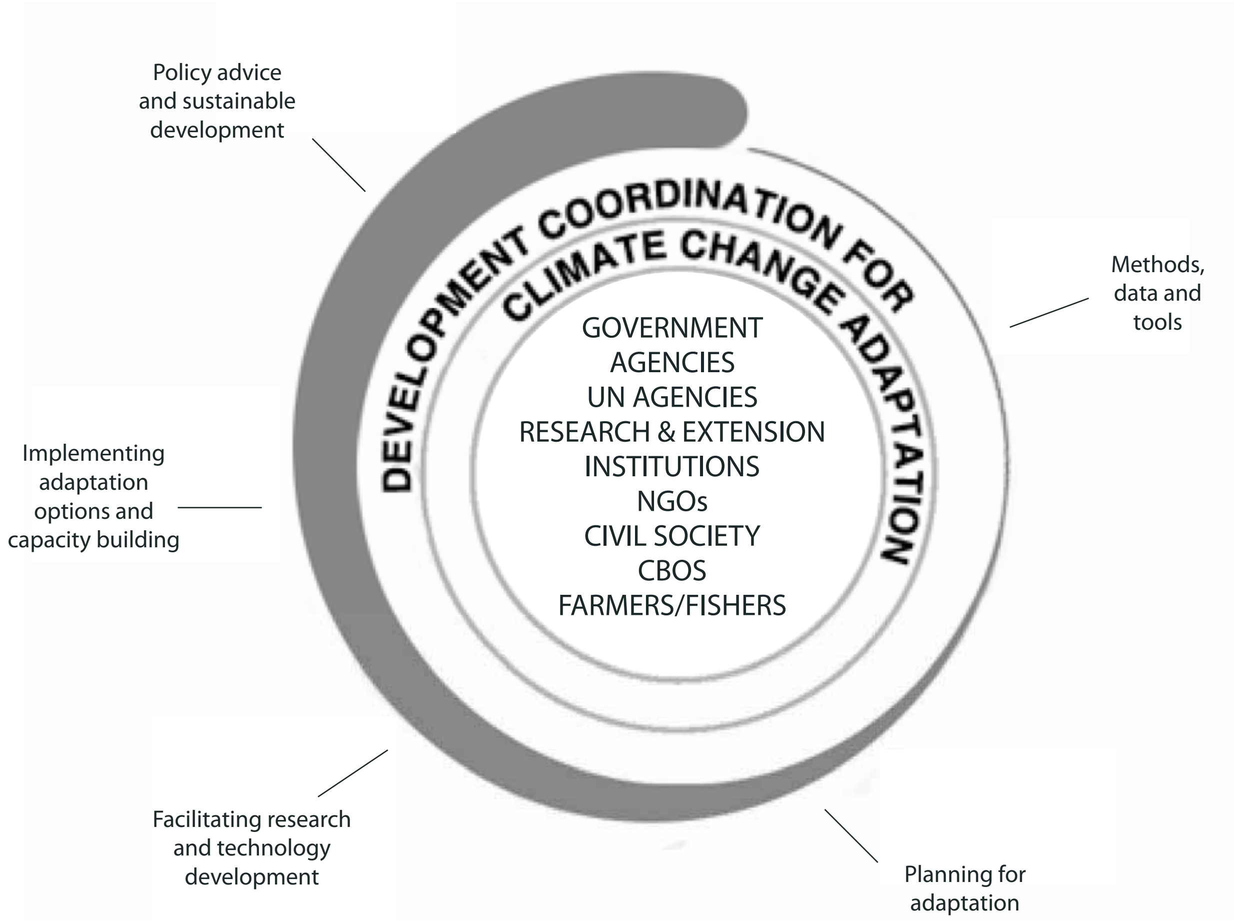
Improving the quality of information and its use

Information is a crucial tool in decision-making, particularly in the context of climate change where there is high uncertainty. The type of information, its source(s), to whom it is targeted, and how it is to be used are important elements in determining the impact and response that information may generate. Good information about uncertainties and risks can make the difference between resilience and collapse for an affected livelihood system or ecosystem, as in the case of climate change.

The rest of this section explores vulnerable people's needs for information about climate change, how best to satisfy these, the current state of the art regarding weather and climate monitoring, and priorities for improving scientific understanding of climate change.

Reaching vulnerable rural people with useful information: Information generation and dissemination are political in that they involve the power of one person's perception to influence that of another. This is illustrated by Turton's (2001) example of how hidden value judgements underlie the dominant perception of climate change. He points out that the concept of climate changes is commonly understood to mean not only that a change is occurring but also that there is need for some sort of response.

Figure 9. Multistakeholder processes for mainstreaming climate change adaptation into sustainable development approaches



Source: FAO/NRCB, 2008.

This perception is not universally shared, however. Although it has been scientifically demonstrated that climate is changing worldwide, not everyone has the same understanding of, or places the same value on, the significance of scientific results. For example, the climate data made available to rural farmers often do not refer to local knowledge on climate and agriculture, which leads to resentment towards scientific data, or the abandonment of information that may have been useful. Despite the increasing variability in climatic conditions, many rural farmers still predict climate using traditional methods, which may not be capable of detecting longer-term trends.

One implication of increasing variability and uncertainly about future weather patterns is that traditional knowledge will not necessarily be adapted to the new climatic conditions. There will therefore need to be more reliance on scientific knowledge and assessment of viable options, and bridging the gap between scientific and traditional perceptions of climate change will be fundamental for successful adaptation.

Ethnographic research suggests that the current mismatch between the understanding and interpretations of climate by farmers who rely on traditional knowledge and the understanding and interpretations of the scientific research community constitutes an important challenge for climate adaptation work that aims to provide climate information for a range of decision-makers, with differing education and resource levels (Roncoli, 2006). Participatory approaches to climate predictions have become a popular way of eliciting farmers' understanding of climate and climate information and determining how to improve the relation between these perspectives and scientific forecasts. Roncoli argues that participatory technology development and collaborative learning would be promoted by a better understanding of how scientists' cultural models may (or may not) be affected by interaction with farmers and other stakeholders, including other scientists, funding agencies, policy-makers and the media (Roncoli, 2006).

The benefits of applying gender-sensitive participatory approaches for using information to avert loss of property and life during cyclones are illustrated in Box 1 with the case of Bangladesh.

Another important issue is the availability of climate data for rural farmers who are often inaccessible to field site educators. When information is available and farmers show interest in it, institutional structures need to be in place to disseminate the information to farmers in remote rural areas, otherwise the only farmers to benefit will be those who already have the advantages of being in cooperatives and having the necessary disposable resources to act according to the information. Successful adaptation to climate change depends on reaching the most vulnerable, who may not have easy access to and appropriate understanding of existing climate information.

Box 1. Benefits of women's participation in cyclone preparedness in Bangladesh

An International Federation of Red Cross and Red Crescent Societies (IFRC-RCS) case study illustrates the importance of gender-sensitive participation in decision-making about cyclone preparedness. This study of a community-based cyclone preparedness programme in Bangladesh found that the highest proportions of cyclone victims came from sites where women were not involved in the village-level disaster preparedness committees responsible for maintaining cyclone shelters and transmitting warnings. In Cox's Bazaar in east Bangladesh, women are fully involved in disaster preparedness and support activities (education, reproductive health, self-help groups, and small and medium-sized enterprises), and there have been enormous reductions in the numbers of women killed or affected by cyclones.

Source: IFRC-RCS, 2002, cited in Lambrou and Laub, 2004.

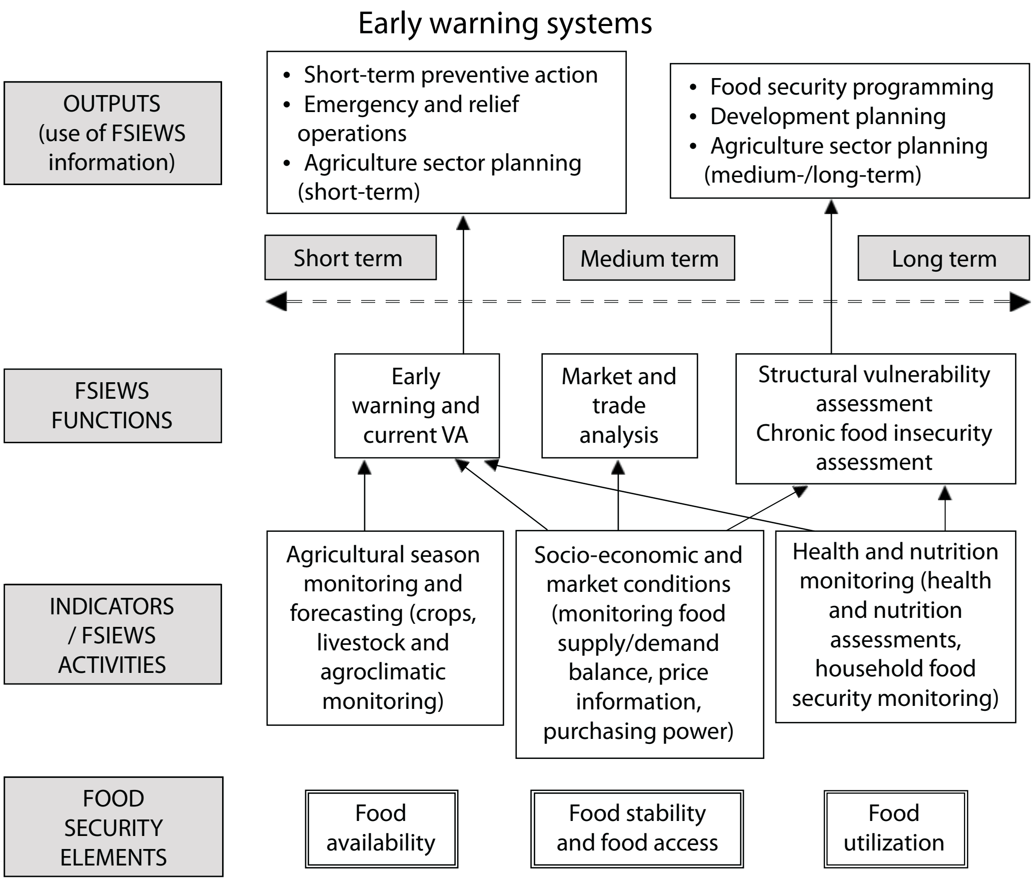
Monitoring weather and improving scientific understanding of climate change: Scientific work in response to the challenge of climate change includes development of tools and technologies for improved monitoring of weather and climate, incorporation of climate change variables and assessments into food security information and early warning systems, and observation and modelling of climate impacts on rural livelihoods. As already noted, it is critical that information generated by early warning systems and climate change models be packaged in ways that are accessible to vulnerable people, so it can assist them in making sound choices about how to adapt to climate change and other stressors. All actors in the food system need access to reliable information about climate change and its potential impacts, to avoid breakdowns in the system and adverse food security outcomes.

Figure 10 depicts FAO's view of the short-, medium- and long-term functions of a Food Security Information and Early Warning System (FSIEWS) that covers the information needs of all components of the food system and addresses all aspects of food security. Typically, these systems have focused on monitoring current weather and using this information, together with other socio-economic data, to forecast the adequacy of food supplies and assess food aid needs in developing countries with high risk of drought.

Time series data generated by FSIEWS are increasingly used to support longer-term policy and planning work. Once improved methods and tools for monitoring climate change variables and assessing their significance at the local level become more widely available, it is expected that these will be adopted by FSIEWS.

At present, the main users of FSIEWS are the national authorities and non-governmental organizations (NGOs) that implement safety net programmes covering the basic needs of people who are experiencing either temporary or chronic food insecurity. One of the challenges for these information systems is to develop channels for disseminating relevant and usable information directly to communities that are experiencing climate change and need to understand what is happening in order to adapt in constructive ways.

Figure 10. Providing timely weather information for all actors in the food system



Source: FAO, 2000b.

An important gap is the lack of weather stations in many rural parts of the developing world, particularly in Africa, where climate change is expected to have important local impacts. These impacts cannot be assessed without reliable weather data, and without such assessments, there is no solid basis for recommending adaptation options. Increased investment in regular and timely collection of weather data in Africa should therefore be accorded very high priority for protecting food security in the face of climate change in that region.

Adequate preparedness for foreseeable natural disasters is an important adaptation strategy that is relevant in many parts of the globe, and not only in Africa, where FSIEWS are most commonly found. Other types of monitoring systems give advance warning of sudden-onset events such as high winds and storm surges associated with hurricanes, cyclones, typhoons and tornadoes; risk of flooding and landslides after heavy rains; and heat waves and increased wildfire risk. These warnings enable people to protect property and stock appropriate supplies or move to safe shelters before the forecasted event.

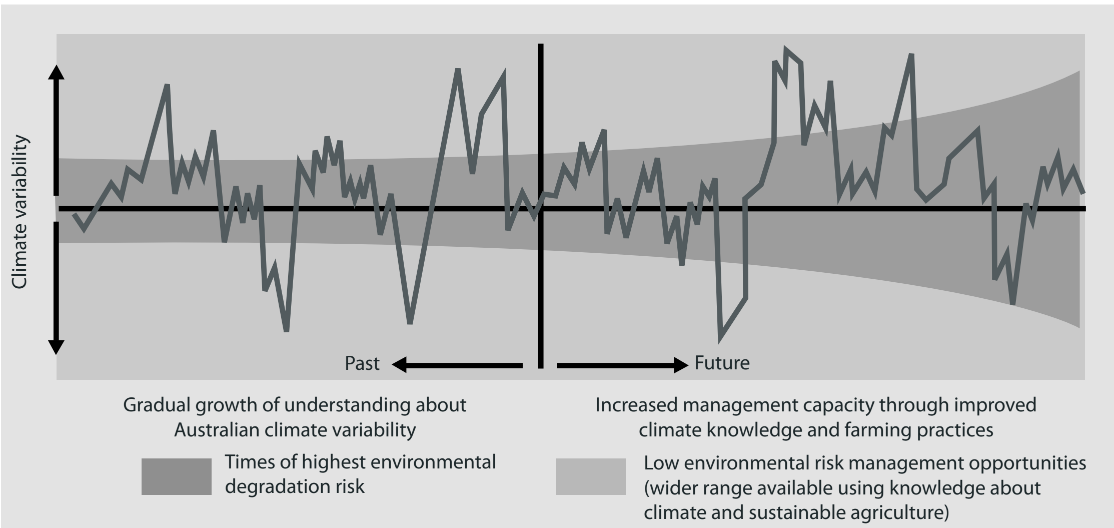
Among FAO's efforts to improve the quality of weather and climate information and its use are:

- maintaining up-to-date agrometeorological data;
- developing methods and tools for assessing extreme weather impacts and guiding adaptation;
- agro-ecological zoning for impact modelling and vulnerability assessment;
- land-cover mapping;
- global assessments, such as of crops and forest resources;
- tailoring information to the perceptions and needs of rural households and providing gender-sensitive guidance for adaptive livelihood development.

For rural people who depend on the natural resource base for their livelihoods, protecting food security in the face of climate change will require improved management of the environment, especially during climate extremes, which bring the greatest risk of degradation of the environment and threat to the sustainability of the livelihood systems that depend on it.

Figure 11 uses data from Australia to illustrate how improved climate understanding and forecast skill may increase the range of low-risk conditions, and enhance the capacity to manage high-risk periods.

Figure 11. Benefits of improved climate information for reducing risk in Australia



Source: Australian Bureau of Meteorology, 2006.

Promoting insurance schemes for climate change risk

In 2007, the World Economic Forum outlined the five core areas of global risk as economic, environmental, geopolitical, societal and technological. Within these, climate change is seen as one of the defining challenges for the twenty-first century, as it is a global risk with impacts far beyond the environment (World Economic Forum, 2007). The insurance industry is among the economic sectors that are already experiencing adverse impacts of climate change.

Wealthy countries depend heavily on the private insurance industry to protect their citizens against natural disasters. According to a recent report, these countries account for 93 percent of the global insurance market (Hamilton, 2004). This market is increasingly strained as it tries to respond to astronomical increases in claims related to the impacts of extreme weather events in North America and Europe.

In the United States, a 2005 study on the availability and affordability of climate risk insurance found that weather-related losses were growing ten times faster than both premiums and the overall economy, and more than ten times faster than the population; it also noted that this trend would be compounded by continued settlement in high-risk areas (Mills, Roth and Lecomte, 2005).

Higher losses are already leading the insurance industry to charge higher premiums, raise deductibles, lower maximum coverage limits, and restrict the types of natural disasters or catastrophic events that can be insured. The authors conclude that, "Given the critical role that insurance plays in the US and global economy, reduced access to affordable insurance would have profound impacts on both consumers and businesses" (Mills, Roth and Lacomte, 2005). Although this statement refers to the United States economy, it is equally applicable everywhere in the world, and the implications for future food security are potentially very serious.

Typical forms of insurance coverage for weather- and climate-related events (e.g., floods, windstorms, thunderstorms, hailstorms, ice storms, wildfires, droughts, heat waves, lightning strikes, subsidence damage and coastal erosion) include coverage for property damage, business interruptions, and loss of life or limb. If climate stresses cause the insurance industry in the developed world to stop providing such coverage when natural disasters are involved, many previously food-secure people will be exposed to significant uncompensated losses of property and means of livelihood, which could plunge them into a state of vulnerability that has previously been associated mainly with developing countries.

Increasing climate stresses and the retreat of the private sector insurance industry from covering losses caused by catastrophic natural events will lead to increasing calls for national and local governments to step in. Most governments already operate public sector insurance programmes for major risks if there is no private sector coverage, such as for crop loss, flood and earthquake damage; they also typically pay for disaster preparedness and recovery operations. These programmes are also experiencing increasing losses, however, so the financial burden of maintaining the current social safety net protection in the face of additional demands generated by the impacts of climate change may be beyond what many governments in developed countries can afford.

Because there is little private sector insurance in developing countries, other approaches to insurance have evolved to accommodate low-income groups. Informal, locally based micro-insurance initiatives offer a popular alternative because the premiums are low and the rules are often less stringent than for commercial insurance (Hashemi and Foose, 2007). Public-private partnerships are also increasingly popular, and often involve the government coordinating and/or adding to premium payments made by those to be insured. An example from Ethiopia is given in Box 2.

As climate-related risks affect everybody, insurance against the consequences of catastrophic weather events needs to be globalized, and costs minimized through action to mitigate climate change. The World Economic Forum suggests the following two global approaches for addressing climate risk (World Economic Forum, 2007):

Box 2. Drought insurance in Ethiopia

In Ethiopia, contingency funding was secured through a private sector reinsurance company, AXA Re, to experiment with a new approach to weather insurance whereby vulnerable households sign financial contracts obligating them to pay an insurance premium prior to each growing season. The contracts entitle them to receive insurance payouts whenever abnormally low rainfall cause the value of crops in the ground to fall below a specified trigger. The scheme's success depends on the ability of local weather stations to track the development of the growing season accurately, so capacity building for the meteorological service was part of the initial experiment. Payout funds from this insurance scheme help vulnerable households when crops fail because of drought, and reduce their dependence on emergency relief.

Source: Hess, 2006.

- Designating country risk officers – analogous to chief risk officers in the corporate world – to serve as focal points for managing a portfolio of risks across disparate interests, setting national prioritization of risk and allowing governments to engage in the necessary actions to begin managing global risks rather than coping with them.
- Creating cooperation among relevant governments and companies around different global risks – "coalitions of the willing" – to make risk mitigation a process of gradually expanding alliances rather than a proposition requiring permanent consensus.

Innovative insurance schemes, such as a global reinsurance fund for climate change damage or expanded local coverage of weather-based insurance, are likely to be needed (Osgood, 2008).

Developing national risk management policies

It is possible to reduce risks by mainstreaming national risk management policy frameworks within policies and programmes for sustainable development. From a food security perspective, the objective of such frameworks is to protect local food supplies, assets and livelihoods against the effects of increasing weather variability and the increased frequency and intensity of extreme events. Frameworks should include pre-event preparedness, risk mitigating strategies, reliable and timely early warning and response systems, and innovative risk financing instruments to spread residual risks. Elements of such frameworks that are applicable for both rural and urban populations in all ecosystems include effective early warning systems; emergency shelters, provisions and evacuation procedures; and weather-related insurance schemes.

The objectives of managing climate change risk are to: (i) reduce risk exposure; and (ii) reduce negative outcomes. The process entails first risk mapping, which includes identifying areas, populations and livelihoods at risk, followed by analysis of the kinds of risks involved, and estimation of the levels of risk exposure of different areas, groups and livelihoods in terms of their risk absorption capacity and the size and degree of risk, with explicit attention to the gender dimension.

Participatory approaches to assess vulnerability and needs should involve representatives of all community members in a dynamic process of reflection, planning and action that is livelihoods-based and gender-sensitive, and that draws on local knowledge and priorities. Typical components of national risk management policies and programmes include:

- infrastructure investments to protect against asset loss;
- climate information and advisory services for agricultural communities;
- reliable and timely early warning systems;
- rapid emergency response capacity;
- innovative risk financing instruments and insurance schemes to spread residual risks.

To protect local food supplies, assets and livelihoods from the effects of increasing weather variability and increased frequency and intensity of extreme events, adaptation measures will need to respond to a variety of risks, many of which are specific to particular ecosystems.

The Millennium Ecosystem Assessment report (2005) evaluated potential climate change impacts for ten ecosystems: urban, marine, coastal, inland water and floodplain, forest, dryland, island, mountain, polar, and cultivated. The nature of the risks and the affected livelihood groups vary considerably from one ecosystem to another, so adaptation responses have to be tailored to local conditions and needs.

STRENGTHENING RESILIENCE AND MANAGING CHANGE

In addition to risk management, climate change also requires adaptive management that focuses on modifying behaviours over the medium-to-long term to cope with gradual changes in precipitation and temperature regimes. These modifications are likely to concern consumption patterns, health care, food and agricultural production practices, sources and use of energy, and livelihood strategies.

Strengthening resilience for all vulnerable people involves adopting practices that enable them to:

- protect existing livelihood systems;
- diversify their sources of food and income;
- change their livelihood strategies;
- migrate if there is no other option.

Additional action areas that can strengthen resilience of agriculture-based livelihood systems include:

- research and dissemination of crop varieties and breeds adapted to changing climatic conditions;
- effective use of genetic resources;
- promotion of agroforestry, integrated farming systems and adapted forest management practices;
- improved infrastructure for small-scale water capture, storage and use;
- improved soil management practices.

Adjusting consumption and responding to new health risks

Current projections for continued economic growth to 2030 and beyond imply a continued increase in demand for animal protein as average incomes in developing countries rise. This will lead to increased demand for water and, to a lesser extent, land for livestock production. Increased demand, coupled with growing scarcities of water, land and fuel, could bring about increases in food prices, even without climate change.

Additional pressures on water availability, due to climate change, the introduction of mitigation practices that create competition for land, and the attribution of market value to environmental services to mitigate climate change, could also cause significant changes in relative prices for different food items, and an overall increase in the cost of an average food basket for the consumer. Although not foreseen in the projections, current market developments suggest that some of these factors may already be at work in global food markets, driving up prices and increasing the number of people who lack access to an adequate supply of food daily.

Faced with rising prices and increased awareness of the environmental consequences of their food choices, consumers may modify their spending and eating habits. Environmentally conscious consumers may choose to change their food consumption patterns – relying more on local produce with a lower carbon footprint, and reducing their consumption of grain-fed livestock with large requirements for increasingly scarce land and water resources. Examples of possible changes in food consumption patterns include:

- shift in staple food preferences;
- shift away from grain-fed livestock products;
- increased consumption of new food items;
- reduced consumption of wild foods;
- reduced quantities and/or variety of food consumed.

As well as adjusting consumption patterns to obtain a sufficient quantity of food, it will also be necessary to make adjustments to maintain dietary quality. This could involve:

- protecting biodiversity and exploiting wild foods;
- promoting urban and school gardens;
- increasing use of dry cooking methods to conserve water;
- promoting energy-efficient and hygienic food preparation practices;
- teaching good eating habits to reduce malnutrition and diet-related diseases.

Increased incidence of water-borne diseases in flood-prone areas, change in disease vectors and habitats for existing diseases, and emergence of new diseases will pose new risks for food security, food safety and human health. Vector changes are a virtual certainty for pests and diseases that flourish only at specific temperatures and under specific humidity and water irrigation management regimes. This will expose crops, livestock, fish and humans to new risks to which they have not yet adapted. It will also place new pressures on care givers within the home, who are often women, and challenge health care institutions to respond to new parameters. Where such vector changes can be predicted, varieties and breeds that are resistant to the likely new arrivals can be introduced as an adaptive measure (WHO, 2007).

Intensifying food and agricultural production

To meet the food demand of a global population that is projected to increase by 2.5 billion by 2050, it will be essential to intensify production, obtaining higher yields per unit of input – whether this be land, water, nutrient, plant or animal. Improved land management practices can contribute to soil moisture retention, maintain appropriate amounts of nutrients in the soil, strengthen resilience and enhance productivity. Maintaining and enhancing plant and animal genetic resources, and managing livestock operations and fisheries more efficiently will also be crucial. Above all, however, a more variable climate and less reliable weather patterns will make increased capacity for storing water for agricultural use and greater efficiencies in its application essential.

Managing agricultural water more efficiently: Even without climate change, the global water economy is already in trouble. A major study, *Water for food, water for life*, released in 2007 by Earthscan and the International Water Management Institute (IWMI), reveals that one in three people today face water shortages (CA, 2007). Although there is theoretically sufficient freshwater to meet all the world's projected needs for the foreseeable future, water is not necessarily accessible in the locations where it is needed. Unsustainable use (with use rates exceeding recharge rates) is putting additional pressure on available supplies in many parts of the world. One important reason for this is the increased per capita demand for water that accompanies modern life styles.

The water needs of a single human being grow exponentially as that person's wealth and position in life increase. Each person requires a mere 2 to 5 litres of water a day for survival, and from 20 to 50 litres for cooking, bathing and cleaning. In urban areas worldwide, however, average household water consumption is about 200 litres per person per day. This includes all uses of running water in and around the home, plus other withdrawals from city water supplies for use by public or commercial properties (CA, 2007). Without water, people cannot produce the food they eat. FAO estimates that it takes an average of about 1 000 to 2 000 litres of water to produce 1 kg of irrigated wheat and 13 000 to 15 000 litres to produce the same quantity of grain-fed beef. Thus, each human being “eats” an average of 2 000 litres of water a day (CA, 2007).

Water use has been growing at more than twice the rate of population increase in the last century, and although there is no global water scarcity as such, an increasing number of regions are chronically short of water. As the world population continues to increase, and rising incomes and urbanization cause food habits to change towards richer and more varied diets, even greater quantities of water will be required to guarantee food security (UN Water and FAO, 2007).

Water scarcity is being exacerbated by climate change, especially in the driest areas of the world, which are home to more than 2 billion people, including half of the world’s poor. Climate change is expected to account for about 20 percent of the global increase in water scarcity, and countries that already suffer from water shortages will be hit hardest. Even the increasing interest in bioenergy created by the need to reduce the carbon emissions that cause global warming could increase the burden on scarce water resources.

Although precipitation is projected to increase at the global level, this will not necessarily lead to increased availability of water where it is needed. In fact, FAO’s 2015/2030 projections, citing a 1999 Hadley Centre report, state that “substantial decreases are projected for Australia, India, southern Africa, the Near East/North Africa, much of Latin America and parts of Europe” (FAO, 2003b: 364).

Increasing water scarcity and changes in the geographic distribution of available water resulting from climate change pose serious risks for both rainfed and irrigated agricultural production globally. With a more variable climate and less reliable weather patterns it will be essential to increase the water storage capacity for agriculture, to maintain global food supplies while satisfying other competing uses for agricultural water (Parry *et al.,* 2007).

Looking ahead to 2030, irrigated areas will come under increasing pressure to raise the productivity of water, both to buffer the more volatile rainfed production (and maintain national production) and to respond to declining levels of this vital renewable resource. This risk will need to be managed by progressively adjusting the operation of large-scale irrigation and drainage systems to ensure higher cropping intensities and reduce the gaps between actual and potential yields.

The inter-annual storage of excess rainfall and the use of resource-efficient irrigation remain the only guaranteed means of maintaining cropping intensities. Water resource management responses for river basins and aquifers, which are often transboundary, will be forced to become more agile and adaptive (including near-real-time management), as variability in river flows and aquifer recharge becomes apparent.

Competing sectoral demands for water will increase pressure on the agriculture sector to justify the allocations it receives. Water allocation strategies should protect the ecological reserve – the water required by the environment for the effective maintenance of hydrological ecosystems and services – as a crucial component of adaptive capacity and a buffer against the ecological risks that ensue when water becomes scarce.

Key adjustments for maintaining cropped areas include:

- optimizing operational storage, i.e., manageable water resources such as water stored behind a dam;
- controlling releases to improve hydraulic performance and salinity control;
- optimizing crop water productivity.

Water allocations and releases to agriculture across river basins are essential for improving operational performance. Well-targeted investments in small-scale water control facilities and the upgrading of larger-scale facilities, together with associated institutional reforms, will pay off in the medium term. Other strategies that can increase water productivity directly or have indirect water saving benefits include (Pretty et al., 2006):

- reducing soil evaporation through conservation agriculture practices;
- planting more water-efficient crop varieties;
- enhancing soil fertility to increase yields per unit of water utilized;
- decreasing runoff from cultivated land;
- reducing crop water requirements through microclimatic changes;
- reusing wastewater for agricultural purposes.

Currently, about 2 million hectares are irrigated by reused wastewater, but this area could grow (CA, 2007).

In the longer term, a transition towards more precision-irrigated agriculture should be anticipated. Conservation agriculture, precision-irrigated agriculture and the resulting improved water productivity require specialized tools and equipment; incentives are needed to ensure that these inputs are adopted in areas where the expansion of commercial agricultural is desirable.

Managing land sustainably: Production risks can be spread and buffered by a broad range of land management practices and technologies. Enhancing residual soil moisture through land conservation techniques assists significantly at the margin of dry periods, while buffer strips, mulching and zero-tillage mitigate soil erosion risk in areas with increasing rainfall intensity.

Conservation agriculture is an option for adaptation as well as for mitigation because the increase in soil organic matter reduces vulnerability to both excessive rainfall and drought. The impact is not immediate; soil under zero-tillage tends to increase the soil organic matter content by approximately 0.1 to 0.2 percent per year, corresponding to the formation of 1 cm of new soil over a ten-year period (Crovetto, 1999). However, not only does organic matter facilitate soil structuring, and hence the infiltration and storage of water in the soil, but it also directly absorbs up to 150 m^3 water per hectare for each percent of soil organic matter. In addition, under conservation agriculture, no soil moisture is lost through tillage and seedbed preparation.

This means that seeding often does not need rainfall, because the seed can use the existing soil moisture. The total water requirements for a given crop are also lower in conservation than in conventional agriculture, which is of particular interest where water is scarce; reported water savings amount to at least 30 percent. This is because less water is lost through surface runoff and unproductive evaporation, and more is stored in the soil. Crops under conservation agriculture suffer much less from drought conditions, and are often the only crops to yield in such situations. Yield fluctuations under conservation agriculture are generally much less severe than under comparable conventional agriculture (Tebrügge and Bohmsen, 1998; Derpsch, 2005).

Among the disadvantages of conservation agriculture are its tendency to produce weed problems that require chemical herbicides to control; it is a technology requiring relatively high management skills, as many of the field operations must be implemented with a considerable degree of precision; and although permanent soil cover is ideal in the long term, there are short-term costs that must be covered before the system is well-established. Start-up incentives and training may therefore be needed to encourage farmers to adopt the conservation agriculture approach.

Maintaining biodiversity: Promoting agrobiodiversity is crucial for local adaptation and resilience. Biodiversity in all its manifestations – genes, species, ecosystems, etc. – increases resilience to changing environmental conditions and stresses. Genetically diverse populations and species-rich ecosystems have greater potential to adapt to climate change. FAO promotes the use of indigenous and locally adapted plant and animal diversity, and the selection and multiplication of crop varieties and autochthonous races that are adapted or resistant to adverse conditions.

Effective use of genetic resources can reduce negative effects of climate change on agricultural production and farmers' livelihoods. As women are traditionally the carriers of local knowledge about the properties and uses of wild plants, and the keepers of seeds for cultivated varieties, they have an important role in protecting biodiversity. Providing appropriate compensation for this service could guarantee a sustainable livelihood to these women, many of whom belong to vulnerable and food-insecure groups.

Breeding plants and animals for tolerance to drought, heat stress, salinity and flooding will also become increasingly important. FAO promotes the rebuilding of developing country national capacities to breed such crops, especially those in which the private sector is not involved. The Global Partnership Initiative for Plant Breeding Capacity Building (GIPB), facilitated by FAO, was launched on the margins of the first Governing Body Meeting of the International Treaty on Plant Genetic Resources in June 2007. It will contribute to Article 6 of the treaty, regarding sustainable use of plant genetic resources.

Adapting crops cannot be separated from other management options within agro-ecosystems; for example, rice is both affected by and has an effect on climate. Climate change is expected to have a significant impact on the productivity of rice systems, and thus on the nutrition and livelihood of millions of people. Rice systems, especially in south and east Asia, are under increasing pressure because of their high water needs and their role as a source of methane emissions. New crop management systems are therefore required that increase rice yields and reduce production costs by enhancing the efficiency of input application, increasing water use efficiency, and reducing greenhouse gas emissions.

Rice is currently the staple food of more than half the world's population. In Asia alone, more than 2 billion people obtain 60 to 70 percent of their calories from rice and its products. It is the most rapidly growing source of food in Africa, and is of significant importance to food security in an increasing number of low-income, food-deficit countries. Rice-based production systems and their associated post-harvest operations employ nearly 1 billion people in rural areas of developing countries.

About 80 percent of the world's rice is grown by small-scale farmers in low-income and developing countries. Efficient and productive rice-based production systems are therefore essential for economic development and improved quality of life for much of the world's population (FAO, 2004c).

Rice is a highly adaptable staple with many properties that have not yet been exploited in large-scale production systems. It is tolerant to desert, hot, humid, flooded, dry and cool conditions, and grows in saline, alkaline and acidic soils. At present, however, only two of the 23 rice species are cultivated. Science can help improve the productivity and efficiency of rice-based systems. Improved technologies enable farmers to grow more rice on limited land with less water, labour and pesticides, thus reducing damage to the environment. In addition, improved plant breeding, weed and pest control, water management and nutrient-use efficiency can increase productivity, reduce costs and improve the quality of the products of rice-based production systems.

New rice varieties being developed exhibit enhanced nutritional value, require less water, produce high yields in dryland conditions, minimize post-harvest losses, and have increased resistance to drought and pests and increased tolerance to floods and salinity. For example, rice varieties with salinity tolerance have been used to expedite the recovery of production in areas damaged by the 2005 Asian tsunami.

The Consultative Group on International Agricultural Research and FAO are promoting Rice Integrated Crop Management Systems (RICMS). By introducing integrated soil, water and nutrient management practices for sustainable rice-wheat cropping systems in Asia, RICMS would complement the introduction of new varieties and address the environmental problems that have emerged in these systems since earlier yield-enhancing technologies were introduced (International Rice Commission, 2002).

Improving livestock management: In its recent publication, *Livestock's long shadow: Environment issues and options*, FAO points out that approximately 70 percent of the world's agricultural land is used by the livestock sector, including grazing land and cropland for feed production (FAO, 2006c). Current prices of land, water and feed do not reflect true scarcities, leading to the overuse of resources and major inefficiencies in the livestock sector. Full-cost pricing of inputs and widespread adoption of improved land management practices by both intensive and extensive livestock producers would help to resolve more sustainably the competing demands for animal food products and environmental services.

Increased intensification and industrialization are improving efficiency and reducing the land area required for livestock production, but they are also marginalizing smallholders and pastoralists, increasing inputs and wastes and concentrating the resultant pollution. Extensive grazing still occupies and degrades vast areas of grassland.

Overgrazing is the greatest cause of grassland degradation, an important contributor to deforestation and the overriding human-influenced factor in determining soil carbon levels of grasslands. In many systems, improved grazing management, such as optimized stock numbers and rotational grazing, will therefore result in substantial increases in carbon pools. Improved pasture management and integrated agroforestry systems that combine crops, grazing lands and trees in ecologically sustainable ways are also effective in conserving the environment and mitigating climate change, while providing more diversified and secure livelihoods for inhabitants.

Improving fisheries management: Worldwide, some 200 million people and their dependants, most of them in developing countries, live from fishing and aquaculture. Fish provide an important source of cash income for many poor households and are a widely traded food commodity. As well as stimulating local market economies, fish can also be an important source of foreign exchange.

Variability across different time scales has always been a feature of fisheries, especially capture fisheries. Recruitment and productivity in most fisheries vary from year to year, and are also subject to longer-term variability that typically occurs on a decadal scale. For example, populations of small pelagic fish in upwelling systems vary both from year to year and on a decadal scale, often showing shifts in productivity patterns and dominant species.

Where management is effective, fishery systems have developed adaptive strategies and, through monitoring and feedback, fishing effort and catches are regularly modified according to the state of the stock. Fishers must have adequate robustness and/or flexibility to absorb the changes in resource abundance, while avoiding negative ecological, social or economic impacts (FAO, 2007b).

Creating an eco-friendly energy economy

A fundamental principle for adaptation in the energy sector is that meeting the demand for bioenergy should not undermine food security. This demand has been growing because of the rising cost of petroleum, concern about dependence on fossil fuel imports, the climate change mitigation benefits of reducing reliance on fossil fuels, and the increase in demand for fuelwood and charcoal for expanding populations in many parts of the developing world. This section explores the intersections among climate change, energy security and food security, and the prospects for second-generation biofuels and increased energy efficiency as alternatives to biofuel crops. Another important issue, which is sometimes overlooked in discussions of the global energy economy, is the role of sustainably managed forests and trees as a source of energy at the national and household levels.

Understanding linkages among climate change, energy security and food security: It is hypothesized that ethanol produced from biomass[4] can help mitigate climate change and reduce greenhouse gas emissions by substituting fossil fuel. IPCC estimates that by 2030,

[4] As yet, there is no consistent international usage of bioenergy terminology. This paper uses the following terms and meanings: *biomass* = material of biological origin (excluding material embedded in geological formations and transformed to fossil); *biofuel feedstock* = organic materials used in the production of liquid and gaseous biofuels; *biofuel* = fuel produced directly or indirectly from solid, liquid or gaseous biomass; *bioenergy* = energy production from biofuels, including wood energy (derived from fuelwood, charcoal, forestry residues, black liquor and any other tree product) and agro-energy (derived from purpose-grown crops and from agricultural and livestock by-products, residues and wastes); *first-generation biofuels* = fuels produced from purpose-grown crops; *second-generation biofuels* = fuels produced from cellulosic materials (woody material and tall grasses), crop residues, and agricultural and municipal wastes.

liquid biofuels could supply 3 percent of the transport sector's energy needs, rising to 5 to 10 percent if second-generation biofuels take off (IPCC, 2007b). As a spin-off benefit, the rural sectors in developing countries can attract investment by generating tradable emission reduction credits – certified emission reductions (CERs) – through the Kyoto Protocol and the international market for greenhouse gas emission reductions.

There are uncertainties surrounding the potential climate change-related benefits, however. For example, with respect to the implications for climate change, the energy balance needs to be calculated over the whole production chain from bioenergy crop to biofuel end-product. Biofuels can be considered to contribute to climate change mitigation only if their use has produced fewer net emissions of greenhouse gases at the end of the production process than the average emissions from fossil fuel use. Even if there is a net contribution, producing biofuel from purpose-grown crops is not necessarily the most efficient use of available land.

A UN-Energy publication sponsored by FAO (UN Energy, 2007) identifies nine factors that must be considered in determining the sustainability of bioenergy development:

- ability of modern bioenergy to provide energy services for the poor;
- implications for agro-industrial development and job creation;
- health and gender implications;
- implications for the structure of agriculture;
- implications for food security;
- implications for government budget;
- implications for trade, foreign exchange balances and energy security;
- impacts on biodiversity and natural resources management;
- implications for climate change, including avoidance of deforestation and creation of a positive energy balance.

Biofuel crops have potential for large-scale production wherever food crops are currently grown or could be grown. Table 4 indicates the areas of land that would have to be devoted to the production of first-generation biofuel feedstocks if they were to substitute 25 percent of the current demand for transportation fuels (or 10 percent of total energy demand). It uses data on the potential yields of a number of crops and their fuel conversion efficiencies.

TABLE 4
Land required to replace 25 percent of current fuel demand for transport (45 EJ/year)

	Yield (gross) (GJ/ha/year)	Agricultural land required (% of currently available 2.5 billion ha)
Sugar cane	104	17
Sugar beet	90	20
Palm-oil	81	22
Maize	54	33
Wheat	45	40
Barley	20	91
Rape	20	91
Sunflowers	16	111
Soybean	9	200

Source: Dutch EnergyTransition.

TABLE 5
Distribution of global land area, 2004

Land use, 2004	Area (billion ha)
Arable land	1.4
Permanent crops	0.1
Pastures	3.4
Forest	3.9
Other	4.5
Total	**13.4**

Source: FAO Online, FAOStat.

As Table 4 clearly shows, grain crops in particular have too low a production potential for this ambitious target to be realized, underlining the need to increase efficiency of the whole production and conversion process. Moreover, as Table 5 shows, the assumption that 2.5 billion ha of agricultural land is available is optimistic, given the far smaller area that current statistics give as land for arable crops.

If production of feedstocks for liquid biofuels takes good arable land out of food production, it could reduce the availability of food on global markets and raise market prices, with consequent negative effects on food security at all levels (household, national and global). Furthermore, most sources of liquid biofuels are currently not commercially viable without subsidies, mandates and/or tariffs. If subsidized production of liquid biofuel from field crops becomes an important factor in global agricultural markets, competition for land and water will increase, putting upwards pressure on food prices and increasing the prevalence of food insecurity.

There are other possible negative effects of biomass production for bioenergy, including the risk that dedicating large tracts of land to monocropping of energy crops will contribute to deforestation, land degradation, carbon emissions, contaminated surface and groundwater, and loss of biodiversity, and it is not clear that the net energy gain from biofuel production will be positive. In response to these and other concerns about whether large-scale production of bioenergy crops is really sustainable (Dutch EnergyTransition), the United Nations Special Rapporteur on the Right to Food, Mr Jean Ziegler, called for a five-year moratorium on the conversion of arable land to biofuel production. Speaking at a press conference for the opening of the Fifth Special Session of the Human Rights Council in New York, he stated that:

"The creation of 'pure fuels', or biofuels, to protect the environment and reduce oil dependence is not a bad idea, but its negative impact on hunger would be catastrophic. When tonnes of maize, wheat, beans and other food staples are converted to fuel, food prices rise and arable land is lost to food production. Last year, the price of wheat doubled and of maize quadrupled.
"As prices rise, the poorest countries cannot pay, and the poorest people, generally living without access to subsistence farming, cannot purchase more expensive foodstuffs. The amount of corn needed to make enough ethanol to fill a single car's fuel tank could fill a child for an entire year.
"Non-food agricultural products that could grow in soil unfit for food production could be used as an alternative source of biofuels. For example, in a project in Rajasthan, India, the Mercedes company is growing jatropha for biodiesel in arid land. Following a moratorium, such projects could be evaluated and new fuels produced." (UNDPI, 2007)

An expert meeting convened by FAO in February 2008 confirmed that there were significant concerns about the potential impacts of biofuels on food security. Early evidence suggests that the introduction of biofuels initially reduces food availability and increases food prices, with immediate adverse impacts on the food security situation for poor consumers in both urban and rural areas. These impacts affect people's access not only to starchy staples, but also – and often more important – to foods needed for a balanced diet, such as vegetable oil and animal products. Because food and energy supply are both subject to random shocks, profitability will lead to cycles of expansion and contraction, which will increase food security concerns (FAO, 2008).

It is already anticipated that traditional safety nets may not be adequate in the face of new and increasing vulnerabilities caused by climate change. Market-induced vulnerability attributable to higher and more variable prices for food as a consequence of biofuel demand will only compound this problem. Expansion of liquid biofuel production would intensify the impact on food prices and land availability if the expansion were based on the continued use of present technologies in current policy environments (FAO, 2008).

However, experts at the meeting also expressed the view that liquid biofuel development does not have to be adverse for food security, particularly if production is allowed to find its natural competitive equilibrium, which today would favour production of sugar cane and discourage production of starchy crops as liquid biofuel feedstocks. Emergent poor farmers with sufficient skills and assets to become successful commercial farmers can take advantage of the emerging liquid biofuel market, provided they live in locations where growing conditions are suitable and appropriate infrastructure is present. If domestic markets are functioning efficiently, higher prices can benefit the farmers producing such cash crops as sunflower, soybean, rapeseed or sugar cane, irrespective of the final use of the harvested crop. However, higher prices for staple cereals such as maize will increase food insecurity for poor farming households that are net buyers of the staple concerned, as is often the case (FAO, 2008).

On the other hand, if second-generation biofuels come on stream during the next decade or two, as many experts predict they will, they could create new livelihood opportunities and improve food security for many currently vulnerable people living on degraded lands where cellulosic feedstocks could be produced. Such a development would also constitute a good option for mitigating and adapting to climate change on these lands, because the introduction of woody vegetation would sequester carbon, improve the water retention capacity of the soil and reduce erosion (FAO, 2008).

Even without second-generation biofuels, the mix of feedstocks and biofuels in use is likely to change over the medium term. For example, the International Energy Agency (IEA) foresees changes in the relative importance of different biofuel feedstocks over time (IEA, 2006), and FAO projects that traditional sources of biofuel will decline in importance as opportunity costs for labour increase and rural people can no longer afford the time to collect fuelwood or burn charcoal. At some point, rising prices for oil will make methane (biogas) competitive, and eventually butanol is likely to replace ethanol for mixture with gasoline as a transport fuel.

Planted forests represent only 7 percent of global forest cover, but they account for more than half of global industrial roundwood production (FAO, 2006b). There is significant potential for expanding planted forests on marginal lands or lands released from crop or livestock production. Increasing proportions of sustainably produced industrial roundwood and wood for energy generation will come from planted rather than native forests.

Increasing energy efficiency: Although the debate about biofuel/food security tradeoffs has so far focused on how to manage competing demands for scarce productive resources, it is equally important to consider energy saving and efficient use for reducing the demand for energy, including bioenergy.

Inefficient use of water for irrigation also results in energy inefficiency, so gains in irrigation efficiency can be expected to lead to energy savings and reduced pumping costs. Over the entire cropping cycle, conservation agriculture generates diesel fuel saving of about 60 percent compared with conventional tillage. Reduced fuel requirements for primary and secondary tillage operations and planting are particularly significant. Use of other inputs that require energy for their manufacture, such as machinery, fertilizer and pesticides, is also lower. One study (FAO/SDR Energy Programme, 2000) estimates that overall, conservation agriculture consumes 40 to 50 percent less energy than conventional tillage, including the energy requirements for producing inputs. This lower fossil fuel requirement for field operations is the main driving force for adopting zero-tillage cropping systems in mechanized farming, under scenarios of increasing fuel costs.

The fisheries sector can play only a small part in reducing CO_2 emissions through greater energy efficiency, but there may be synergies among emissions reductions, energy savings and responsible fisheries. For example, reducing the fuel subsidies granted to fishing fleets would encourage energy efficiency and assist the reduction of overcapitalization in fisheries; static gear – pots, traps, longlines and gillnets – uses less fuel than active gear such as trawls and seines.

Micro- and small-scale agroprocessing industries have an important role in increasing and diversifying livelihood opportunities for the rural poor. However, these people are often handicapped by poverty and lack of assets, low education levels, poor understanding of the sector, and low levels of inputs, reducing their competitiveness. In addition, the practices that they employ often degrade and contaminate the environment. Regarding energy use, most small-scale agroprocessing operations are intensive consumers of fuelwood, so contribute to the problems referred to in the previous section. More energy-efficient technologies could be employed by small-scale agroprocessing industries, but operators need to obtain the necessary skills and start-up capital to adopt them. Many operators are women, who could be reached through programmes that target women as a vulnerable group (FAO, 2002).

Exploiting forests sustainably: Sustainable forest management is a dynamic and evolving concept. The aim is to maintain and enhance the economic, social and environmental values of all types of forests for the benefit of present and future generations (UNFF, 2007). In its broadest sense, forest management encompasses the administrative, legal, technical, economic, social and environmental aspects of the conservation and use of forests. It implies various degrees of deliberate human intervention, ranging from actions to safeguard and maintain the forest ecosystem and its functions, to favouring specific socially or economically valuable species or groups of species for the improved production of goods and services.

Especially in the tropics and subtropics, however, many of the world's forests and woodlands are still not managed in accordance with the Forest Principles adopted at the United Nations Conference on Environment and Development (UNCED) in 1992. Many developing countries have inadequate funding and human resources for the preparation, implementation and monitoring of forest management plans, and lack mechanisms to ensure the participation and involvement of all stakeholders in forest planning and development. Where forest management plans exist, they are frequently limited to ensuring sustained production of wood, without due concern for non-wood forest products and services or social and environmental values. In addition, many countries lack appropriate forest legislation, regulation and incentives to promote sustainable forest management practices.

Climate change will influence forests in all regions. In Africa, for example, lower rainfall is expected to decrease forest productivity and increase the area of dryland forests. In Latin America, the forest of the eastern Amazon is expected to be replaced by savannah. In North America and northern Europe, higher temperatures may make forests more productive and alter the ranges of some species.

Trees under stress are also more susceptible to harmful insect pests and diseases. Recent outbreaks of insect pests, especially in temperate regions, have been linked to alterations in their fertility and mortality related to climate change. An example of this is the recent outbreak of the mountain pine beetle, which has already destroyed 12 million ha of forests in Canada.

Sustainable forest management includes adapting and planning ahead for these changes, as well as managing forests and woodlands to cope with new climatic conditions so that they contribute to flood prevention and provide habitats and wildlife corridors for a diversity of flora and fauna. When planting new forests, careful consideration needs to be given to species choice, particularly where timber production is important.

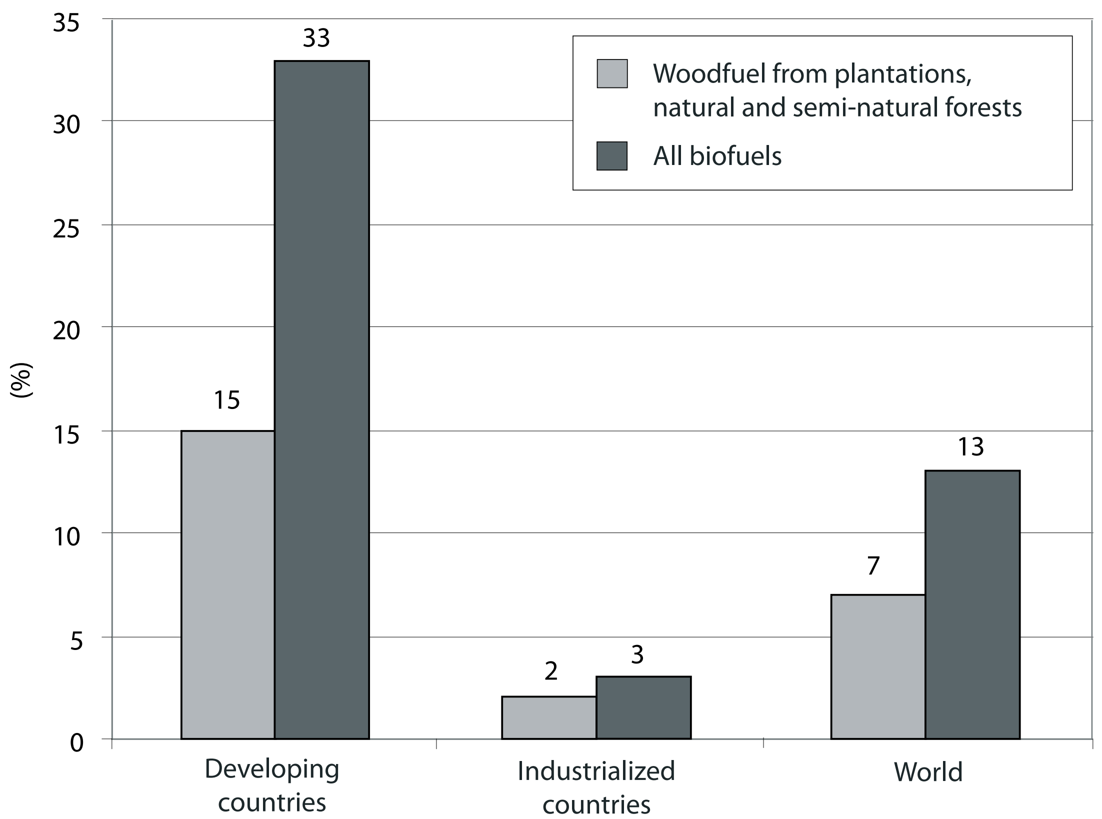
The United Nations Forum on Forests (UNFF) has provisionally identified seven thematic areas that need to be addressed to achieve more sustainable forest management (FAO Online Forestry):

- extent of forest resources;
- biodiversity;
- forest health and vitality;
- productive functions of forest resources;
- protective functions of forest resources;
- socio-economic functions of forest resources;
- the legal, policy and institutional framework for sustainable forest management.

Achieving the transition from deforestation to forest conservation and management is a huge challenge. It involves protecting and managing what already exists, reducing deforestation and forest degradation, restoring more of the world's forest cover, using more wood for energy, making greater industrial use of wood to replace other materials, ensuring the livelihoods of forest-dependent people and safeguarding the ecosystem services of forests.

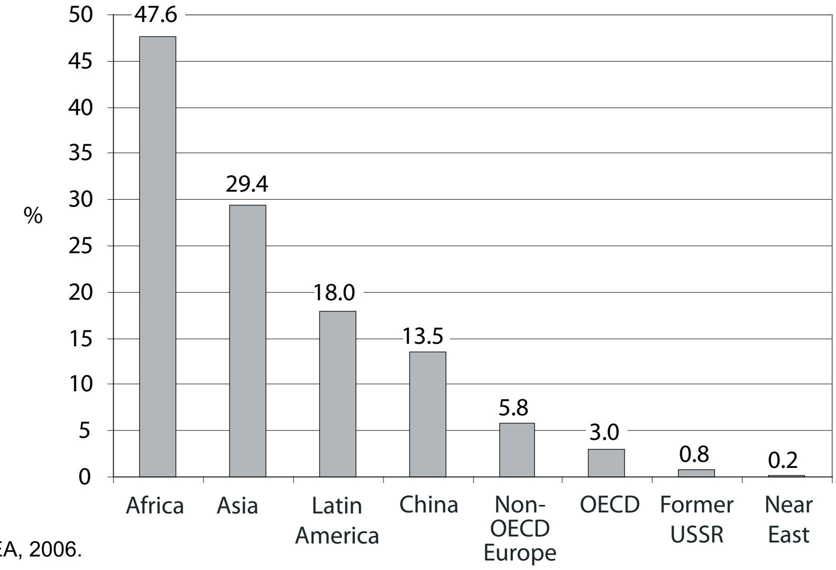
Improving household energy security and food security simultaneously: Less publicized, but equally important, is the energy demand of both rural and urban poor people. Bioenergy is already the dominant source of energy for about half of the world's population, most of whom live on less than US$2 per day (FAO Online, Bioenergy). Figures 12 and 13 show how important this form of energy already is in developing countries – a point that is sometimes overlooked in the current enthusiasm about bioenergy as a substitute for fossil fuel in the transport sector.

Figure 12. Shares of bioenergy in total energy supply



Sources: FAO, 2000a.

Figure 13. Shares of bioenergy in total primary energy supply in different regions in 2004



Source: IEA, 2006.

For food system performance and food security, improving the management of biomass sources for household use can make important contributions in parts of the developing world where large numbers of poor or very poor people live. The incidence of poverty and food insecurity correlates almost exactly with what is called the "energy ladder." At the household level, the poorest people use manure, twigs and low-grade biomass for cooking and heating, and only human force in their productive activities. As they become less poor and move up the economic ladder, they switch to fuelwood, progressing through charcoal, kerosene and gas to electricity, and integrating animals and simple tools into production processes. At a certain level of development, they will integrate some level of mechanization, irrigation and fertilization, moving on – if successful – to mechanized equipment such as tractors and harvesters, which imply a switch to fossil fuels (FAO, 2005).

In both household and economic activities, the energy ladder follows and influences the economic ladder. If attempts to alleviate hunger and promote rural development and food security are to have lasting success, they must recognize and address the key role of energy. Current practices are adding to carbon emissions through deforestation and desertification caused by increasing population pressure on natural fuelwood sources. They also have adverse health impacts caused by smoke inhalation from unvented cooking stoves and outdoor fires. Scarcity of fuel restricts the amount of cooked food that can be prepared, often with adverse consequences for food security and the nutritional quality of the diet. Box 3 illustrates the multiple cascading effects of inaction for the case of Rwanda and eastern Democratic Republic of the Congo (DRC).

Incorporating trees and woodlands in traditional farming systems enhances energy and food security and protects the environment. Various fast-growing tree species are well-adapted to grassland ecosystems, where many currently vulnerable people live. Introducing such species in managed woodlots could provide a vital source of fuel and fodder, as well as holding soil, retaining water, eliminating the need for continued cutting of natural stands of trees and shrubs, and contributing tree crops to the diet. In the past, however, such introductions have often failed when local people have not perceived the need to manage the trees.

Thus the cycle of energy impoverishment, environmental degradation, rising rates of carbon emissions and increasing food insecurity is perpetuated (ETFRN, 2003). Essential investments to break this cycle include: (i) sustainable development of agroforestry parklands; (ii) introduction of integrated food and bioenergy systems at the household level; and (iii) promotion of smallholder production of such crops as palm-oil, rapeseed and jatropha, which can produce oils for making biodiesel for decentralized power generation and water pumps (FAO, 2007e).

Box 3. Gorilla slaughter, conflict, deforestation and demand for charcoal in Rwanda and eastern DRC

"It will take a focused global initiative to end the conflict, introduce alternative sources of household fuel, and create alternative livelihoods."

Millions of people were horrified by the slaughter of mountain gorillas that occurred in DRC's Virunga National Park in the summer of 2007. In one month, nine gorillas – more than 1 percent of the known population of these charismatic relatives of humankind – were wiped out. Wildlife conservation organizations leapt into action and began raising funds to deal with the slaughter, and a crisis team entered the area. In the following four weeks, people's desire to help save the species produced donations amounting to tens of thousands of dollars.

However, if the underlying demand for charcoal is ignored and interventions focus too much on the gorillas alone, the result will be the extermination of not only the mountain gorillas, but also the forests, woodlands and all the unique species that inhabit this biologically diverse landscape. The climate mitigation services provided by the intact forests will also be lost, which could lead to a human crisis that dwarfs the tragedy of nine gorillas.

Living at the epicentre of the bloodiest conflict since the Second World War, the mountain gorillas share their habitat with heavily armed militia. In other lawless regions, where wild meat comes into contact with hungry soldiers, species are slaughtered for food, or for trophies to be traded for cash and weapons. However, these gorilla deaths were repulsive because the animals' corpses were of no use to the killers. Instead, it is the mountain gorillas' presence in the Virunga National Park that puts them at risk, because they draw attention to an area that unscrupulous people would rather was forgotten.

At the heart of the crisis is charcoal – the main form of household energy in Africa – and charcoal making means felling forests, destroying wildlife habitats and damaging ecosystem services such as water catchments and soil fertility. Charcoal production has been going on for millennia, but recent events in eastern DRC have led to a sharp escalation in demand. In neighbouring Rwanda, an enormous human population has stripped almost all of its indigenous forests bare; while in the DRC border town of Goma, refugees fleeing the region's crises have swelled the population to more than half a million. Together, these factors have created a demand for charcoal worth an estimated US$30 million a year. To save Rwanda's few remaining forests and the gorillas, which have become a major source of tourist revenue, President Paul Kagame has installed an efficient and effective ban on charcoal production in Rwanda, but this has driven the illegal industry across the border into DRC, threatening the habitats of the gorillas in the park, which straddles both countries. Given the lack of effective government in eastern DRC, and the extremely small government salaries – wildlife protection rangers earn just US$5 a month for risking their lives – it is not surprising that the park's forests have become a commons, and virtually everybody is involved in the scramble for resources, from smallholders to high-ranking government officials and rebel militia.

If gorillas focus unwelcome global attention on the park, the people who are enriching themselves from charcoal will seek to remove that attention by getting rid of the animals. Shocking though the gorilla killings were, this is fundamentally a human tragedy, with very human solutions. Alternative sources of energy are needed to meet the demand in both Rwanda and eastern DRC, and the rule of law must return to DRC, to save the forests for the long-term good of all, rather than looting them for the short-term profit of a few.

Although this seems to be a very local problem, the whole world has an interest in protecting the forests. Not only is one of the most charismatic and important species on earth at risk of extinction, but there is also a danger of damaging further the world's warming climate. This makes the forests' destruction a "double whammy". Charcoal burning is one of the greatest sources of atmospheric CO_2, and it also strips away the trees that otherwise soak up so much of the CO_2 in the atmosphere.

Although the alarm has been raised by conservation organizations concerned about gorillas, and the global public has responded, it is clear that the problem is much greater than that of conservation alone. This is a human development crisis and it will take a focused global initiative to end the conflict, introduce alternative sources of household fuel, and create alternative livelihoods for the population living in eastern Kivu.

Source: Leakey, 2007.

In farming systems that include livestock, the conversion of animal wastes into biogas is another potential source of energy that could improve household energy security while reducing methane emissions. Appropriate biogas technologies have not yet attracted widespread interest owing to their lack of market competitiveness, but this is beginning to change. Other options in the bioenergy sector that could offer livelihood opportunities for the rural poor include organizing bioenergy cooperatives or contracting with local growers; encouraging investment in bioenergy plantations that employ local labour; and promoting reclamation of degraded lands that are accessible to existing roads, powerlines and water sources, and zoning these lands for a combination of energy crop production, biofuel manufacture and industrial parks that create a market for the fuel (FAO, 2007e).

Adapting agriculture-based livelihood strategies

Taking ecosystems into account: A number of risks are specific to different ecosystems. Although the convention in sustainability literature is to classify only drylands, mountains and coastal zones as fragile, growing understanding of the likely multiple impacts of climate change may reduce the relevance of distinguishing between fragile and robust ecosystems. All ecosystems will need to adapt to climate change, albeit in different ways and with differing demands for new technologies and investments. Table 6 lists specific examples of adaptations that are already known to be needed in each of the ecosystems evaluated for the Millennium Ecosystem Assessment.

In Mali, for example, the hard reality of existing in rural areas is driving many people to urban areas, thereby exacerbating urban poverty. A study analysing the consequences of various options for adapting to climate change in Mali found that the country's natural resource base has been seriously degraded owing to the high population growth rate, the pressure to grow more and more food, and the low rate of adoption of improved technologies (Butt *et al.,* 2005). Because of rural-urban migration, the country's urban population is expected to grow four times faster than its rural population. However, if potential adaptations to climate change were widely adopted, including a shift in crop mixes and introduction of greenhouse technologies, overall economic surplus in rural areas could improve, despite increased weather variability and more frequent droughts and floods.

The study also considered the implications of climate change in terms of policies that expanded cropland (into rangeland), where food security conditions subsequently showed vast improvement. The study highlights that climate change affects the livelihoods and well-being of people in numerous ways (economic, biophysical, political) and advocates for an approach that can adapt to all these factors to improve food security conditions and realize higher economic benefits, thereby meeting the challenges posed by climate change.

Taking scale into account: The wide range of ways in which livelihoods, particularly of poorer groups, are affected by climate variability and climate change highlights the need to focus on adaptation at the livelihood scale. Some adaptations will be household-level interventions, reducing the negative impact of changing climatic conditions on activities; others will involve support from a higher scale, such as a change in policy or provision of a subsidy for acquisition or maintenance of a certain asset.

At the household level, there are many ways that people might adapt to climate change. If the household is involved in agricultural activities, it is likely to start by changing agricultural strategies to cope better with the local change in climate. This might include using drought-resistant and early-maturing seed varieties, reducing evaporation through mulching, and decreasing soil erosion through wind barriers. To undertake these actions, households might need advice on suitable seed varieties and how to mulch, and resources to create wind barriers.

TABLE 6
Examples of livelihood groups at risk and adaptation responses for each of ten ecosystems evaluated for the Millennium Ecosystem Assessment

Nature of risk	Livelihood groups at risk	Adaptation responses
Urban ecosystem		
Extreme • Heat and cold waves • High winds • Storm surges • Floods *Gradual* • Sea level rise	Elderly people and others susceptible to temperature extremes Low-to-medium-income groups who may lose homes, stored food, personal possessions and means of obtaining livelihoods	Emergency shelters Adaptive infrastructure investments Innovative insurance instruments
Marine ecosystem		
Extreme • More anomalies, in both failures and bonanzas, among multiple species • Drastic shift in the areas where small, migrating fish are found *Gradual* • Changes in ocean currents • Rise in average sea temperature • Sharpening of various gradient structures • Increased discharge of freshwater into oceans *Ratchet-like* • Eutrophication (increase in chemical nutrients and loss of oxygen in ocean waters) • Severe reductions in water quality and in fish and other animal populations	Fishers/aquafarmers who suffer diminishing catches from shifts in fish distribution and aquatic ecosystem productivity	Shift from dynamic to static fishing technologies that are less wasteful of remaining fish stocks Occupational training to facilitate search for new livelihood opportunities
Coastal ecosystem		
Extreme • Heavy rains • High winds • Storm surges • Floods *Gradual* • Saltwater intrusions • Sea level rise	Fishing communities that depend heavily on coral reefs for food and protection from natural disasters Fishers whose infrastructure essential for fishing activities, e.g., port, landing and storage facilities, fish ponds and processing areas, becomes submerged or damaged Farmers whose land becomes submerged or damaged by the sea level rise or saltwater intrusions	Coastal defences: • hard – groynes, revetements, embankments • soft – mangroves, coral reefs, wetland conservation Emergency shelters on high ground, with stocks of food, water and medicine Relocation of settlements, roads and other infrastructure Integrated coastal zone management Desalination plants Weather-related insurance Relocation where a rise of sea level is inevitable
Inland water and floodplain ecosystem		
Extreme • High winds • Heavy rains • Floods *Gradual* • Changing water levels	Low-income groups in drought- and flood-prone areas with poor food distribution infrastructure and limited access to emergency response	Changes to dam and infrastructure specifications Storm- and flood-resilient building codes Improved river defences Watershed management, including zero-tillage farming systems Restricting development in high-risk (floods, mudslides) zones Weather-related insurance

Nature of risk	Livelihood groups at risk	Adaptation responses
Forest ecosystem		
Extreme • Heavy rains • High winds • Floods • Droughts • Wildfires *Gradual* • Sea level rise • Forest dieback • Pests and disease	Low-income, forest-dependent people People indirectly dependent on forest ecosystem services	Integrated forest pest management systems Integrated forest fire management systems Integrated watershed management approaches Adjusted silvicultural practices Forest conservation Promotion of small-scale forest-based enterprises for local income diversification
Dryland ecosystem		
Extreme • Droughts • Floods *Gradual* • Changes in rainfall patterns	Low-income groups in drought- and flood-prone areas with poor food distribution infrastructure and limited access to emergency response Producers of crops that may not be sustainable under changing temperature and rainfall regimes Poor livestock keepers where changes in rainfall patterns will affect forage availability and quality	Improved crop, grassland and livestock management Promotion of cropping systems that increase soil organic matter and water infiltration capacity (zero-tillage systems) Research and dissemination of crop varieties and breeds adapted to changing climatic conditions Introduction of integrated agroforestry systems Community grain storage for food distribution Weather-related insurance
Island ecosystem		
Same as coastal ecosystem	Same as coastal ecosystem	Same as coastal ecosystem
Mountain ecosystem		
Extreme • Floods • Landslidex	People indirectly dependent on mountain ecosystem services Producers of crops that may not be sustainable under changing temperature and rainfall regimes	Integrated watershed management approaches Adjusted silvicultural practices Research and dissemination of crop varieties and breeds adapted to changing climatic conditions
Polar ecosystem		
Not specified	Not specified	Not specified
Cultivated ecosystem		
Extreme • High winds • Floods • Droughts *Gradual* • Changing temperature and rainfall regimes	Producers of tree crops that are susceptible to wind damage Producers of crops that may not be sustainable under changing temperature and rainfall regimes	Introduction of cropping systems that do not move and expose soil Introduction of integrated agroforestry systems Research and dissemination of crop varieties and breeds adapted to changing climatic conditions

Source: FAO/NRCB and ESAC.

There are great opportunities to improve poor people's ability to lift themselves out of poverty under conditions of greater water security and sustainability. With the right incentives and investments to mitigate risks for individual farmers, improving water control in small-scale agriculture is feasible and holds considerable potential as an adaptation strategy in parts of the world that are vulnerable to increasing water scarcity as a result of climate change.

The introduction of improved techniques for water harvesting and exploitation of shallow aquifers can contribute to local food security for poor people in drought- and flood-prone areas, ensuring that local food production is as productive as possible and stable, and that households have access to sufficient, safe supplies of water for domestic use, despite irregularities in the timing and intensity of rainfall and consequent unevenness in the recharge rates for underground and surface-level water sources.

Taking gender differences into account: Changes in the variability of prevailing weather conditions may shorten time windows for field work – be it land preparation, weeding, pest management or harvest – inevitably resulting in higher demand for human labour, animal traction or mechanized farm power to carry out the activities in shorter periods. Changes in weather variability also require greater flexibility to start operations as soon as weather conditions permit.

In mechanized farming systems, shorter time windows result in increasing machinery investments. Where these are not possible, untimely operations can result in yield reductions and eventually complete crop failure or harvest loss. Where there is a shift from labour to mechanization, men and women whose livelihoods depend on employment can lose those livelihoods and consequently have less access to income, thereby reducing their capacity to buy food. In this process, women are likely to suffer disproportionately (FAO, 2007d).

In non-mechanized farming systems, where women provide the bulk of farm labour, the increased burden of agricultural work during the shortened growing seasons could have adverse consequences for women's health and ability to provide adequate care to their families, owing to a variety of factors such as lack of nutritious food and inadequate and inappropriate health care. In addition, women may not be able to produce enough to feed everyone in the family, so they will eat last, after the men and the boys. Agricultural mechanization and gender-appropriate machinery can provide some relief.

Studies for Europe indicate that owing to the long-term effects of climate change, cropping patterns and crop yields can be expected to change, but not necessarily decrease (Audsley *et al.,* 2005). In a given location, when climate variations differ over the years, farmers are likely to try to adapt to experienced worst-case scenarios. One of the farmers' first responses to short-term climate variability will be adaptation of working capacity, meaning an increase in human workload or, in mechanized systems, in equipment capacity. However, in food-insecure areas, such as sub-Saharan Africa, the prevailing farm power source is manual labour, which is already limited by the HIV/AIDS pandemic and subsequent deaths of able-bodied men and women. The manual labour resources for additional requirements are therefore not available. Instead, existing labour bottlenecks would be tightened further, with different consequences for men and women, whose specific needs must be taken into consideration (IFAD and FAO, 2003).

As a consequence of increased bottlenecks for timely field operations, higher investment in farm power and equipment capacity is needed, if yield reductions and possible crop failure or harvest loss are to be avoided. The irregular nature of climate variation makes it difficult to quantify its actual impacts, however.

Box 4. Adaptation by small-scale tea farmers in South Africa

In South Africa, small-scale rooibos tea farmers in the Suid Bokkeveld, near Nieuwvoudville in the Northern Cape, are involved in a project that aims to increase their resilience to climate change, specifically drier, hotter conditions and more frequent droughts. Workshops have been held with the farmers to supply them with information about the expected climate for the season and provide an opportunity to discuss how to respond. Participants also visited other rooibos farms in the area to see what works for them. Technologies that help to respond better to existing and expected climate variability include wind erosion barriers, and methods for enhancing soil moisture and maintaining biodiversity, such as establishing mulch strips on which belts of natural vegetation can be grown to act as wind breaks. Farmers have also started intercropping wild rooibos with other cultivars and trying to ensure that harvests are sustainable.

Source: Archer *et al.,* in press.

Providing incentives through payments for environmental services: All the measures discussed in this document are technically feasible, but important socio-economic obstacles need to be overcome for them to be adopted on the required scale. Incentives to make the adoption of good mitigation and adaptation practices attractive are often lacking. Options include improved information, technology transfer, favourable regulations and both positive and negative monetary incentives, such as polluter- and user-pays principles and the removal of perverse incentives, such as production subsidies. Devising innovative financial instruments for environmental service payments will also be important.

Although farmers' adoption of good mitigation and adaptation practices can create on-farm benefits such as increased crop yields, the adoption of such practices on a wider scale depends on the extent to which farmers are affected by the environmental consequences of their current practices and on the incentives that exist to make the switch to alternative practices attractive. Farmers may also need additional knowledge and resources for investing in such practices.

In the 2007 issue of *The State of Food and Agriculture* (FAO, 2007g), FAO presents the argument for paying farmers for environmental services to encourage them to make adaptive changes in their agricultural practices. The idea is that the value of mitigating and adapting to climate change needs to be established through the operation of market forces. If a global market for environmental services emerges, it will have macrolevel implications for food, land and labour markets, which have yet to be analysed (Zilberman, Lipper and McCarthy, forthcoming).

Creating off-farm employment opportunities and planning for human migration: Other adaptations could support access to food through improving off-farm household incomes. In areas where farming is no longer feasible owing to low or uncertain rainfall and increasing temperatures, or where agricultural employment opportunities are declining, the most suitable adaptation might be to develop off-farm sources of income. Support for small business development would be an appropriate strategy, which would enable people to shift from producing to purchasing food. Farmers might also benefit from better access to credit and markets, and there have been recent developments in supporting weather-indexed insurance for small-scale farmers. Other adaptations might be to stop farming and find alternative income-generating projects or migrate to find work. Migration often occurs in response to drought and flood events, with migrants remitting money back to villages to sustain their extended families.

3. PROTECTING FOOD SECURITY THROUGH MITIGATION OF CLIMATE CHANGE

In the long term, mitigating climate change will be critical to avoiding future breakdowns in food and livelihood systems and sharp increases in the number of food-insecure people worldwide. Historically, land conversion from forest to pasture- or cropland, and intensive crop and livestock production practices have been important sources of greenhouse gas emissions. Food systems also have enormous potential to mitigate climate change, however, particularly at the production end of the food chain. Moreover, many of the most effective mitigation measures also represent highly effective adaptation strategies, especially for commercial agriculture.

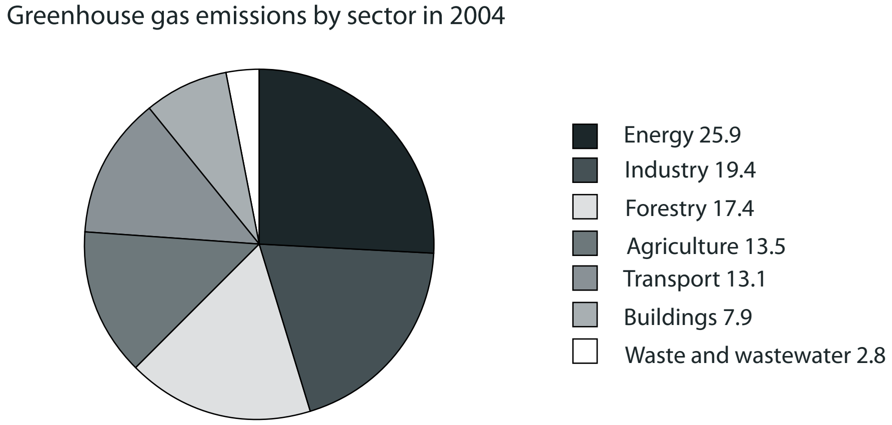
Investing in wider adoption of best practices for mitigation in the food and agriculture sector could therefore have multiple payoffs for food security, including contributing to the stability of global food markets and providing new employment opportunities in the commercial agriculture sector, as well enhancing the sustainability of vulnerable livelihood systems. Such practices include:

- *reducing emissions of CO_2*, such as through reduction in the rate of land conversion and deforestation, better control of wildfires*,* adoption of alternatives to the burning of crop residues after harvest*,* reduction of emissions from commercial fishing operations, and more efficient energy use by forest dwellers, commercial agriculture and agro-industries;
- *reducing emissions of methane and nitrous oxide,* such as through improved nutrition for ruminant livestock, more efficient management of livestock waste and of irrigation water on rice paddies, more efficient applications of nitrogen fertilizer on cultivated fields, and reclamation of treated municipal wastewater for aquifer recharge and irrigation;
- *sequestering carbon*, such as through improved management of soil organic matter, with conservation agriculture involving permanent organic soil cover, minimum mechanical soil disturbance and crop rotation (which also saves on fossil fuel usage); improved management of pastures and grazing practices on natural grasslands, including by optimizing stock numbers and rotational grazing; introduction of integrated agroforestry systems that combine crops, grazing lands and trees in ecologically sustainable ways: use of degraded, marginal lands for productive planted forests or other cellulose biomass for alternative fuels; and carbon sink tree plantings.

According to the most recent data released by IPCC, clearing of forested area for agriculture accounted for 17.4 percent of total greenhouse gas emissions in 2000, with emissions from intensive crop and livestock production contributing another 13.5 percent (Figure 14). By contrast, studies carried out by the World Resources Institute (WRI) indicate that energy sector emissions attributable to agricultural and food processing use of fossil fuels account for only 2.4 percent of greenhouse gas emissions (WRI, 2006). The share of total transportation emissions attributable to food system activities is not identified, but as total emissions for all forms of transport for all purposes came to just 13.1 percent, the part attributable to transport of food commodities and products is likely to be low.

In the United Kingdom, the Carbon Trust, established in 2001 with government funding, has promoted the concept of the "carbon footprint". By undertaking a carbon investigation of their supply chains, all businesses can minimize the carbon emitted at every stage of a product's life cycle, from source to shelf, consumption and disposal. The total amount of carbon emitted to arrive at a final product is that product's carbon footprint (Carbon Trust).

Figure 14. Contributions of agriculture and forestry to greenhouse gas emissions



Source: Adapted from IPCC, 2007b.

Application of this concept to the food system has led some to argue that food products imported from developing to developed countries, particularly horticultural products transported by air, should not be traded because of their high carbon footprints. However, the principal suppliers of these foods are small-scale farmers who are just emerging into commercial markets, whose livelihood systems are still precarious and whose household food security would be seriously jeopardized if new overseas market opportunities were suddenly denied them.

Moreover, as already described, the carbon footprint of food processing and transport is negligible compared with the emissions generated by production processes in the food system. Therefore, although there are opportunities for reducing the carbon footprint of food at all stages of the food chain, the focus of mitigation efforts in the food system should be on introducing agricultural production practices that reduce emissions or increase carbon sequestration.

REDUCING EMISSIONS

Good options exist for reducing the current level of agriculture-related emissions and, in the process, introducing more sustainable farming practices that strengthen ecosystem resilience and provide more security for agriculture-based livelihoods in the face of increased climatic variability. These are discussed in the following sections.

Reducing agricultural and forestry emissions of carbon dioxide

The primary source of carbon emissions in the food and agriculture sector is land conversion from forested area to cultivated or grazing land. Carbon emissions can be reduced through more efficient energy use by mechanized agriculture and agro-industries, and through adoption of alternatives to the common practice of burning crop residues after harvest. However, the amounts involved are minor compared with the potential contribution that reducing the rate of deforestation could make.

As already noted, intentional land conversion and deforestation, also referred to as anthropogenic land-use change, currently accounts for an important share of greenhouse gas emissions. Moreover, the reduction in global forested area caused by land clearing and unsustainable logging (in which cut trees are not replaced with new plantings) has reduced the capacity of the world's forests to store carbon. Evidence shows that Amazon deforestation, related to agricultural expansion for livestock grazing and the production of livestock feed and biofuel crops, already contributes substantially to global anthropogenic CO_2 emissions (Carvalho *et al.,* 2004). Continued intensification of the global livestock industry and growing demand for liquid biofuel crops will create additional pressure to clear tropical forests worldwide unless policies are put in place to manage the process sustainably.

UNFCCC and the Kyoto Protocol recognize the potential role of forests in providing a variety of adaptive ecosystem services in addition to mitigating climate change through carbon sequestration. These services include biodiversity preservation, watershed protection on mountain slopes, control of desertification, and maintenance of the environmental integrity of fragile coastal zones. However, current rates of forest degradation and deforestation are threatening the capacity of the world's forests to perform these multiple roles.

Cyclical loss and regrowth of trees and forests is a natural process. Forests are regularly ravaged by the spread of plant pests and fire. Natural fires maintain forest health by clearing away dense brush and dead wood and allowing new growth to emerge; they are also part of the life cycles of some species. The natural burning of trees and other organic matter releases CO_2 into the atmosphere, while the decay of dead plants produces methane. These emissions of greenhouse gases are normally compensated for by the process of photosynthesis in living plants, especially the new vegetation that springs up on cleared land and needs CO_2 in order to grow. In recent times, however, a still largely uncontrolled process of deforestation resulting from human activity has been altering this natural balance.

Changes in temperature ranges and precipitation, attributable to climate change, can harm forests further. Droughts and forest fires are expected to increase, with devastating effects on forests that are already stressed by human activity. There are indications that the Amazon is drying out, which could lead to dangerous fires and desertification. Invasive insect species may also damage forest health. Insects' role in boreal ecology is to decompose litter, supply food for birds and small animals and eliminate diseased trees, but insect attacks are likely to increase in frequency and intensity as established forests succumb to the physiological stress associated with warmer weather (Greenpeace Online). In Canada, for example, more than 12 million ha of forests have been lost in recent years, owing to mountain pine beetle attacks, which are more common when winters are mild.

Forests' capacity to play their natural role in maintaining climatic stability is closely linked to food systems' response to the challenge of climate change. To slow down and eventually reverse the still largely uncontrolled deforestation process, forest clearing, grazing in forested areas, cutting of trees for fuelwood and commercial logging must all become planned activities, based on trade-offs between benefits and costs at different spatial and temporal scales.

Action is needed on several fronts, especially through an integrated approach that simultaneously addresses the global demand for additional land to produce food and fuel, the dependence on forests as a source of livelihood for many rural people in developing countries, and the economic value of ecosystem services provided by forests. The actions required include creating economic alternatives to reduce the incentive for clearing forests or using forest resources unsustainably, promoting second-generation biofuels to avoid land clearing for biofuel crops, and enforcing more strictly the regulations that discourage potential investors from setting wildfires to clear land for commercial development.

Controlling frontier expansion in tropical rain forests can make an important contribution to climate change mitigation, but often the sole option for preserving forested area is through intensifying agricultural production on the better land. It has been demonstrated that when intensification involves increased fertilizer inputs, the related emission increases are far less than the avoided emissions of organic carbon from the forests that have been preserved (Vlek, Rodriguez-Kuhl and Sommer, 2004).

Use of carbon offset schemes to pay rural households for sustainable management of the forested areas that they rely on for fuel and other forest products can provide the incentive to stop them cutting wood to sell as timber, fuelwood or charcoal. To be effective, however, this approach needs to be accompanied by public or private sector investment in alternative sources of timber and cooking fuel to meet the growing demand.

Reducing agricultural emissions of methane and nitrous oxide

Digestive processes and wastes from ruminant livestock that eat a great deal of fibrous material are an important source of methane, especially in intensive production units, where large numbers of animals are concentrated in relatively small spaces. Worldwide, ruminant livestock are the largest source of methane from human-related activities (EPA Online). Through the process of enteric fermentation, which is unique to ruminant animals such as cattle, sheep and goats, unused carbon is released in the form of methane during the digestion of fibrous materials in the diet. Methane emissions from animal manure are also considerable, and increasing rapidly. These two sources account for 60 percent of agricultural emissions of methane and about 30 percent of total anthropogenic methane emissions. The other main source of agricultural methane is rice, accounting for almost 40 percent of agricultural methane emissions and about 20 percent of all human-caused methane emissions (GHG Online a).

Although nitrous oxide is a relatively less important greenhouse gas in terms of share, it is highly potent, and derives almost entirely from manure, cultivated soils that have been fertilized with organic matter or inorganic compounds containing nitrogen, and nitrogen-fixing legumes. The following sections discuss methods for minimizing emissions of methane and nitrous oxide from agricultural activities.

Reducing methane emissions from ruminant livestock: Methane emissions per animal and per unit of livestock product are high when the animals' diet is poor (EPA Online). Range-fed beef cows are the most important source of methane from enteric fermentation because they are very large animals, even compared with dairy cows; their diets, consisting mainly of forages of varying quality, are generally poorer than those in the dairy or feedlot sectors; the level of management is usually not as good; and the beef cow population is very large. Better grazing management and dietary supplementation have been identified as the most effective ways of reducing emissions from this sector because they improve animal nutrition and reproductive efficiency.

There are several technologies for reducing methane release from enteric fermentation. The basic principle is to increase the digestibility of feedstuffs, by either modifying feed or manipulating the digestive process. Most ruminants in developing countries, particularly in Africa and south Asia, have a very fibrous diet. Technically, these diets are relatively easy to improve through the use of feed additives or supplements. However, such techniques are often beyond the reach of smallholder livestock producers, who lack the capital, and sometimes the knowledge, to implement changes. Often, technical improvements may not be economical, such as where there is lack of demand or insufficient infrastructure. Even in Australia, for example, many opportunities to reduce emissions, such as through dietary fat supplementation or increased grain feeding, are not part of the low-cost range-fed dairy system, which focuses on per hectare rather than per cow production (Eckard, Dalley and Crawford, 2000)

Another approach is to increase the level of starch or rapidly fermentable carbohydrates in the diet, thereby reducing excess hydrogen and the subsequent formation of methane. These too are measures that extensive range-fed production systems may not be able to adopt without external support, but national or regional planning strategies in areas where such systems are important could promote change. More advanced technologies that are being studied but are not currently operational would be applicable to free-ranging ruminants.

Livestock fed on improved diets produce more milk and meat per animal. This increased production efficiency reduces the amount of methane emitted per unit of production and the size of the herd required to produce a given level of product. Because many developing countries are striving to increase production from ruminant animals (primarily milk and meat), improvements in production efficiency are urgently needed to meet goals while avoiding increase methane emissions.

In the United States, the Environmental Protection Agency (EPA) reports that more efficient livestock production has already led to increased milk production, and methane emissions have decreased over the last several decades (EPA Online). Technically speaking, the potential for efficiency gains – and therefore for methane reductions – is even larger for beef and other ruminant meat production, which is typically based on poorer management, including inferior diets. Better grazing management and dietary supplementation have been identified as effective ways of improving efficiency and reducing emissions from this sector.

In evaluating the emission reductions obtained from dietary modifications, it is important to consider that the feed and feed supplements used to enhance productivity and reduce methane emissions may have considerable embodied greenhouse gas emissions that have a negative affect on the balance. Increased reliance on mechanized production of feedgrains for both ruminants and non-ruminants has made the livestock food chain more fossil fuel-intensive.

Relying more on non-ruminant sources of animal protein (pigs, poultry, fish) in the diet can mitigate emissions from enteric fermentation and contribute to food security by improving the livelihoods of livestock-dependent households and adding diversity to the diet. Most of the increase in demand for animal protein to 2030 and beyond is projected to occur in emerging developing countries in Asia, where pig and poultry meat is preferred, so the relative share of beef in total animal protein consumption is likely to decline over time. If rising costs for water, feed and fuel trigger significant increases in the market price for ruminant livestock products, the result could be a shift in consumer behaviour among those who currently prefer beef..

Reducing methane emissions from rice: At between 50 and 100 million tonnes of methane a year, rice agriculture is a large source of atmospheric methane, possibly the greatest of the human-incurred methane sources. The warm, waterlogged soil of rice paddies provides ideal conditions for methanogenesis, and although some of the methane produced is usually oxidized by methanotrophs in the shallow overlying water, the vast majority is released into the atmosphere (GHG Online b).

As the world population increases, reducing rice agriculture remains largely untenable as a strategy for reducing methane emissions from paddy rice fields. However, substantial reductions are possible through a more integrated approach to rice paddy irrigation and varietal selection. Many rice varieties can be grown under much drier conditions than those traditionally employed, with large reductions in methane emission without any loss in yield. Intermittent and/or alternating dry-wet irrigation of rice fields can be employed with these varieties.

Applying the principles of conservation agriculture to crops such as irrigated rice would provide chances for reducing the water consumption of this cropping system and, by changing the soil environment from mostly anaerobic to aerobic, could also make it easier to fine-tune the irrigation pattern to reduce the emission of methane. There is also great potential for improved varieties of rice that can produce much larger crops per area of rice paddy, thereby allowing for reduced areas of rice paddies without reducing production. The addition of compounds that favour the activity of other microbial groups over that of the methanogens, such as ammonium sulphate, has proved successful under some conditions.

Reducing methane emissions from manure: Although manure is the residue from animals' digestive processes – so is a waste product – it contains important amounts of nitrogen, phosphates and potassium that provide valuable soil nutrients when applied to farmers' fields. Poor manure management can increase the loss of pollutants to the environment, however. Nitrogen in manures can be lost as nitrate, nitrous oxide (a greenhouse gas) or ammonia (a constituent of acid rain and a cause of terrestrial eutrophication). Phosphorus-rich manure particles can be washed into watercourses, and can raise soil phosphorus contents to levels where phosphorus leaching begins.

If manure is managed as a liquid substance, it decays and forms methane (University of Hertfordshire Online). In the wild, animal manure is spread over a wide area and decomposes aerobically in the oxygen in the natural environment. Intensive livestock rearing methods cause high concentrations of manure to build up in relatively small areas, however, leading to a predominance of anaerobic (oxygen-free) decomposition of the manure, which produces methane (GHG Online c).

There are options for managing manure in ways that do not contribute to greenhouse gas accumulation. Methane is not released when manure is managed as a solid substance through composting and drying, or is applied and worked into the fields without being left to stand. Moving away from intensive rearing methods to increased grazing time for animals, so greater dispersal of their manure, also increases aerobic rather than anaerobic decomposition and reduces the rate of methane production.

The temperature at which manure is stored can have a significant effect on methane production. In farming systems where manure is stored in stables, such as in pig farms where effluents are stored in a pit in the cellar of the stable, emissions can be higher than when manure is stored outside at lower ambient temperatures. Greenhouse gas production can also be reduced through deep cooling of manure. Cooling of pig slurry can reduce indoor methane and nitrous oxide emissions by 21 percent (Sommer, Peterson and Møller, 2004).

Trapping the methane released by livestock manure, for example in slurry tanks, has already proved very successful in reducing methane emissions to the atmosphere. The recovered methane, often called “biogas”, can be flared off as CO_2 or used as a fuel.

The capture and burning of methane released from animal wastes is an increasingly applied form of energy generation and forms the basis for several carbon reduction and trading projects. Biogas is typically made up of 65 percent methane and 35 percent CO_2, so the combustion of methane releases CO_2, but this is 23 times less noxious in terms of global warming impact than methane is. A further mitigation dividend is obtained when combustion provides an energy source to replace the use of fossil fuels.

There are various storage systems for exploiting this huge potential, including covered lagoons and other structures for liquid storage, such as pits and tanks. These are suitable for large- or small-scale systems and cover a wide range of technological options and degrees of sophistication. Covered lagoons and biogas systems produce a slurry that reduces methane emission when applied to rice fields, instead of untreated dung (Mendis and Openshaw. 2004).

The wider use of biogas systems (either for generating energy for on-farm use or for delivering electricity to the public net) depends on the relative prices of other energy sources. Until recently, biogas systems have not usually been competitive without subsidies, apart from in remote locations where electricity and other forms of energy are unavailable or unreliable. However, interest in this source of energy is growing.

It is assumed that manure emissions in cool climates could be reduced by 50 percent through adoption of an alternative management option to replace the storage of manure as liquid slurry in open pits. In warmer climates, where methane emissions from liquid slurry are estimated to be more than three times as high (IPCC, 2007b), a reduction potential of 75 percent is considered reasonable.

Reducing nitrous oxide emissions from agricultural soils: A major direct source of nitrous oxide from agricultural soils is the widespread increase in the use of synthetic nitrate-based fertilizers, driven by the need for greater crop yields and by more intensive farming practices. Where large applications of these fertilizers are combined with irrigation practices that saturate soils, the resulting lack of oxygen in the soil produces conditions that are favourable to anaerobic conversion of solid nitrates and nitrites into nitrogen-containing gases (denitrification) and release of large amounts of nitrous oxide into the atmosphere.

The widespread and often poorly controlled use of animal waste as fertilizer can also lead to substantial emissions of nitrous oxide from agricultural soils. The ammonia in urea-based fertilizers and manures vaporizes when exposed to the air. Ammonia, a compound containing nitrogen and hydrogen, can also be a source of nitrous oxide through volatilization following fertilizer application or during storage of manure.

Some additional nitrous oxide is thought to arise from agricultural soils through the planting of leguminous crops that fix nitrogen, but the importance of this source is not yet clear. Nitrogen leaching and runoff from agricultural soils is another source of nitrous oxide emissions. After fertilizer application or heavy rain, large amounts of nitrogen may leach from the soil into drainage ditches, streams, rivers and eventually estuaries. Part of the nitrous oxide produced in agricultural soils is emitted to the atmosphere as soon as drainage water is exposed to the air, and another part is deposited in aquatic and estuarine sediments and emitted from there after undergoing denitrification (GHG Online d).

Net nitrogen use in farming affects climate change, because it is linked to nitrous oxide emissions, and water pollution, because nitrates pollute soil, fresh and marine waters. Net nitrogen use can be measured relatively easily by recording the amounts of nitrogenous fertilizers and manures that are used on the farm, adding the nitrogen estimated to be fixed by legumes, and subtracting the nitrogen harvested in the crop and by-products. The net climate change impact is calculated by deducting the sequestration of greenhouse gases absorbed by the additional plant growth caused by fertilizer use from the temperature-forcing impacts of nitrogen fertilizers.

The best way to manage human interference in the nitrogen cycle is to maximize the efficiency of nitrogen uses (Smil, 1999). Better targeting of fertilizer applications, in both space and time, can significantly reduce releases of nitrous oxides from agricultural soils. Land management strategies that consider the optimum amounts of fertilizer necessary for maximum crop yield and minimum waste are crucial, both environmentally and economically. The exact form of nitrogen-based fertilizer and the best time of year to use it are other key factors on which to base fertilization campaigns.

Rapid incorporation and shallow injection of livestock wastes reduce nitrogen loss to the atmosphere by at least 50 percent, and deep injection into the soil essentially eliminates the loss (Rotz, 2004). Crop rotations that efficiently recycles these nutrients, and fertilizer applications near to when they are needed by crops reduce the potential for further loss. RICMS uses a variety of these methods to increase the efficiency of nitrogen fertilizer in rice production.

Options for reducing emissions from grazing systems are also important. Adding nitrification inhibitors to urea or ammonium fertilizer compounds before application can substantially reduce emissions of nitrous oxide (Monteny, Bannink and Chadwick, 2006). On pastures, this technology inhibits the production of nitrous oxide from animal urine (Di and Cameron, 2003). Balanced feeding is also important; for example, feed that is high in nitrogen will produce manure with high nitrogen content, which emits greater levels of nitrous oxide than manure with low nitrogen content does.

Land drainage is another option for reducing nitrous oxide emissions before nitrogen enters the next phase of the nitrogen cascade. The compacting of soil by traffic, tillage and grazing livestock can reduce its oxygen content and enhance conditions for denitrification. Reducing soil wetness through better drainage can increase oxygen content and may reduce nitrous oxide emission significantly, especially in more humid environments.

SEQUESTERING CARBON

Although it can take much longer for carbon to be released from the atmosphere than it takes for it to get there (Doney and Schimel, 2007), carbon capture and sequestration can slow global warming significantly, even if emissions continue to increase. What matters is the amount of carbon that is added to the atmosphere per year, compared with the carbon sequestered in addition to the historical average per year.

As Table 7 shows, the global terrestrial carbon sequestration potential is about 4.5 to 5 billion tonnes per year, compared with net releases into the atmosphere of about 3.5 billion tonnes per year for the period 1980 to 1989 (UNEP-GRID-Arendal). In response to this imbalance, land is being set aside for the creation of carbon sinks in new-growth forests, grasslands are being rehabilitated and conservation agriculture on cultivated soils is being promoted as important climate mitigation measures. Because the creation of sinks involves changes in land and forest management practices and difficult land-use policy decisions, the food and agriculture sector will be critical for the success or failure of many carbon sink initiatives.

TABLE 7
Global terrestrial carbon sequestration potential

Carbon sink	Potential (billion tonnes per year)
Arable lands	0.85–0.90
Biomass crops for biofuel	0.50–0.80
Grasslands and rangelands	1.70–1.70
Forests	1.00–2.00
Total	**4.05–5.40**

Source: adapted from Rice, 1999.

Carbon sequestration involves increasing the carbon storage in terrestrial systems, above or below ground. The main thrust of efforts to use agriculture to manage greenhouse gases has so far been to increase above-ground sequestration, primarily through planting trees, which allows large per-hectare amounts of carbon to be sequestered. New-growth forests are an especially important form of carbon sink, because of the amount of carbon dioxide that they absorb.

Recent studies have shown that well-managed grasslands and conservation agriculture can work as well or better as techniques for sequestering carbon (Mannetje, L.'t. 2006). If the carbon stock in soils has been depleted as a consequence of past land-use changes and agricultural activities, changes in soil management practices can trigger a process of carbon accumulation below ground, over time. Eventually, the system reaches a new carbon stock equilibrium or saturation point, and no new carbon is absorbed, but until then carbon sequestration is low-cost and can be readily implemented.

Practices that increase carbon sequestration have additional benefits, including increased root biomass, soil organic matter, water and nutrient retention capacity and, hence, land productivity. Investments in improved land management leading to increased soil fertility and carbon sequestration can often be justified by their contributions to agronomic productivity, national economic growth, food security and biodiversity conservation (FAO, 2004a).

This section explores four feasible options for carbon sequestration: reforestation and afforestation, rehabilitating degraded grasslands, rehabilitating cultivated soils, and promoting conservation agriculture. Enhancing carbon sequestration in degraded drylands and mountain slopes by any of these methods could have direct environmental, economic and social benefits for local people, with consequent improvement in their food security status.

Reforestation and afforestation

Reforestation involves planting new trees in existing forested areas where old treess have been cut or burned; afforestation involves planting stands of trees on land that is not currently classified as forest. Sustainable forest management requires that a new tree be planted for every tree cut down by logging, fuelwood gathering or land clearing activities. At the global level, however, meaningful carbon sequestration through reforestation and afforestation would require that more new trees be planted each year than were lost to deforestation in the previous year.

Farmers, commercial logging companies, industrial roundwood producers and fuelwood plantation managers all have the possibility to plant large numbers of new trees as part of their normal operations. Public sector programmes to replant forested areas that have been destroyed by wildfires or arson can also be managed so that they add to the global carbon sink reserve.

Areas that have been intentionally converted from forest to other land uses need to be transformed into stable agricultural areas as quickly as possible, so they are not left in the vulnerable transition period for too long. Cleared land is at high risk of erosion and loss of soil moisture, so fast-growing cover crops should be planted as soon as possible after clearing, even if they are subsequently replaced by something else. In addition to reducing the risk of erosion, these crops will absorb some CO_2 and can later be ploughed under to enhance the fertility and water-retention capacity of the soil.

Increasing the extent of protected areas and natural parks is another way of augmenting carbon stores. Preserving forests is therefore a vital part of any strategy to mitigate climate change. For example, Greenpeace estimates that the Canadian and Russian boreal forests alone hold 40 percent of the world's terrestrial carbon stocks. In addition, protected areas and natural parks such as mangrove swamps in southeast Asia or wildlife reserves in southern Africa can be managed by local people in ways that simultaneously improve their livelihoods, sequester carbon, preserve biodiversity and provide residues for second-generation biofuels.

Forest-dependent people and vulnerable people living on degraded land can provide forest-related environmental services with carbon sequestration potential, as long as appropriate compensation is paid. Such services include the incorporation of reforestation and afforestation in sustainable upper watershed management schemes, and the introduction of integrated agroforestry farming systems that include planting fast-maturing tree crops and woodlots to prevent soil erosion, restore the soil's water retention capacity and contribute to farm income, as well as sequestering carbon.

Rehabilitating degraded grasslands

Rain forests and grasslands (or rangelands as they are also called) are the world's last remaining land resources still to exist in more or less their natural state. Both are in danger of degradation and disappearance through inappropriate use, overexploitation and destruction, posing a major threat to the capacity of the earth's climate system to mitigate global warming (FAO, 2007e). Grasslands in semi-arid, increasingly overpopulated regions, such as in Africa, Central Asia, northern China and Mongolia, are in even greater danger than rain forests, because they are subject to regular droughts, intense cropping, overgrazing and fuelwood depletion, leading to degradation and desertification (Mannetje, 2002, cited in FAO, 2007e).

Grasslands cover about 25 percent of the world's surface and contribute to the livelihoods of more than 800 million people, including many poor smallholders and pastoralists. In this ecosystem, vegetation and large herbivorous mammals have co-evolved to keep the system in equilibrium. Scattered stands of trees form a natural part of the ecosystem, but there are no closed forests. Grasslands are particularly adapted for grazing livestock, and pastoral farming systems are important, especially in more arid parts. Mixed farming systems are also important. However, overgrazing, reduction of fallow, water scarcity and cutting of trees for fuel and timber are degrading the land, creating energy scarcities and increasing the prevalence of poverty and food insecurity for many rural people. With better management, these grasslands can produce feedstocks for manufacturing biofuel for local markets, give their inhabitants more secure and sustainable livelihoods that will be resilient in variable and uncertain weather conditions, and provide carbon sequestration services to the world.

Several aspects of dryland soils work in favour of carbon sequestration in arid regions. Dry soils are less likely to lose carbon than wet soils, as lack of water limits soil mineralization and therefore the flux of carbon into the atmosphere. As a result, carbon's residence time in dryland soils is long, sometimes even longer than it is in forest soils. Although carbon sequestration in these regions occurs at low rates, it may be cost-effective, particularly taking into account all the side-benefits resulting from soil improvement and restoration (FAO, 2004a).

Improved grassland management through the incorporation of trees, improved species, fertilization and other measures can reverse carbon losses, lead to net sequestration and yield additional benefits, particularly by preserving/restoring biodiversity. In 1991, up to 71 percent of the world's grasslands were reported to be degraded to some extent (Dregne, Kassa and Rzanov, 1991). Given the large extent of drylands, and the fact that degradation processes have caused carbon levels in dryland soils to drop well below the saturation point, drylands have a great potential for carbon sequestration.

Overgrazing is the greatest cause of degradation in grasslands, and the overriding human-influenced factor in determining their soil carbon levels. In many systems, improved grazing management practices, such as optimizing stock numbers and rotational grazing, will therefore result in substantial increases in carbon pools. Among the many other technical options are fire management, protection of land and set-asides, and enhancement of grassland production, such as through fertilization and the introduction of deep-rooted/legume species. Models can indicate the respective effects of these practices in a particular situation.

More severely degraded land requires landscape rehabilitation and erosion control. This is more difficult, particularly from an economic perspective, but Australian research has reported considerable success in rehabilitating landscape function by promoting the rebuilding of patches (Baker, Barnett and Howden, 2000). In many situations, improved pasture management and integrated agroforestry systems that combine crops, grazing lands and trees in ecologically sustainable ways are effective in conserving the environment and mitigating climate change, while providing more diversified and secure livelihoods for inhabitants.

The real potential for terrestrial soil carbon sequestration is uncertain, because data are lacking and there is insufficient understanding of the dynamics of soil organic carbon at all levels, including the molecular, the landscape, the regional and the global (Metting, Smith and Amthor, 1999). Lal estimates the ecotechnological scope for soil carbon sequestration in dryland ecosystems to be about 1 billion tonnes of carbon per year, but realization of this potential would require a "vigorous and a coordinated effort at a global scale towards desertification control, restoration of degraded ecosystems, conversion to appropriate land uses, and adoption of recommended management practices on cropland and grazing land" (Lal, 2004b).

Dryland conditions offer very few economic incentives to invest in land rehabilitation for agricultural production. Compensation for carbon sequestration may tip the balance in some situations, but significant local obstacles would need to be overcome before carbon credit schemes can be used to realize grasslands' potential for mitigating climate change and securing more adequate and sustainable livelihoods for pastoral peoples. These obstacles include the following:

- Pastoral areas usually have less infrastructure and much lower population density than other rural areas.
- Carbon credit schemes require communication among groups that are often distant from one another; cultural values will be both a constraint and an opportunity in pastoral lands.
- The payment required to motivate pastoralists to change their grazing practices may be higher than the market can bear. (Reid *et al.,* 2004 estimate that payments of US$10 per tonne of stored carbon would increase the income of extremely poor herders by only 15 percent; payments of US$65 would be required to lift them out of poverty.)
- The government institutions required to implement such schemes often have insufficient strength and ability (Reid *et al.,* 2004).

Rehabilitating cultivated soils

The relatively low CO_2 emissions from arable land leave little scope for mitigation, but there is great potential for net sequestration of carbon in cultivated soils. According to Lal, the carbon sink capacity of the world's agricultural and degraded soils is 50 to 66 percent of the total carbon loss since 1850 (Lal, 2004b).

Under conventional cultivation practices, the conversion of natural systems to cultivated agriculture results in soil organic carbon losses of about 20 to 50 percent compared with pre-cultivation stocks in the surface metre (Paustian *et al.,* 1997). Non-conventional cultivation practices allow soil quality to improve and soil organic carbon levels to increase. Such practices can be grouped into three classes: agricultural intensification, conservation agriculture and erosion reduction. Sustainable intensification practices include improved cultivars, well-managed irrigation, organic and inorganic fertilization, management of soil acidity, green manure and cover crops in rotations, integrated pest management, double cropping and crop rotation. Increased crop yields result in more carbon accumulation in crop biomass, or alteration of the harvest index. The higher residue inputs associated with higher yields favour enhanced soil carbon storage (Paustian *et al.,* 1997). IPCC provides an indication of the "carbon gain rate" that can be obtained from some of these practices (IPCC, 2007b). Table 8 suggests which common conventional soil management practice can be replaced by which improved practice to restore soil quality and sequester carbon.

These improved agricultural practices were developed to achieve the larger objectives of Agenda 21 Chapter 14 – Sustainable agriculture and rural development – adopted by UNCED in Rio de Janeiro in 1992. Efforts to promote them have demonstrated that farmers will decide whether or not to adopt an improved practice depending on the expected net returns, in the context of existing agricultural and environmental policies. Although farmers' adoption of the practices brings such on-farm benefits as increased crop yields, these benefits must result in an overall net improvement to farmers' livelihoods, otherwise the improved practices will not be widely accepted.

Promoting conservation agriculture

Conventional tillage involves the use of mechanical implements to break up the soil. The simplest such implement is the hand hoe. Mechanized soil tillage allows higher working depths and speeds and involves the use of such implements as tractor-drawn ploughs, disk harrows and rotary cultivators. This initially increases fertility because it mineralizes soil nutrients and makes it easier for plants to absorb them through their roots. In the long term, however, repeated ploughing and mechanical cultivation breaks down the soil structure and leads to reduced soil organic matter and loss of soil nutrients. This structural degradation of soils results in compaction and the formation of crusts, leading to soil erosion. This process is dramatic under tropical climatic situations, but can also be noticed all over the world. The heavy machinery used for tillage in intensive crop agriculture has particularly detrimental effects on soil structure.

The logical approach to this is to reduce tillage. Movements promoting conservation tillage, especially zero-tillage, first emerged in southern Brazil, North America, New Zealand and Australia. Over the last two decades, the technologies have been improved and adapted for nearly all farm sizes, soils, crop types and climatic zones. Experience is still being gained with this new approach to agriculture, which FAO has supported for many years.

Conservation agriculture is based on enhancing natural biological processes above and below ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at optimum levels and in ways and quantities that do not interfere with or disrupt biological processes.

TABLE 8

Agricultural practices for enhancing productivity and increasing the amount of carbon in soils

Conventional practice	Recommended practice
Plough tilling	Conservation tilling or zero-tillage
Residue removal or burning	Residue return as mulch
Summer fallow	Growing cover crops
Low off-farm inputs	Judicious use of fertilizers and integrated nutrient management
Regular fertilizer use	Site-specific soil management
No water control	Water management/conservation, irrigation, water table management
Fence-to-fence utilization	Conversion of marginal lands to nature conservation
Monoculture	Improved farming systems with several crop rotations
Land use along poverty lines and political boundaries	Integrated watershed management
Draining wetlands	Restoring wetlands

Source: FAO. 2004a.

Intensive cultivation with tractors and ploughs is a major cause of soil erosion and land degradation in many developing countries, especially where the topsoil is thin. As well as reducing tillage, the farmers who adopt conservation agriculture also keep a protective soil cover of leaves, stems and stalks from the previous crop, which shields the soil surface from heat, wind and rain, keeps soils cooler and reduces moisture losses by evaporation. Less tillage also means lower fuel and labour costs, and farmers need to spend less on heavy machinery. In zero-tillage agriculture, the soil is never turned over, and soil quality is maintained entirely by the continuous presence of a cover crop. Crop rotation over several seasons is essential to minimize the outbreak of pests and diseases (EuropaWorld, 2001).

Conservation agriculture increases soil organic matter, and this in turn increases the amount of carbon stored in the soil. Under conventional tillage, this carbon is metabolized by soil microorganisms into CO_2. Experiences with conservation agriculture so far show that the increase in soil organic matter continues for about 30 years, before levelling out to a new equilibrium, which generally corresponds to the organic matter content of the virgin soil, before it was taken under cultivation. In some cases however, the organic matter content can exceed this original level, where other land amelioration techniques have improved the production potential of the land compared with the virgin soil.

The global application of conservation agriculture could result in a total sequestration of up to 3 billion tonnes of carbon per year, for about 30 years; this is nearly the equivalent of the atmospheric net increase in CO_2 of anthropogenic origin. Soil carbon sequestration can be increased further when cover crops are used in combination with conservation tillage, but because many of these cover crops are nitrogen fixers, the additional nitrous oxide that they release is obviously detrimental.

Overall, FAO projections suggest that the global area of rainfed land under zero-tillage/conservation agriculture could increase considerably. If these projections materialize – although it is by no means certain that they will – the results would be such benefits as reduced soil erosion, smaller losses of plant nutrients, higher rainfall infiltration and better soil moisture-building capacity, making a significant contribution to mitigating the impacts of climate change (FAO, 2003b: 344). Similar conclusions have been reached by other scientific research teams engaged in projecting the impact of climate change on agriculture, notably those of the International Food Policy Research Institute (IFPRI) (Rosegrant, Agcaoli-Sombilla and Perez, 1995; Scherer and Yadav, 1996).

4. THE WAY FORWARD

THE INSTITUTIONAL SETTING FOR ADDRESSING FOOD SECURITY AND CLIMATE CHANGE LINKAGES

The Intergovernmental Panel on Climate Change

Recognizing climate change as a potential global problem, WMO and UNEP established IPCC in 1988; the first IPCC Assessment Report was completed in 1990. Since then, IPCC has issued three more reports, each deepening the scientific understanding of climate change processes and their implications for the earth system. The fourth IPCC Assessment Report, released in September 2007, generated much public interest and raised climate change issues to the top of the international political agenda.

The United Nations Framework Convention on Climate Change, its Conference of the Parties, the Kyoto Protocol and the Nairobi Worlk Programme

Largely based on the findings contained in the first IPCC report, UNFCCC was negotiated and adopted in New York in time for signature at UNCED in Rio de Janeiro in June 1992. UNFCCC entered into force in 1994, and provides the overall policy framework for addressing climate change issues. All the governments that have ratified it belong to the Conference of the Parties (COP), which meets annually to review global climate policy and oversee implementation of agreed mitigation and adaptation measures.

In 1997 the Kyoto Protocol to UNFCCC was adopted. This is an international and legally binding agreement to reduce greenhouse gases emissions worldwide, which entered into force in 2005 on ratification by the required number of parties to UNFCCC. The most important aspect of the Kyoto Protocol is its legally binding commitments for 39 developed countries to reduce their greenhouse gas (GHG) emissions by an average of 5.2 percent relative to 1990 levels. These emission reductions must be achieved by 2008–2012, the so-called "first commitment period".

In 2001, the seventh COP acknowledged that least-developed countries (LDCs) do not have the means to deal with adaptation to climate change. It therefore established a work programme for supporting LDCs in the preparation and implementation of National Adaptation Programmes of Action (NAPAs).

The steps that a country typically takes to prepare a NAPA include (UNFCCC Online b):

- synthesis of available information;
- participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase as a result of climate change;
- identification of key adaptation measures and criteria for prioritizing activities;
- short profiles of projects and/or activities to address urgent and immediate adaptation needs in the country.

The NAPA takes into account existing coping strategies at the grassroots level, and builds on these to identify priority activities that would benefit from further support, rather than focusing on scenario-based modelling to assess future vulnerability, and long-term policy at the national level. The NAPA process gives prominence to community-level inputs as an important source of information, recognizing that communities are the main stakeholders.

In 2006, COP adopted the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change (NWP) as a basis for consolidating and intensifying adaptation efforts. NWP was developed to help countries improve their understanding of climate change impacts and their risk exposure, and to increase their ability to make informed decisions on how to adapt successfully. It is an international framework implemented by parties to

UNFCCC, intergovernmental organizations, NGOs, the private sector, communities and other stakeholders (UNFCCC Online a).

At UNFCCC/COP's annual meeting in Bali in December 2007, an opening round of discussions was held on provisions to be included when the convention and Kyoto Protocol come up for renewal in 2012. This served as an occasion to begin defining a global strategic response to both the immediate and the more distant impacts of climate change on human well-being – a process that will continue for the next five years.

Agenda 21 and sustainable agriculture and rural development

The concept of sustainable development was introduced in the 1987 report of the World Commission on Environment and Development (the Brundtland Report) as a means of shifting attention away from narrow sectoral interests towards an approach that embraces environmental, social and economic goals.

This report provided the scientific underpinnings for UNCED. Popularly known as the Earth Summit, UNCED represented a turning point in the way in which environment and development are viewed. At the Earth Summit, world leaders adopted two formal treaties with binding provisions – UNFCCC and the United Nations Convention on Biological Diversity (CBD) – and three non-binding statements on the relationship between sustainable environmental practices and the pursuit of social and socio-economic development: the Rio Declaration, the Statement on Forest Principles, and Agenda 21 (CIESIN, 1996).

Agenda 21 was intended as a blueprint for attaining sustainable development in the twenty-first century. It provides a comprehensive action programme for attaining sustainable development and addressing both environmental and developmental issues in an integrated manner at the global, national and local levels. Actions to address climate change are dealt with in Chapter 9, Protecting the atmosphere, while Chapter 14 defines priority action areas for achieving sustainable agriculture and rural development (SARD).

Agenda 21, Chapter 9 recognizes that certain practices related to terrestrial and marine resources and land use can decrease greenhouse gas sinks and increase atmospheric emissions, and establishes, among others, the following objective:

"(a) To promote terrestrial and marine resource utilization and appropriate land-use practices that contribute to:
i. the reduction of atmospheric pollution and/or the limitation of anthropogenic emissions of greenhouse gases;
ii .the conservation, sustainable management and enhancement, where appropriate, of all sinks for greenhouse gases;
iii. the conservation and sustainable use of natural and environmental resources." (Agenda 21, Chapter 9)

Agenda 21, Chapter 14 articulates the concept of SARD. It contains 12 action areas for achieving SARD (Agenda 21, Chapter 14), many of which are also priority action areas for adapting to climate change in the food and agriculture sector. Since 1992, a body of knowledge about best practices and technologies has been developed for the purposes of implementing Agenda 21; these SARD best practices provide a menu of adaptation and mitigation options that could be adopted immediately, providing the requisite investment resources are forthcoming. Practices that have been advocated in the past as good practices for SARD should not be excluded from the list of recommended options for responding to climate change. The best options often involve innovative modifications of known good practices, rather than completely new solutions.

Integrating adaptation and mitigation

IPCC recognizes the merit of an integrated strategic response to climate change (IPCC, 2007d), but because resources for mitigation and those for adaptation are managed through different funding mechanisms, they are still treated separately on the international climate policy agenda of UNFCC/COP and its subsidiary bodies. Nevertheless, although adaptation and mitigation are conceptually distinct, they are interdependent in practice, and both are equally urgent from a food security perspective. Managing the increasing risk as storms, floods and droughts become more frequent and intense is an immediate necessity. It is equally imperative to begin adapting immediately to foreseeable shifts in agroclimatic zones, water availability and related changes in species composition and disease vectors, as it will take time for appropriate adaptive practices to take effect.

As there is still considerable uncertainty about how these more gradual changes are going to play out, there is also a pressing need to improve the information base for selecting appropriate adaptation options. Rather than lack of appropriate technologies, it is institutional weakness that has often been the main obstacle to adopting sustainable agricultural and rural development practices. Adaptation of institutions, including customs and behaviours as well as laws, regulations and formally constituted structures, may therefore be the priority in many situations.

Mitigation is also a major concern because, if global warming is not brought under control, there could be large-scale disruptions of food systems in the future that the world is unable to manage. In addition, the agriculture sector's important contribution to emissions, and its equally important potential contribution to emission reductions and carbon sequestration, mean that mitigation merits greater attention than it has hitherto received. In general, mitigation in the food and agriculture sector will be most feasible when it is linked to better-adapted agricultural practices, and this should be reflected in national strategies and programmes with the flexibility to implement an integrated approach.

ACCESS TO FUNDS

The UNFCCC Climate Change Funds and the Global Environment Facility

Several funds within the United Nations system finance activities aimed at reducing greenhouse gas emissions and increasing resilience to the negative impacts of climate change. The Global Environment Facility (GEF) was established in 1991 as an independent financial organization providing grants to developing countries for projects that benefit the global environment and promote sustainable livelihoods in local communities.

In its role as a financing mechanism of UNFCCC, GEF supports mitigation and adaptation measures that generate global benefits through the GEF Trust Fund. GEF projects in climate change help developing countries and economies in transition to contribute to the overall objective of UNFCCC by reducing or avoiding greenhouse gas emissions in the areas of renewable energy, energy efficiency and sustainable transport, and by supporting interventions that increase resilience to the adverse impacts of climate change in vulnerable countries, sectors and communities (GEF Online). The GEF Secretariat administers two funds under UNFCCC that focus on development – the Special Climate Change Fund (SCCF) and the Least Development Countries' Fund (LDCF) –and will administer the start-up of the Adaptation Fund which has only just become operational (Box 5).

Box 5: UNFCCC funding for climate change adaptation and mitigation

SCCF finances adaptation activities, especially projects on water resources management, land management, agriculture, health, infrastructure development, fragile ecosystems such as mountain ecosystems, and coastal area integrated management. The current total for the fund is US$62 million.

LDCF is dedicated to LDCs. It finances the same activities as SFCC. LDCs have access to expedition procedures for the approval of funding to support implementation of projects in the context of NAPAs. The current total for the fund is US$116 million.

The Adaptation Fund is financed through a 2 percent share of the profits from CDM and finances adaptation projects and programmes in developing countries that are signatories of the Kyoto Protocol. The fund has only just started operations, but could become much larger than SCCF or LDCF.

Source: GEF, 2007.

The Clean Development Mechanism

CDM allows developed nations to achieve part of their emissions reduction obligations under the Kyoto Protocol through projects in developing countries that offset greenhouse gas emissions. Greenhouse gas offsets may involve anything from low-carbon energy production to energy efficiency measures, the destruction of such greenhouse gases as methane and nitrous oxide, tree planting or soil carbon enhancement activities. Rules and conditions for CDM projects are shown in Annex IV.

The greenhouse gas benefits of each CDM project will be measured according to internationally agreed methods and will be quantified in standard units – CERs. These are expressed in tons of CO_2 emission avoided. Such carbon credits can be bought and sold in a new global carbon market and are already becoming a commodity (CDM Capacity Online).

Under CDM, although it is recognized that forms of land use other than forestry are integral to the carbon cycle, only afforestation and reforestation activities are eligible for credits. These activities may be large- or small-scale, involve single or multiple species, and be implemented through either pure forestry or on-farm agroforestry systems.

As the global carbon market evolves, it is likely to follow the path of much of foreign direct investment over the past decades, with the bulk going to a dozen or so larger developing countries with the infrastructure and institutions to handle large projects easily. In fact, projects approved thus far under the CDM have been mainly for low-carbon energy production in a few rapidly industrrializing developing countries.

Other funding sources

For the vast majority of the poorer developing countries, the private sector is unlikely to pay much attention unless steps are taken to attract CDM projects. This could be done by using:

- portfolio investors, such as the Prototype Carbon Fund of the World Bank and other large financial institutions, which may wish to spread their projects around the developing world, especially in poorer developing countries where the private sector would not invest (CDM Capacity Online);
- international development assistance funds to help poorer developing countries to build national capacity to develop and promote CDM projects (CDM Capacity Online);
- the growing voluntary carbon market, in which businesses and consumers purchase greenhouse gas reductions instead of reducing their own emissions (Gillenwater *et al.,* 2007).

In addition, the development community has recently begun to consider climate change, and an increasing share of aid resources is likely to be allocated to adaptation measures that are consistent with broader development objectives.

FAO's ROLE

FAO possesses technical expertise relevant to climate change adaptation in a variety of ecosystems, including agro-ecosystems (crops, livestock, grasslands), forests and woodlands, inland waters, and coastal and marine ecosystems. It works to build national, local and community-level capacities to raise awareness of and prepare for climate change impacts, assists member countries in identifying potential adaptation options and helps local people understand which are the most applicable to their particular circumstances.

Since 2002, FAO has been promoting National and Regional Programmes for Food Security (NPFS and RPFS) as instruments that help countries enhance productivity and diversify the livelihoods of rural people on a scale sufficient to achieve the 2015 targets set by WFS and the Millennium Development Goals (MDGs). In 2007, recognizing that climate change is of critical importance for food security, FAO introduced guidelines for incorporating actions to mitigate and adapt to climate change in NPFS. In countries with both an NPFS and a NAPA, FAO will facilitate the inclusion of appropriate actions from the NAPA in the NPFS. Where there is no NAPA, FAO will provide necessary support for incorporating priority adaptation measures in the NPFS. FAO will also assist countries in integrating forest-related climate change mitigation and adaptation measures into their NAPAs, National Forest Programmes (NFPs) and other forest policy and planning processes.

An important focus of FAO's work is on achieving the last of the five expected outcomes of NWP: "enhanced integration of actions to adapt to climate change with those to achieve sustainable development". Rather than enforcing a pre-selected mitigation practice or adaptation option on any affected community or population group, the ultimate goal is to inform and promote local dialogue about the likely impacts of climate change and the options for reducing vulnerability, and to provide local communities with site-specific solutions.

The final word on the relationship between climate change and food security will therefore be written, not by FAO experts, but rather by the people whose lives are most immediately affected and whose choices will determine whether their future will be more or less food-secure.

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ANNEX I

ESSENTIAL CLIMATE VARIABLES FOR THE GLOBAL CLIMATE OBSERVING SYSTEM, THE GLOBAL OCEAN OBSERVING SYSTEM AND THE GLOBAL TERRESTRIAL OBSERVING SYSTEM

Essential climate variables (ECVs) are required to support the work of UNFCCC and IPCC. All ECVs are technically and economically feasible for systematic observation. They require international exchange for both current and historical observations. Additional variables for research purposes are not included in the following table. The ordering in the table is for convenience and is not an indicator of relative priority.

Atmospheric (over land, sea and ice)	Oceanic	Terrestrial
Surface: Air temperature Precipitation Air pressure Surface radiation budget Wind speed and direction Water vapour **Upper-air:** Earth radiation budget, including solar irradiance Upper-air temperature including MSU radiances Wind speed and direction Water vapour Cloud properties **Composition:** Carbon dioxide Methane Ozone Other long-lived greenhouse gases, including: ▪ nitrous oxide ▪ chlorofluorocarbons ▪ hydrochlorofluorocarbons ▪ hydrofluorocarbons ▪ sulphur hexafluoride ▪ perfluorocarbons Aerosol properties	**Surface:** Sea-surface temperature Sea-surface salinity Sea level Sea state Sea ice Current Ocean colour (for biological activity) Carbon dioxide partial pressure **Sub-surface:** Temperature Salinity Current Nutrients Carbon Ocean tracers Phytoplankton	**Surface:** River discharge Water use Groundwater Lake levels Snow cover Glaciers and ice caps Permafrost and seasonally frozen ground Albedo, i.e., diffuse reflectivity Soil moisture (recognized as an emerging ECV) Land cover, including vegetation type Fraction of absorbed photosynthetically active radiation Leaf area index Biomass Fire disturbance

Notes: Measurement units for terrestrial variables are:

- runoff, m^3/s^{-1}
- groundwater extraction rates, m^3/yr^{-1}, and location
- snow cover extent, km^2, and duration, snow depth, cm
- glacier/ice cap inventory and mass balance, kg m^{-2}/yr^{-1}
- glacier length, m
- ice sheet mass balance, kg m^{-2}/yr^{-1}, and extent, km^2
- permafrost extent, km^2, temperature profiles and active layer thickness
- above-ground biomass, t/ha
- burned area, ha
- date and location of active fire
- burn efficiency, %vegetation burned/unit area.

Source: GCOS Online b.

ANNEX II

INTERNATIONALLY AGREED CLIMATE AND CLIMATE CHANGE TERMINOLOGY

Carbon cycle: The exchange of carbon, in various forms, among the atmosphere, ocean, terrestrial biosphere and geological deposits (IPCC, 1995).

Climate: The synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probabilities of extreme values, etc.) for the meteorological elements in that area (WMO, 1992, updated on 12 June 2006).

Climate is usually defined as the "average weather", or more rigorously as the statistical description of the weather in terms of the mean and variability of relevant quantities over periods of several decades (typically three decades, as defined by WMO). These quantities are most often surface variables, such as temperature, precipitation and wind, but in a wider sense the "climate" is the description of the state of the climate system (IPCC, 1995).

Climate variability: (1) In the most general sense, this term denotes the inherent characteristic of climate that manifests itself as changes of climate over time. The degree of climate variability can be described by the differences between long-term statistics of meteorological elements calculated for different periods. (In this sense, the measure of climate variability is the same as the measure of climate change.)

(2) The term is often used to denote deviations of climate statistics over a given period (such as during a specific month, season or year) from the long-term climate statistics relating to the corresponding calendar period. (In this sense, climate variability is measured by those deviations, which are usually termed anomalies.) (WMO, 1992, updated on 12 June 2005)

Climate system: A system consisting of the atmosphere, the hydrosphere (comprising the liquid water distributed on and beneath the earth's surface, and the cryosphere, i.e., the snow and ice on and beneath the surface), the surface lithosphere (comprising the rock, soil and sediment of the earth's surface), and the biosphere (comprising earth's plant and animal life, and humanity), which, under the effects of the solar radiation received by the earth, determines the climate of the earth. Although climate essentially relates to the varying states of the atmosphere only, the other parts of the climate system also have significant roles in forming climate, through their interactions with the atmosphere (WMO, 1992, last updated on 10 June 2005).

Climate classification: The division of the earth's climates into a worldwide system of contiguous regions, each defined by the relative homogeneity of its climatic elements. Examples are Köppen's and Thornthwaite's climate classifications (WMO, 1992, updated on 10 June 2006).

Climate change (WMO usage): (1) In the most general sense, this term encompasses all forms of climatic inconstancy (i.e., any differences from long-term statistics of the meteorological elements calculated for different periods but relating to the same area), regardless of their statistical nature or physical causes. Climate changes may result from such factors as changes in solar emission, long-term changes in the earth's orbital elements (eccentricity, obliquity of the ecliptic, precession of the equinoxes), natural internal processes of the climate system, or anthropogenic forcing (e.g., increasing atmospheric concentrations of CO_2 and other greenhouse gases).

(2) The term is often used in a more restricted sense to denote a significant change (i.e., a change with important economic, environmental and social effects) in the mean values of a

meteorological element (particularly temperature or amount of precipitation) in the course of a certain period, where the means are taken over periods of a decade or longer (WMO, 1992, updated on 10 June 2005).

Climate change (UNFCCC usage): A change of climate that is attributed, directly or indirectly, to human activity, alters the composition of the global atmosphere and is in addition to the natural climate variability observed over comparable periods (IPCC, 1995).

Climate change (IPCC usage): Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction among its components, or because of changes in external forcing, either for natural reasons or because of human activities. It is generally not possible to make clear attributions between these causes. Projections of future climate change reported by IPCC generally consider the influence on climate of only anthropogenic increases in greenhouse gases and other human-related factors (IPCC, 1995).

ANNEX III

GLOBAL WARMING AND CLIMATE CHANGE

Climate change, global environmental change and global change

The terms “climate change”, “global environmental change” and “global change” are often used interchangeably to refer to essentially the same phenomenon: the rapid changes in earth system dynamics that have been occurring at an increasing rate over the past two or more centuries. Whether referring to the climate system, the natural environment or the earth system, the five components remain the same: atmosphere, biosphere, cryosphere, hydrosphere and lithosphere. However, the perspectives and concerns are different.

The Earth System Science Partnership (ESSP) defines the earth system as follows:

“The Earth System is the unified set of physical, chemical, biological and social components, processes and interactions that together determine the state and dynamics of Planet Earth, including its biodata and its human occupants.” (ESSP Online)

As well as average weather, many other features of the earth’s environment have been changing rapidly during the past few centuries, owing in large part to technological advance and rapid population growth. Examples include deforestation and loss of soil quality; erosion; desertification; urbanization and industrialization; pollution/contamination of air, water and soil; unsustainable drawing of underground water reserves; gradual depletion of fossil fuel reserves; and overfishing and loss of marine fish stocks.

On a global scale, the ability to measure and monitor pertinent variables and predict their future trajectories has improved dramatically in recent years. Nevertheless, considerable uncertainty remains about how the complex interactions involved will unfold at the local scale. Although it is not yet possible to foresee precisely what the specific impacts of these changes on food security will be, it can be stated with confidence that the world is heading into a more uncertain and potentially precarious future – one in which the old rules about how nature behaves may or may not hold for coming generations, and where sudden shocks may profoundly alter the natural environment that humans inhabit.

The excerpt from the 2001 Amsterdam Declaration on Global Change cited in the box sets out very clearly the seriousness with which environmental scientists regard current trends for the earth system as a whole. Although this paper is concerned primarily with the climate aspects of global change, with a particular focus on interactions between the climate system and food systems and their potential consequences for food security, the implications of other uncertainties about the future of the earth system as a whole cannot be ignored.

Global warming

Until the industrial revolution, all climate change occurred because of natural forces acting on the climate system, and these forces are still at work today. On an astronomical time scale, the earth’s climate system alternates between cold conditions that support large-scale continental glaciations and warm conditions that make the planet extensively tropical and lacking in permanent ice caps, even at the poles. The time required for each cycle is roughly 140 million years. Evidence suggests that this behaviour is due to cyclical changes in the position of the earth’s orbit around the sun and the angle of its rotational axis, usually referred to together as “astronomical forcing of climate” (Shaviv and Veizer, 2003). Other natural forces that are thought to contribute to changes in the climate system on a geological time scale include sunspot activity, meteorite bombardment, erosion, earthquakes, volcanic activity, mountain building, movement of sea beds, and ocean trench formation. Variations in the concentration of greenhouse gases due to natural geological processes have created alternating periods of glacier advance (ice ages) and glacier retreat (interglacials) within the longer astronomical cycles. On the scale of decades, many climate fluctuations, the best known being the El Niño southern oscillation, owe their existence at least in part to periodic changes in the patterns by which the oceans store and circulate hot and cold water.

Excerpt from the Amsterdam Declaration on Global Change

Research carried out over the past decade under the auspices of the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), WCRP and Divertitas has shown that:

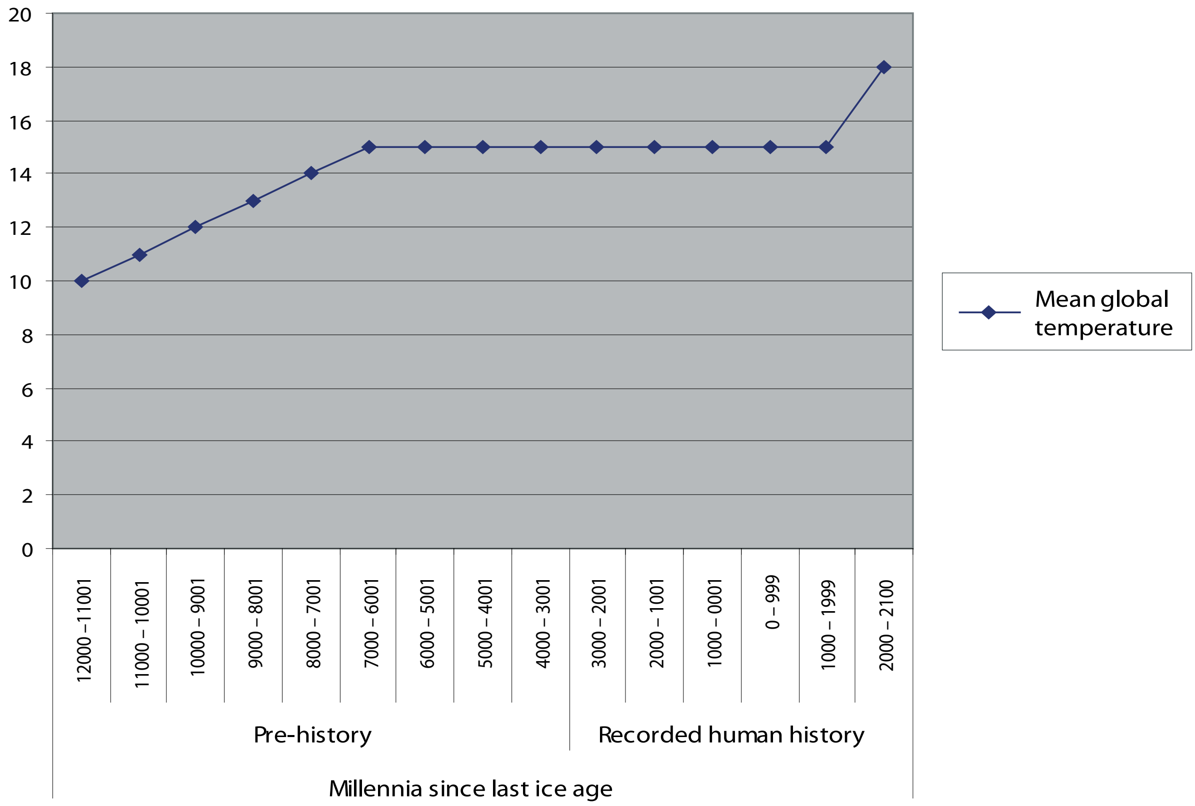
- "The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components. The interactions and feedbacks between the component parts are complex and exhibit multiscale temporal and spatial variability. The understanding of the natural dynamics of the Earth System has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.
- "Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change. Anthropogenic changes to Earth's land surface, oceans, coasts and atmosphere and to biological diversity, the water cycle and biogeochemical cycles are clearly identifiable beyond natural variability. They are equal to some of the great forces of nature in their extent and impact. Many are accelerating. Global change is real and is happening *now*.
- "Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth System in complex ways. These effects interact with each other and with local- and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict. Surprises abound.
- "Earth System dynamics are characterized by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants. The Earth System has operated in different states over the last half million years, with abrupt transitions (a decade or less) sometimes occurring between them. Human activities have the potential to switch the Earth System to alternative modes of operation that may prove irreversible and less hospitable to humans and other life. The probability of a human-driven abrupt change in Earth's environment has yet to be quantified but is not negligible.
- "In terms of some key environmental parameters, the Earth System has moved well outside the range of the natural variability exhibited over the last half million years at least. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented. The Earth is currently operating in a no-analogue state."

Source: Open Science Conference, 2001.

Recently, concern has grown that human activity may be causing global-scale changes in climate, with accompanying shifts in regional climate regimes all over the world. This is known as "anthropogenic forcing of climate". By increasing the amount of greenhouse gases in the atmosphere through the burning of fossil fuels (coal, oil, gas) and deforestation, humans have enhanced the earth's natural greenhouse effect. This means that more of the sun's radiation is now trapped in the earth's atmosphere, where the additional heat causes mean air and sea surface temperatures to rise all over the globe. This phenomenon is called global warming.

As shown in the following figure, during the last ice age, which ended only 14 000 years ago, global average surface temperature was 5 ^oC lower than it is today. At that time, less energy was being received from the sun as a consequence of the position of the earth's orbit, CO_2 levels in the atmosphere were lower, and heat redistribution by ocean circulation was weaker. Over a period of about 5 000 years, the global surface temperature gradually rose to an average of about 15 ^oC, where it remained until about 100 years ago. Then, as a result of human activity, what UNFCCC calls a "thickening" of the blanket of greenhouse gases occurred and the earth's average surface temperature started to increase rapidly. Today it has risen to over 15.5 ^oC, with most of the increase occurring since the 1980s; it is projected to rise by a further 2 to 3 ^oC before the end of the century. This means that, over a period of only 100 years, the earth will have experienced an increase in global mean temperature comparable to the one that took 2 500 years to occur ten millennia ago. Moreover, the increase that is now occurring is pushing global mean temperatures towards what may be an upper limit for human survival.

Changes in mean global temperature since the end of the last ice age, by millennium



Source: FAO/NRCB.

Life forms have flourished on earth at even higher temperatures than those currently projected to be reached as a result of human activity in the current epoch. Nevertheless, according to one report, "the earth is now within +/- 1 °C of its maximum temperature in the past million years" (Hansen *et al.,* 2006), and it is clear that the recent rapid increase in global temperatures has already begun to alter the complex web of systems that allow life to thrive on earth. These global changes threaten the balance of climatic conditions under which life evolved and is sustained. The current speed of change also threatens social and economic systems, including agriculture, food and water supply, coastal infrastructure, climate-dependent livelihood systems, and vulnerability to pests and diseases (UNFCCC, 2006).

The carbon and nitrogen cycles

Seven biogeochemical cycles are important for earth system dynamics: the carbon cycle, the hydrogen cycle, the nitrogen cycle, the oxygen cycle, the phosphorous cycle, the sulphur cycle and the water cycle. All are relevant, but it is primarily changes in the carbon cycle and, to a lesser extent, the nitrogen cycle that are driving the climate change processes observed today. The global warming potential of greenhouse gases containing these two elements is estimated to be: 72 percent CO_2; 18 percent carbon-containing methane; 9 percent nitrous oxide; and 1 percent other carbon-containing gases.

Latest IPCC estimates show that, while the agriculture sector contributes less than 10 percent of total CO_2 emissions and offsets approximately the same amount, it accounts for more than half of total methane emissions and nearly 60 percent of nitrous oxide emissions. The following brief explanations of how the carbon and nitrogen cycles work, and the impacts of human action on them, provide background for understanding agriculture's potential contribution to carbon sequestration and emissions reduction (IPCC, 2007b).

Carbon stocks in the earth system, excluding carbonate rock and kerogen in the ocean depths

Location of carbon stocks	Gt of carbon (highest estimate)	
	UNEP-GRID	Lal
Atmosphere	750	760
Geologic deposits (coal, oil and gas)	3 300	5 000
Soil organic carbon to 1 m depth	1 600	1 550
Soil inorganic carbon to 1 m depth		750
Terrestrial vegetation/biota	600	560
Total	**6 250**	**8 610**

Sources: UNEP-GRID Arendal Online; Lal, 2004a.

The carbon cycle: Carbon in its pure form is a solid, but numerous chemical compounds that contain carbon are also found in liquid and gaseous states, including the greenhouse gases CO_2 and methane (CH_4). Carbon in one form or another is present in all organic compounds. For example, organic plant material, which is essential to the human food chain, is created from the combination of CO_2 and water through the process of photosynthesis.

The stock of carbon in the earth system is constant. This carbon is distributed and exchanged in various forms among four major reservoirs: the atmosphere, the ocean, the terrestrial biosphere and geological deposits. Scientists do not know the exact amount of carbon in the earth system. Estimates range from more than 100 to nearly 150 million gigatonnes (Gt), where 1 gigatonne equals 1 billion (thousand million) tonnes. What is known is that virtually all of the total carbon stock is stored in marine sediments and deep ocean water. Terrestrial, geologic and atmospheric carbon amounts to only about 8 000 Gt, or less than 0.0001 percent of the total, broken down as shown in the table. The continuous circulation of this tiny proportion of the total carbon stock from one part of the earth system to another through the carbon cycle is vital for the survival of life.

At present, slightly more carbon is being released into the atmosphere from the burning of fossil fuels, the clearing of forested area, land degradation and agricultural emissions than is being reabsorbed by terrestrial vegetation and oceans, causing atmospheric concentrations of CO_2 and methane to increase. As explained, the increasing atmospheric concentration of carbon-containing greenhouse gases is the primary cause of global warming and climate change.

Carbon can be released into the atmosphere in many different ways: exhalation by animals; decay of animal and plant matter; release of CO_2 (when oxygen is present) or methane (when oxygen is not present) from combustion of organic matter, including live and recently dead vegetation and fossil fuels; production of cement; release of dissolved CO_2 at the surface of the oceans where the water becomes warmer; volcanic eruptions; and permafrost melt.

Food system practices that emit carbon include deforestation to clear new land for agricultural use, and burning of fuelwood and agricultural wastes and residues for heating and cooking. Accumulation of poorly managed animal wastes in intensive livestock operations, and standing water in irrigated rice fields are important sources of methane. Fortunately, as explained in more detail in Chapters 2 and 3, there are technologies that could substantially reduce the current rate of carbon emission from the food and agriculture sector, as long as market forces support their adoption.

The nitrogen cycle: Nitrogen in its pure form is an inert gas that comprises 78 percent of the earth's atmosphere. It is essential to all life processes, as it forms the amino acids, proteins, nucleic acids and DNA that are vital for all living cells. The nitrogen cycle begins with the fixation of nitrogen, through the transformation of pure, non-reactive nitrogen into reactive nitrogen-containing compounds. Before the industrial revolution, biological nitrogen fixation by leguminous plants, and atmospheric deposition caused by lightning were the primary means by which the nitrogen cycle was triggered. Nitrogen-containing compounds are initially deposited in the soil, then taken up by plants, utilized by the animals and humans that eat the plants, deposited as wastes, mineralized, oxidized, reduced to their original gaseous state and returned to the atmosphere. At the beginning of the twentieth century, the discovery of a process for artificially fixing nitrogen made possible the industrial production of fertilizer.

Large-scale application of artificial fertilizer on farmers' fields made the green revolution possible and guaranteed food security for an increasing proportion of the world's rapidly growing population. One of the sources of food insecurity for many small-scale farming households is the low yields they obtain from the crops they sow, owing to lack of adequate nitrogen to nourish the plants. However, the sharp increase in fertilizer use that has accompanied the development of commercial agriculture has also led to a sharp increase in emissions of nitrous oxide and other nitrogen-containing compounds that pollute the air and water.

These emissions can be visualized as leakages from a pipe. Human-induced nitrogen inputs from agricultural activities are fed into the pipe via fertilizer and animal manure. Nitrogen outputs exit from the pipe in the form of harvested crops and livestock products. If the build-up of nitrogen in the pipe exceeds the amount needed by plants and animals for good nutrition, the surplus is released into the air in the form of anhydrous ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO_2) and molecular nitrogen (N_2). Soil runoff also carries excess nitric oxide, ammonium (NH_4) and dissolved organic nitrogen (N_2) into freshwater bodies, where they pollute the water and may eventually become another source of nitrous oxide emissions (INI Online, 2007). Disturbances in the nitrogen cycle created by excess nitrogen accumulation in the soil and in the diets of ruminant livestock as a consequence of industrial agricultural production methods have created other environmental problems as well as the increase in greenhouse gas emissions. The urgent need to act to reduce emissions provides a strong incentive to bring the nitrogen cycle back into balance – a challenge that the food and agriculture sector is best placed to meet.

ANNEX IV

RULES AND CONDITIONS FOR THE CLEAN DEVELOPMENT MECHANISM

CDM projects need to seek approval from the CDM Executive Board. A number of rules and conditions apply, some to all project types and others specifically to afforestation and reforestation projects. Although several of the detailed procedures to be applied to CDM forestry projects are still to be agreed, the overall framework is already established for approving projects and accounting for the carbon credits generated:

1. Only areas that were not forest on 31 December 1989 are likely to satisfy the CDM criteria for afforestation or reforestation.
2. Projects must result in real, measurable and long-term emission reductions, as certified by a third party agency (an "operational entity" in the language of the convention). The carbon stocks generated by the project need to be secure over the long term (a point referred to as "permanence"), and any future emissions that might arise from these stocks must be accounted for.
3. Emission reductions and sequestration must be additional to any that would occur without the project. They must result in a net storage of carbon, and therefore a net removal of CO_2 from the atmosphere. This is called "additionality" and is assessed by comparing the carbon stocks and flows of project activities with those that would have occurred without the project (its "baseline"). For example, the project may be proposing to afforest farmland with native tree species, increasing its stocks of carbon. The net carbon benefit can be calculated by comparing the carbon stored in the project plantations (high carbon) with the carbon that would have been stored in the baseline abandoned farmland (low carbon). Technical discussions are still ongoing regarding the interpretation of the additionality requirement for specific contexts.
4. Projects must be in line with sustainable development objectives, as defined by the government hosting them.
5. Projects must contribute to biodiversity conservation and sustainable use of natural resources.
6. Only projects starting from 2000 onwards will be eligible.
7. Two percent of the carbon credits awarded to a CDM project will be allocated to a fund to help cover the costs of adaptation in countries severely affected by climate change (the "adaptation levy"). This fund may provide support for land-use activities that are not at present eligible under CDM, such as conservation of existing forest resources.
8. Some of the proceeds from carbon credit sales from all CDM projects will be used to cover CDM administrative expenses (the proportion is still to be decided).
9. Projects need to select a crediting period for activities. This can be for a maximum of seven years and renewable at most twice, or a maximum of ten years with no renewal option.
10. The funding for CDM projects must not come from a diversion of official development assistance funds.
11. Each CDM project management plan must address and account for potential leakage. Leakage is the unplanned, indirect emission of CO_2 resulting from project activities. For example, if the project involves establishing plantations on agricultural land, leakage could occur if people who were farming on this land migrate to clear forest elsewhere.

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