Training Course

Climate Change and its Impact on Water Resources

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LECTURE - 14

CLIMATE CHANGE: ADAPTATION AND MITIGATION

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CLIMATE CHANGE: ADAPTATION AND MITIGATION

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer whether due to natural variability or as a result of human activity. It is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. Climate variability refers to variations in the mean state and other statistics of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.

1.0 Defining Climate Adaptation and Mitigation

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as the, "adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation." Climate adaptation refers to the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. Adaptation can be of different types. Anticipatory or proactive adaptation is the adaptation that takes place before impacts of climate change are observed. Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems is known as autonomous or spontaneous adaptation. Further, adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state is known as planned adaptation.

With reference to climate change impacts, adaptive capacity refers to: a) the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences, or b) the whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures.

IPCC defines mitigation as: "An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (GHG)." Climate mitigation is any action taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life, property. Mitigation of climate change is a global responsibility. Agriculture and forestry provide, in principle, a significant potential for GHG mitigation.

"Adaptation" and "mitigation" are two important terms that are fundamental in the climate change debate. Adaptation basically is an understanding of how individuals, groups and natural systems can prepare for and respond to changes in climate or their environment. Adaptation is crucial to reduce vulnerability to climate change. While mitigation tackles the causes of climate change, adaptation tackles the effects of the phenomenon. The potential to adjust to minimize negative impact and maximize any benefits from changes in climate is known as adaptive capacity. A successful adaptation can reduce vulnerability by building on and strengthening existing coping strategies.

Resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. Since impacts and adaptive capacity of systems may vary substantially over the next decades and within countries, vulnerabilities can be highly dynamic in space and time. Consequently, there is a strong need to build resilient agricultural systems that have a high capacity to adapt to stress and changes and can absorb disturbances.

In general the more mitigation there is, the less will be the impacts to which we will have to adjust, and the less the risks for which we will have to try and prepare. Conversely, the greater the degree of preparatory adaptation, the less may be the impacts associated with any given degree of climate change. Adaptation is not altogether passive, rather it is an active adjustment in response to new stimuli.

The idea that less mitigation means greater climatic change, and consequently requiring more adaptation is the basis for the urgency surrounding reductions in greenhouse gases. Climate mitigation and adaptation should not be seen as alternatives to each other, as they are not discrete activities but rather a combined set of actions in an overall strategy to reduce GHG emissions.

1.1 Impacts and Vulnerability

Impacts of climate change on food security could be global and local. Climate change will affect agricultural food systems in all countries, including exporters and importers as well as those at subsistence level. Changes in mean rainfall and temperate as well as the increase in extreme events will affect agriculture, livestock, forestry as well as fisheries (see Table 1). Many impacts, such as increased land degradation and soil erosion, changes in water availability, biodiversity loss, more frequent and more intense pest and disease outbreaks as well as disasters need to be addressed across sectors.

2.0 Adaptation

Any adaptation planning must recognize the levels of uncertainty in climate change scenarios and the plans themselves must be adaptable. The following indicates some of the problems adaptation planning may face and what must be considered in looking for a solution.

- *Adaptation is urgent, but also requires substantial resources.* It is unlikely that developing countries, in particular the least developed countries, have the financial resources and technical knowledge for anticipatory and planned intervention.
- *Climate change is local and location specific.* Methodologies to assess adaptation need to analyze local impacts in detail to understand and plan interventions but recognize that, at implementation, it will be necessary to include interventions into larger scale coherent adaptation programmes.
- *Climate change impacts will change over time, and individual elements of adaptation must change with them.* Adaptation work requires a variety of technical measures that can be applied at different speeds at different times. This also means that any required inputs should be programmed and sustained for the whole of the adaptation period.
- *Areas affected by climate change become unsuitable for pre-change activities.* Diversification to other economic activities and migration will need to be considered seriously under such conditions.

Table 1: Risks for water and other sectors due to climate change

	Water resources	Agriculture, ecosystems	Health	Industry and society
Heavy precipitation events	• Flooding • Adverse effects on quality of surface and groundwater due to sewer overflows • Contamination of water supply • Water scarcity may be relieved	• Damage to crops • Soil erosion • Inability to cultivate land due to waterlogging	• Increased risk of deaths, physical injuries and infectious, respiratory and skin diseases • Risk of psychological disorders	• Disruption of settlements, commerce, transport and life due to flooding, migration • Pressures on urban and rural infrastructures • Loss of property
Higher variability of precipitation, including increased droughts	• Changes in run-off • More widespread water stress • Increased water pollution due to lower dissolution of sediments, nutrients, dissolved organic carbon, pathogens, pesticides, as well as thermal pollution • Salinization of coastal aquifers	• Land degradation • Lower yields/crop damage and failure • Increased livestock deaths • Increased risk of wildfire	• Increased risk of food and water shortage; • Increased risk of malnutrition; • Increased risk of water and food-borne diseases	• Water shortages for settlements, industry and societies • Reduced hydropower generation potentials • Potential for population migration
Increased temperatures	• Increased water temperatures and evaporation • Earlier snow melting • Permafrost melting • Prolonged lake stratification with decreases in surface layer nutrient concentration and	• Less water available for agriculture, more irrigation needed • Changes in crop productivity • Changes in growing season • Changes in species composition,	• Changes in vector-borne diseases • Increase of fatalities due to heatwaves, and decreased personal productivity • Increased risk of	• Risk for infrastructure fixed in permafrost • Degradation of freshwater quality

	prolonged depletion of oxygen in deeper layers • Increased algae growth reducing dissolved oxygen in the water body which may lead to eutro-phication and loss of fish • Changes in mixing patterns and self purification capacity	organism abundance, productivity and phonological shifts, for example earlier fish migration	respiratory and skin diseases due to ozone and pollen	

Based on IPCC (2007) and others.

2.1 The Need for Adaptation

Historically, people whose livelihoods depend on agriculture have developed ways to cope with climate variability autonomously. Today, the current speed of climate change will modify known variability patterns to the extent that people will be confronted with situations they are not equipped to handle. Thus, anticipatory and planned adaptation is an immediate concern. However, vulnerabilities are mostly local and, thus, adaptation should be highly location specific.

Anticipatory adaptation and technology innovation should attempt to improve resilience to future and uncertain impacts. However, they will have immediate and future costs, with trade-offs between optimization in current conditions and minimizing vulnerability to anticipated shocks. For instance, diversifying agriculture may reduce profitability in the short term but will reduce the risk of crop failure and future vulnerability. As with volatile markets that must diversify to reduce the risk of financial losses, agriculture has to diversify in order to enhance food security in a rapidly changing climate. The safest approach is to promote diverse and flexible livelihood and food production strategies at local, national, regional and global levels in combination with flexible and robust institutions, risk reduction initiatives for food and feed, and planned food security adaptation and transformation.

The most effective adaptation approaches are those that address a combination of environmental stresses and factors. Strategies, policies and programmes that are most likely to succeed need to link with coordinated efforts aimed at alleviating poverty, enhancing food security and water availability, combating land degradation and soil erosion, reducing loss of biological diversity and ecosystem services as well as improving adaptive capacity and improving the food production chain within the framework of sustainable development. Where possible, adaptation strategies should address social inequalities, such as differences in land tenure and lack of access to resources such as credit, education and decision-making that affect people's ability to adapt. The Millennium Development Goals are a necessary backdrop to integrating adaptation into development policy.

Food security must be regarded as one of the main criteria for the effectiveness of adaptation at the national and local levels. Food security considerations should be made explicit in adaptation of the agriculture, forestry and fisheries sectors to climate change and variability. This can be achieved by raising awareness of policy-makers, providing incentives and promoting the most resilient food production systems.

Economic diversification within sectors to reduce dependence on climate-sensitive resources, particularly for countries that rely on narrow ranges of climate-sensitive economic activities, such as the export of climate-sensitive crops, is an important adaptation strategy. For example, coffee in Uganda, a vital source of national income, will suffer a drastic reduction in suitable growing areas under climate change. Improved food security through diversification is one of the priority projects identified by National Adaptation Programmes of Action (NAPAs). This includes developing and introducing drought, flood and saline-tolerant crops, improving livestock and fisheries breeding and farming techniques, developing local food banks for people and livestock, and improving local food preservation.

Effective application of good management practices has many requirements:

- *Use of indigenous knowledge and local coping strategies as a baseline and starting point of adaptation planning.* Although there is a large body of knowledge within local communities on coping with climatic variability and extreme weather events, rapidly changing climate conditions will require upgrading local knowledge with more scientific observations and establishing collaboration among neighbours and neighbouring countries to transfer knowledge from areas already experiencing these changes.
- *Development of low-cost strategies with multiple benefits.* This can include establishing meaningful financial incentives such as microcredit, payments for environmental services and reducing the marketing influence of the agricultural supply industry.
- *Inclusion of gender-sensitive strategies.* Strategies should take into account the different roles, responsibilities, rights and resources of men and women, boys and girls.
- *Encouragement of relevant national agricultural research.* Research should focus on varieties adapted to drought, heat, salinity and new pests and diseases, and take into account that methodologies and materials must be developed to meet rapidly changing conditions.
- *Promotion of multidisciplinary and multisectoral institutions and processes.* Broad-based institutions and processes can facilitate changes in resource access and use, solve conflicts, and secure land and natural resource rights of groups and individuals.

2.2 Adaptation Strategies

For developing countries, good adaptation and good development policy are very strongly intertwined, and it is right that climate change should now become central to national planning processes and to development assistance. International support for adaptation will come in large part through the delivery of the commitments made by rich countries.

Adaptation to climate change must also occur through the prevention or removal of maladaptive practices. Maladaptation refers to those measures that increase vulnerability rather than reducing it. Risk transfer mechanisms should be included in adaptation strategies from the national to the household level. This can include crop insurance or diversified livelihoods such as integrated aquaculture-agriculture systems which allow activities to shift in response to changes in the suitability of land and availability of water to produce food. Safety nets will be required in cases where benefits of diversification are limited, such as changes that affect all aspects of the food production systems. Some adaptation is occurring even now, but it is on a limited basis.

Development and diversification are still important strategies wherever possible, but ultimately the international community will have to find ways to support alternative responses, including the managed resettlement of some people. This will bring many challenges, particularly for those people that must move. There will be much greater pressures if climate change leads to sea level rise that threatens much larger populations in low-lying coastal areas.

There are limits to adaptation. Small island developing states threatened by sea level rise have fewer options to adapt. Sea defences are particularly costly for low-lying islands, and may do little to protect the tourism and fisheries that sustain the local economy.

2.3 Issues in Adaptation

Running counter to the technological and economic potential for GHG emissions reduction are rapid economic development and accelerating change in some socio-economic and behavioural trends that are increasing total energy use, especially in developed countries and high-income groups in developing countries. Dwelling units and vehicles in many countries are growing in size, and the intensity of electrical appliance use is increasing. Use of electrical office equipment in commercial buildings is increasing. In developed countries, and especially the USA, sales of larger, heavier, and less efficient vehicles are also increasing.

Key messages regarding adaptation are given below (UNECE 2009):

1. The world needs to adapt to climate change in water management without delay.
2. Uncertainty should never be a reason for inaction. Action and research on adaptation should be pursued simultaneously.
3. Adaptation needs to be flexible.
4. Developing and implementing adaptation measures should build on learning-by-doing.
5. Water is central to many sectors that directly depend on water being available and of high quality. Therefore, water management can limit or enhance adaptation of -related sectors.
6. Implementing integrated water resources management supports adaptation.

7. Any adaptation policy needs to consider climate change as one of many pressures on water resources. Others include population growth, migration, globalization, changing consumption patterns, and agricultural and industrial developments.
8. Effective adaptation to climate change requires a cross-sectoral approach including at the transboundary level, in order to prevent possible conflicts between different sectors and to consider trade-offs and synergies between adaptation and mitigation measures.
9. Barriers to adaptation in the legal, institutional and policy spheres must be removed. Legislation should be developed flexibly, to be able to cope with different possible climate impacts.
10. Implementing national legislation and international commitments supports adaptation.
11. Transboundary cooperation is both necessary and beneficial in adapting to climate change. It is necessary throughout the entire process of developing and implementing an adaptation strategy.
12. When planning adaptation across boundaries, riparian countries should focus on preventing transboundary impacts, sharing benefits and risks in an equitable and reasonable manner and cooperating on the basis of equality and reciprocity.
13. Knowledge and experience need to be exchanged to enhance the capacity of countries to adapt.
14. Ensuring that data and information are readily available is crucial for making climate projections and identifying vulnerable groups and regions. So sharing information, including that from early warning systems, between countries and sectors is essential for effective and efficient climate change adaptation.
15. Effective adaptation strategies are a mix of structural and non-structural, regulatory and economic instruments and measures, education and awareness-raising to tackle the short-, medium- and long term impacts of climate change.
16. Adaptation measures should strive to be cost-effective, environmentally sustainable, culturally compatible and socially acceptable. Prioritization of measures should be based on the results of vulnerability assessments, costs and benefits assessments, as well as on development objectives, stakeholder considerations and the resources available.
17. Water supply and sanitation, especially during extreme weather events, require special attention in adaptation policy, as they are essential for good health.
18. Adaptation may be costly, but it is much more cost-effective to start it now, because costs will be much higher once the effects of climate change are active. Paying for adaptation should be done by a mix of public and private funding.
19. Stakeholder participation is crucial for all steps of the development and implementation of adaptation strategies and measures.
20. Education, capacity-building and communication are imperative for effective adaptation.
21. Climate change and adaptation is also opportunity for innovation and new technologies.

3.0 Mitigation Strategies

The relationship between climate change mitigation measures and water is a reciprocal one. Mitigation measures can influence water resources and their management, and it is important to realise this when developing and evaluating mitigation options. On the other hand, water management policies and measures can have an influence on GHG emissions and, thus, on the respective sectoral mitigation measures; interventions in the water system might be counter-productive when evaluated in terms of climate change mitigation. IPCC discussed seven sectors of mitigation: energy supply, transportation and its infrastructure, residential and commercial buildings, industry, agriculture, forestry, and waste management. Since water issues were not the focus of that volume, only general interrelations with climate change mitigation were mentioned, most of them being qualitative. Other IPCC reports, such as the TAR, also contain information on this issue. Sector-specific mitigation measures can have various effects on water.

In the United Nations Framework Convention on Climate Change (UNFCCC), three conditions are made explicit when working towards stabilisation of GHG in the atmosphere:

1. That it should take place within a time-frame sufficient to allow ecosystems to adapt naturally to climate change;
2. That food production is not threatened and;
3. That economic development should proceed in a sustainable manner

To eliminate or reduce the risk of climate change to human life and property, both policy instruments and technology must be used in the context of sustainable development.

3.1 Means of Mitigation

Scientific consensus on global warming, together with the precautionary principle and the fear of abrupt climate change is leading to increased effort to develop new technologies and sciences and carefully manage others in an attempt to mitigate global warming. Unfortunately most means of mitigation are effective only for preventing further warming, not at reversing existing warming.

The Stern Review (Review on the 'Economics of Climate Change' a report by economist Nicholas Stern (2006) for the British government. It discusses the effect of global warming on the world economy) identifies several ways of mitigating climate change. These include reducing demand for emissions-intensive goods and services, increasing efficiency gains, increasing use and development of low-carbon technologies, and reducing non-fossil fuel emissions.

The energy policy of the European Union has set a target of limiting the global temperature rise to 2 °C compared to preindustrial levels, of which 0.8 °C has already taken place and another 0.5 °C is already committed. The 2 °C rise is typically associated in climate models with a carbon dioxide concentration of 400-500 ppm by volume; the level as of January 2007 was 383 ppm by volume, and rising at 2 ppm annually. Hence, to avoid a very likely breach of the 2 °C target, CO_2 levels would have to be stabilised very soon; this is generally regarded as unlikely, based on current programs in place to date. The importance of change is illustrated by the fact that world economic energy efficiency is presently improving at only half the rate of world economic growth.

At the core of most proposals is the reduction of greenhouse gas emissions through reducing energy use and switching to cleaner energy sources. Frequently discussed energy conservation methods include increasing the fuel efficiency of vehicles (often through hybrid, plug-in hybrid, and electric cars and improving conventional automobiles), individual-lifestyle changes and changing business practices. Newly developed technologies and currently available technologies including renewable energy (such as solar power, tidal and ocean energy, geothermal power, and wind power) and more controversially nuclear power and the use of carbon sinks, carbon credits, and taxation are aimed more precisely at countering continued greenhouse gas emissions. More radical proposals which may be grouped with mitigation include bio-sequestration of atmospheric carbon dioxide and geo-engineering techniques ranging from carbon sequestration projects such as carbon dioxide air capture, to solar radiation management schemes such as the creation of stratospheric sulfur aerosols. The ever-increasing global population and the planned growth of national GDPs based on current technologies are counter-productive to most of these proposals.

3.2 Energy Efficiency and Conservation

Developing countries use their energy less efficiently than developed countries, getting less GDP for the same amount of energy. Reducing fuel use by improvements in efficiency provides environmental benefits and as well as net cost savings to the energy user. Building insulation, fluorescent lighting, and public transportation are some of the most effective means of conserving energy, and by extension, the environment. However, Jevons paradox poses a challenge to the goal of reducing overall energy use by energy conservation methods: improved efficiency lowers cost, which in turn increases demand. To ensure that increase in efficiency actually reduces energy use, a tax must be imposed to remove any cost savings from improved efficiency.

Residential buildings, commercial buildings, and the transportation of people and freight use the majority of the energy consumed each year in many countries. Energy conservation is the practice of increasing the efficiency of use of energy in order to achieve higher useful output for the same energy consumption. This may result in increase of national security, personal security, financial capital, human comfort and environmental value. Individuals and organizations that are direct consumers of energy may want to conserve energy in order to reduce energy costs and promote environmental values. Industrial and commercial users may want to increase efficiency and maximize profit.

On a larger scale, energy conservation is an element of energy policy. The need to increase the available supply of energy (for example, through the creation of new power plants, or by the importation of more energy) is lessened if societal demand for energy can be reduced, or if growth in demand can be slowed. This makes energy conservation an important part of the debate over climate change and the replacement of non-renewable resources with renewable energy. Encouraging energy conservation among consumers is often advocated as a cheaper or more environmentally sensitive alternative to increased energy production.

In developed nations, the way of life today is completely dependent on abundant supplies of energy which is needed to heat, cool, and light homes, fuel cars, and power offices. Energy is also critical to manufacture the products used every day. While the U.S. represents only five percent of the world's population, it consumes 25 percent of its energy and generates about 25 percent of its total GHG emissions.

3.3 Building Design

Emissions from housing are substantial, and government-supported energy efficiency programmes can make a difference. New buildings can be constructed using passive solar building design, low-energy building, or zero-energy building techniques, using renewable heat sources. Existing buildings can be made more efficient through the use of insulation, high-efficiency appliances (particularly hot water heaters and furnaces), double- or triple-glazed gas-filled windows, external window shades, and building orientation and siting. Renewable heat sources such as passive solar energy reduce the amount of GHG emitted. In addition to designing buildings which are more energy efficient to heat, it is possible to design buildings that are more energy efficient to cool by using lighter-coloured, more reflective materials and planting trees. This saves energy because it cools buildings and reduces the urban heat island effect thus reducing the use of air conditioning.

As a mitigation measure, evaporative cooling means substantial savings in annual cooling energy use for residences but places an extra pressure on water resources. Cooling energy use in buildings can be reduced by measures, for example, changing by building shape and orientation.

3.4 Urban Planning and Transport

Urban planning also has an effect on energy use. Inefficient land use development practices have increased infrastructure costs as well as the amount of energy needed for transportation, community services, and buildings. At the same time, a growing number of citizens and government officials have begun advocating a smarter approach to land use planning. These smart growth practices include compact community development, multiple transportation choices, mixed land uses, and practices to conserve green space. These programs offer environmental, economic, and quality-of-life benefits; and they also serve to reduce energy usage and GHG emissions.

New urban development approaches seek to reduce distances travelled, especially by private vehicles, encourage public transit and make walking and cycling more attractive options. This is achieved through medium-density, mixed-use planning and the concentration of housing within walking distance of town centers and transport nodes. Effective urban planning to reduce sprawl would decrease Vehicle Miles Travelled, lowering emissions from transportation. Increased use of public transport can also reduce GHG emissions per passenger kilometer.

Modern energy efficient technologies, such as plug-in hybrid electric vehicles, and development of new technologies, such as hydrogen cars, may reduce the consumption of petroleum and emissions of carbon dioxide. A shift from air and truck transport to electric rail transport would reduce emissions significantly. Bicycles have almost no carbon footprint.

Increased use of biofuels (such as biodiesel and biobutanol, that can be used in 100% concentration in today's diesel and gasoline engines) could also reduce emissions if produced environmentally efficiently, especially in conjunction with regular hybrids and plug-in hybrids.

3.5 Carbon Dioxide Capture and Storage (CCS)

Carbon dioxide (CO_2) capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy related sources, transport to a storage location and long-term isolation from the atmosphere. The injection of CO_2 into the pore space and fractures of a permeable formation can displace *in situ* fluid, or the CO_2 may dissolve in or mix with the fluid or react with the mineral grains, or there may be some combination of these processes. As CO_2 migrates through the formation, some of it will dissolve into the formation water. Once CO_2 is dissolved in the formation fluid, it is transported by the regional groundwater flow. Leakage of CO_2 from leaking injection wells, abandoned wells, and leakage across faults and ineffective confining layers could potentially degrade the quality of groundwater; and the release of CO_2 back into the atmosphere could also create local health and safety concerns.

Technology for capturing of CO_2 is already commercially available for large CO_2 emitters, such as power plants. Storage of CO_2, on the other hand is a relatively untried concept and currently no power plant operates with a full carbon capture and storage system. When this technique is used with biomass, the technique is known as biomass energy with carbon capture and storage and may be carbon negative.

CCS applied to a conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80-90% compared to a plant without CCS. Storage of the CO_2 is envisaged either in deep geological formations, deep oceans, or in the form of mineral carbonates. Geological formations are currently considered the most promising, and these are estimated to have a storage capacity of at least 2000 Gt CO_2. IPCC estimates that the economic potential of CCS could be between 10% and 55% of the total carbon mitigation effort until year 2100.

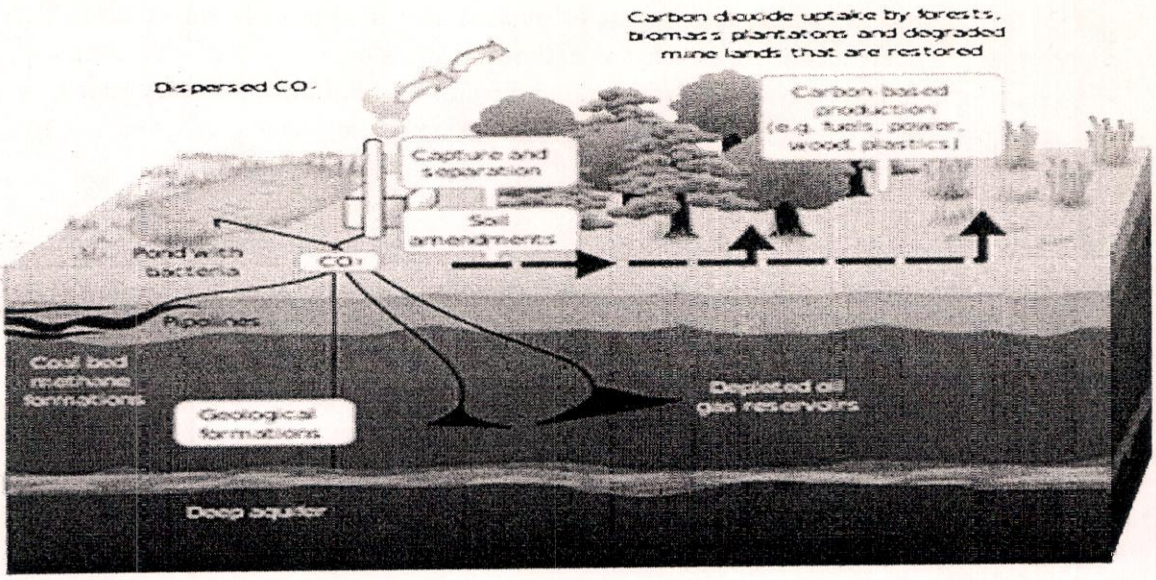

Fig. 1 Schematic showing both terrestrial and geological sequestration of carbon dioxide emissions from a coal-fired plant.

It is important to note that, at this point, there is no complete insight into the practicality, consequences or unintended consequences of this carbon sequestration concept.

3.6 Land-use Change and Management

According to IPCC Good Practice Guidance for LULUCF, there are six possible broad land-use categories: forest land, cropland, grassland, wetlands, settlements, and other. Changes in land use (e.g., conversion of cropland to grassland) may result in net changes in carbon stocks and in different impacts on water resources. Wetland restoration, one of the main mitigation practices in agriculture, results in the improvement of water quality and decreased flooding.

Land management practices implemented for climate change mitigation may also have different impacts on water resources. Many of the practices advocated for soil carbon conservation – reduced tillage, more vegetative cover, greater use of perennial crops – also prevent erosion, yielding possible benefits for improved water and air quality. These practices may also have other potential adverse effects, at least in some regions or conditions. Possible effects include enhanced contamination of groundwater with nutrients or pesticides via leaching under reduced tillage. These possible negative effects, however, have not been widely confirmed or quantified, and the extent to which they may offset the environmental benefits of carbon sequestration is uncertain.

Nutrient management to achieve efficient use of fertilisers has positive impacts on water quality. In addition, practices that reduce N_2O emission often improve the efficiency of nitrogen use from these and other sources (e.g., manures), thereby also reducing GHG emissions from fertiliser manufacture and avoiding deleterious effects on water and air quality from nitrogen pollutants. Agro-forestry systems (plantation of trees in cropland) can provide multiple benefits including energy to rural communities with synergies between sustainable development and GHG mitigation. However, agro-forestry may have negative impacts on water conservation.

3.7 Hydropower

Renewable energy systems such as hydro-electricity can contribute to the security of energy supply and protection of the environment. However, construction of hydro-electric power plants may also cause ecological impacts on existing river ecosystems and fisheries, induced by changes in flow regime (the hydrograph) and evaporative water losses (in the case of dam-based power-houses). Also social disruption may be an impact. Finally, water availability for shipping (water depth) may cause problems. Positive effects are flow regulation, flood control, and availability of water for irrigation during dry seasons. About 75% of water reservoirs in the world were built for irrigation, flood control and urban water supply schemes, and many could have small hydropower generation retrofits added without additional environmental impacts.

Large (>10 MW) hydro-electricity systems accounted for over 2,800 TWh of consumer energy in 2004 and provided 16% of global electricity (90% of renewable electricity). Hydro projects under construction could increase the share of hydro-electricity by about 4.5% on completion and new projects could be deployed to provide a further 6,000 TWh/yr or more of electricity economically, mainly in developing countries. Repowering existing plants with more powerful and efficient turbine designs can be cost-effective whatever the plant scale.

Small (<10 MW) and micro (<1 MW) hydropower systems, usually run-of-river schemes, have provided electricity to many rural communities in developing countries such as Nepal. Their present generation output is uncertain, with predictions ranging from 4 TWh/yr to 9% of total hydropower output at 250 TWh/ yr. The global technical potential of small and micro-hydro is around 150–200 GW, with many unexploited resource sites available.

3.8 Alternative Energy Sources

One means of reducing carbon emissions is the development of new technologies such as renewable energy say wind power. Most forms of renewable energy generate no appreciable amounts of GHGs except for biofuels derived from biomass, as well as some biofuels derived from fossil fuel sources. Currently many governments subsidize fossil fuels. However, in some countries, government action has boosted the development of renewable energy technologies—for example, a program to put solar panels on the roofs of a million homes has made Japan a world leader in that technology, and Denmark's support for wind power ensured its former leadership of that sector.

Nuclear power currently produces over 15% of the world's electricity. Due to its low emittance of greenhouse gases (comparable to wind power) and reliability, it is a possible alternative to fossil fuels, but is controversial for reasons of capital cost and possible environmental impacts. Also, there are political factors in some countries. Current uranium production is expected to be adequate at current consumption rates for about a century. There are a number of alternative nuclear fission technologies, such as breeder reactors, which could vastly extend fuel supplies if successfully developed and utilized.

3.9 Afforestation or Reforestation

Forests, generally, are expected to use more water (the sum of transpiration and evaporation of water intercepted by tree canopies) than crops, grass, or natural short vegetation. This effect, occurring in lands that are subjected to afforestation or reforestation, may be related to increased interception loss, especially where the canopy is wet for a large proportion of the year or, in drier regions, to the development of more massive root systems, which allow water extraction and use during prolonged dry seasons.

Interception losses are greatest from forests that have large leaf areas throughout the year. Thus, such losses are greater for evergreen forests than deciduous forests and may be expected to be larger for fast-growing forests with high rates of carbon storage than for slow-growing forests. Consequently, afforestation with fast-growing conifers on non-forest land commonly decreases the flow of water from catchments and can cause water shortages during droughts. In a study, it was, found that establishing high-water-demanding species of pines to restore degraded Thai watersheds markedly reduced dry season streamflows relative to the original deciduous forests. Although forests lower average flows, they may reduce peak flows and increase flows during dry seasons because forested lands tend to have better infiltration capacity and a high capacity to retain water. Forests also play an important role in improving water quality.

In the dry tropics, forest plantations often use more water than short vegetation because trees can access water at greater depth and evaporate more intercepted water. Newly planted forests can use more water (by transpiration and interception) than the annual rainfall, by mining stored water. Extensive afforestation or reforestation in the dry tropics can therefore have a serious impact on supplies of groundwater and river flows. It is less clear, however, whether replacing natural forests with plantations, even with exotic species, increases water use in the tropics when there is no change in rooting depth or stomatal behaviour of the tree species. In the dry zone of India, water use by *Eucalyptus* plantations is similar to that of indigenous dry deciduous forest: both forest types essentially utilise all the annual rainfall.

Afforestation and reforestation, like forest protection, may also have beneficial hydrological effects. After afforestation in wet areas, the amount of direct runoff initially decreases rapidly, then gradually becomes constant, and baseflow increases slowly as stand age increases towards maturity, suggesting that reforestation and afforestation help to reduce flooding and enhance water conservation. In water-limited areas, afforestation, especially plantations of species with high water demand, can cause a significant reduction in streamflow, affecting the inhabitants of the basin, and reducing water flow to other ecosystems and rivers, thus affecting aquifers and recharge. In addition, some possible changes in soil properties are largely driven by changes in hydrology. The hydrological benefits of afforestation may need to be evaluated individually for each site. Afforestation of previously eroded or otherwise degraded land may have a net positive environmental impact; in catchments where the water yield is large or is not heavily used, streamflow reduction may not be critical.

Stopping or slowing deforestation and forest degradation (loss of carbon density) and sustainable management of forests may significantly contribute to avoided emissions, may conserve water resources and prevent flooding, reduce runoff, control erosion, reduce siltation of rivers, and protect fisheries and investments in hydro-electric power facilities; and at the same time preserve biodiversity. Preserving forests conserves water resources and prevents flooding. By reducing runoff, forests control erosion and salinity. Consequently, maintaining forest cover can reduce siltation of rivers, protecting fisheries and investment in hydropower facilities.

Deforestation and degradation of upland catchments can disrupt hydrological systems, replacing year-round water flows in downstream areas with flood and drought regimes. Although there are often synergies between increased carbon storage through afforestation, reforestation and deforestation (ARD) activities and other desirable associated impacts, no general rules can be applied; impacts must be assessed individually for each specific case. Associated impacts can often be significant, and the overall desirability of specific ARD activities can be greatly affected by their associated impacts.

3.10 Cropland Management

Agricultural practices which promote the mitigation of GHGs can have both negative and positive effects on the conservation of water, and on its quality. Where the measures promote water-use efficiency (e.g., reduced tillage), they provide potential benefits. But in some cases, the practices could intensify water use, thereby reducing streamflow or groundwater reserves. Rice management has generally positive impacts on water quality through a reduction in the amount of chemical pollutants in drainage water.

Conservation tillage is a generic term that includes a wide range of tillage practices, including chisel plough, ridge till, strip till, mulch till and no till. Adoption of conservation tillage has numerous ancillary benefits. Important among these benefits are the control of water and wind erosion, water conservation, increased water-holding capacity, reduced compaction, increased soil resilience to chemical inputs, increased soil and air quality, enhanced soil biodiversity, reduced energy use, improved water quality, reduced siltation of reservoirs and waterways, and possible double-cropping. In some areas (e.g., Australia), increased leaching from greater water retention with conservation tillage can cause downslope salinisation. Important secondary benefits of conservation tillage adoption include soil erosion reduction, improvements in water quality, increased fuel efficiency, and increases in crop productivity. Tillage/residue management has positive impacts on water conservation.

3.11 Waste and Wastewater Management

Controlled landfill (with or without gas recovery and utilisation) controls and reduces GHG emissions but may have negative impacts on water quality in improperly managed sites. This also holds for aerobic biological treatment (composting) and anaerobic biological treatment (anaerobic digestion). Recycling, reuse and waste minimisation can be negative for waste scavenging from open dump sites, with water pollution as a potential consequence.

When efficiently applied, wastewater transport and treatment technologies reduce or eliminate GHG generation and emissions. In addition, wastewater management promotes water conservation by preventing pollution from untreated discharges to surface water, groundwater, soils, and coastal zones, thus reducing the volume of pollutants, and requiring a smaller volume of water to be treated. Treated wastewater can either be reused or discharged, but reuse is the most desirable option for agricultural and horticultural irrigation, fish aquaculture, artificial recharge of aquifers, or industrial applications.

3.12 Bio-Energy Crops

Bio-energy produces mitigation benefits by displacing fossil fuel use. However, large-scale bio-fuel production raises questions on several issues including fertiliser and pesticide requirements, nutrient cycling, energy balances, biodiversity impacts, hydrology and erosion, conflicts with food production, and the level of financial subsidies required. The energy production and GHG mitigation potentials of dedicated energy crops depends on the availability of land, which must also meet demands for food as well as for nature protection, sustainable management of soils and water reserves, and other sustainability criteria. Various studies have arrived at differing figures for the potential contribution of biomass to future global energy supplies, ranging from below 100 EJ/yr to above 400 EJ/yr in 2050. The ultimate technical potential for energy cropping on current agricultural land, with projected technological progress in agriculture and livestock, could deliver over 800 EJ/ yr without jeopardising the world's food supply. Differences between studies are largely attributable to uncertainty in land availability, energy crop yields, and assumptions about changes in agricultural efficiency. Those with the largest projected potential assume that not only degraded/surplus lands are used, but also land currently used for food production, including pasture land.

Agricultural practices for mitigation of GHGs could, in some cases, intensify water use, thereby reducing streamflow or groundwater reserves. For instance, high-productivity, evergreen, deep-rooted bio-energy plantations generally have a higher water use than the land cover they replace. Some practices may affect water quality through enhanced leaching of pesticides and nutrients. Agricultural mitigation practices that divert products to alternative uses (e.g., bio-energy crops) may induce the conversion of forests to cropland elsewhere. Conversely, increasing productivity on existing croplands may 'spare' some forest or grasslands. The net effect of such trade-offs on biodiversity and other ecosystem services has not yet been fully quantified.

If bio-energy plantations are appropriately located, designed and managed, they may reduce nutrient leaching and soil erosion and generate additional environmental services such as soil carbon accumulation, improved soil fertility, and the removal of heavy metals from soils or wastes. In the case of forest plantations for obtaining bio-fuels, negative environmental impacts are avoidable through good project design. Environmental benefits include, among others, reduced soil degradation, water runoff, and downstream siltation and capture of polluting agricultural runoff.

Non-hydro renewable energy supply technologies, particularly solar, wind, geothermal and biomass, are currently small overall contributors to global heat and electricity supply, but are increasing most rapidly, albeit from a low base. Growth of biomass electricity is restricted due to cost, as well as social and environmental barriers. For the particular case of biomass electricity, any volumes of biomass needed above those available from agricultural and forest residues will need to be purpose-grown, so could be constrained by land and water availability. There is considerable uncertainty, but there should be sufficient production possible in all regions to meet the additional generation from bio-energy of 432 TWh/yr by 2030. In general, the substitution of fossil fuels by biomass in electricity generation will reduce the amount of cooling water discharged to surface water streams.

3.13 Mitigation Options in Agriculture and Forestry Sector

Agriculture and land-use change (deforestation) are major contributors to climate change. The IPCC Fourth Assessment Report found that agriculture, which consists of cropland, pasture and livestock production, and forestry contribute, respectively, 13 and 17 percent of total anthropogenic GHG emissions. This contribution does not include other emissions associated with agriculture such as production of fertilizers (accounted under industry), food supply (transport and industry), packaging (waste), and cooling and heating (energy supply).

While CO_2 emissions from agriculture are small, the sector accounts for about 60 percent of all N_2O and about 50 percent of CH_4 emitted, mainly from soils and enteric fermentation, respectively. The GHG impact through radiative forcing of N_2O is 300 times that of CO_2. Methane and nitrous oxide emissions increased by 17 percent from 1990 to 2005 and are projected to increase by another 35 to 60 percent by 2030, driven by growing nitrogen fertilizer use and increased livestock production. Increases in agricultural emissions are expected as population and economic growth increase food demand.

Table 2 gives selected examples of mitigation technologies, policies and measures, constraints and opportunities for agriculture and forestry sectors.

4.0 Societal Controls

Many innovative societal controls and option are being advanced to control carbon emission. A method being examined is to make carbon a new currency by introducing tradable "Personal Carbon Credits" hoping that it will encourage and motivate individuals to reduce their 'carbon footprint'. It has been suggested that by using this concept it could actually solve two problems; pollution and poverty, old age pensioners will actually be better off because they fly less often, so they can cash in their quota at the end of the year to pay heating bills, etc.

4.1 Emissions Tax

An emissions tax on GHG emissions requires individual emitters to pay a fee, charge or tax for every tonne of GHG released into the atmosphere. Most environmentally related taxes with implications for GHG emissions in OECD countries are levied on energy products and motor vehicles, rather than on CO_2 emissions directly. Emission taxes can be both cost effective and environmentally effective. Difficulties with emission taxes include their potential unpopularity, and the fact that they cannot guarantee a particular level of emissions reduction. Emissions or energy taxes also often fall disproportionately on lower income classes. In developing countries, institutions may be insufficiently developed for the collection of emissions fees from a wide variety of sources.

Table 2: mitigation technologies for agriculture and forestry sectors.

Sector	Key mitigation technologies and practices currently commercially available.	Environmentally effective policies, measures and instruments	Key constraints or opportunities
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; mulch farming, conservation tillage, cover cropping and recycling of bio-solids.	Financial incentives and regulations for improving land management, maintaining soil carbon content, and making efficient use of fertilizers and irrigation	Opportunities: May encourage synergy with sustainable development, reducing vulnerability to climate change, and thereby overcoming barriers to implementation
Forestry	Afforestation; reforestation; forest management; harvested wood product management; reduced deforestation; use of forest products for bioenergy to replace fossil fuel use. By 2030, forest mitigation technologies will include: tree species improvement to increase biomass productivity and carbon sequestration.	Financial incentives (national and international) to increase forest area, reduce deforestation and maintain and manage forests; land-use regulation and enforcement	Constraints: lack of investment capital and land tenure issues. Opportunities: Help poverty alleviation and provide essential ecosystem services to protect watershed, conserve biodiversity and advance conservation

	Improved remote sensing technologies for analysis of vegetation and soil carbon sequestration potential, and mapping land-use change		recreation

4.2 Personal Choices

While many of the proposed methods of mitigating global warming require governmental funding, legislation and regulatory action, individuals and businesses can also play a part in the mitigation effort. Environmental groups encourage individual action against global warming, often aimed at the consumer. Common recommendations include lowering home heating and cooling usage, burning less fossil fuel, supporting renewable energy sources, buying local products to reduce transportation, turning off unused devices, and various others. There are suggestions to use communications technologies such as videoconferencing to reduce travel to attend meetings.

5.0 Mitigation in Developing Countries

To reconcile economic development with mitigating carbon emissions, developing countries need particular support, both financial and technical. One of the means of achieving this is the Kyoto Protocol's Clean Development Mechanism (CDM).

In July 2005 the U.S., China, India, Australia, as well as Japan and South Korea, agreed to the Asia-Pacific Partnership for Clean Development and Climate. The pact aims to encourage technological development that may mitigate global warming, without coordinated emissions targets. The highest goal of the pact is to find and promote new technology that aid both growth and a cleaner environment simultaneously. An example is the Methane to Markets initiative which reduces methane emissions into the atmosphere by capturing the gas and using it for growth enhancing clean energy generation. Critics have raised concerns that the pact undermines the Kyoto Protocol.

However, none of these initiatives suggest a quantitative cap on the emissions from developing countries. This is considered as a particularly difficult policy proposal as the economic growth of developing countries are proportionally reflected in the growth of GHG emissions. Critics of mitigation often argue that, the developing countries' drive to attain a comparable living standard to the developed countries would doom the attempt at mitigation of global warming. Holding down emissions would shift the human cost of global warming from a general one to one that was borne most heavily by the poorest populations on the planet.

5.1 Population Control

Various organizations promote population control as a means for mitigating global warming. Proposed measures include improving access to family planning and reproductive health care and information, public education about the consequences of continued population growth, and improving access of women to education and economic opportunities. Population control efforts are impeded by there being somewhat of a taboo in some countries against considering any such efforts. Also, various religions discourage or prohibit some or all forms of birth control. Population size has a different per capita effect on global warming in different countries, since the per capita production of anthropogenic greenhouse gases varies greatly by country.

Fig. 2 Population density of the countries.

5.2 National Awareness and Capacity

In many countries, the general attitude of decision-makers towards climate change, appears to be a lack of concern, often justified by the uncertainties that affect many projected impacts at the local level. That is why it is necessary to build capacity to raise awareness of the future risks and immediate benefits that can be derived from developing national strategies for adaptation and mitigation including prevention of new GHG-producing activities. Policy-makers and agricultural research and extension services need to be sensitized to the issues related to the climate change and food security nexus.

The capacity to identify, collect and share data, use information and build knowledge relevant for climate change adaptation, mitigation and food security is critical because of rapidly changing climatic, environmental and socio-economic conditions. Countries should be enabled to undertake an assessment of impacts, adaptation and mitigation options and potentials, to participate in international fora and to take advantage of existing international options for the benefit of their agriculture, forestry and fisheries sectors.

6.0 Costs and Limitations of Mitigation

There are proposals to stabilise the concentration of GHG in the atmosphere at a maximum of 550ppm CO_2e by 2050. This would mean cutting total GHG emissions to three quarters of 2007 levels. Further, the cost of these cuts would be about +20% of GDP, These costs are contingent on steady reductions in the cost of low-carbon technologies. Mitigation costs will also vary according to how and when emissions are cut: early, well-planned action will minimise costs.

One way of estimating the cost of reducing emissions is by considering the likely costs of potential technological and output changes. Policy makers can compare the marginal abatement costs of different methods to assess the cost and amount of possible abatement over time. The marginal abatement costs of the various measures will differ by country, by sector, and over time.

Mitigation technologies aimed at reducing emissions, as opposed to enhancing sinks, do not seek to remove greenhouse gases from the atmosphere. As such, their efficacy at reversing global warming is limited.

6.1 Trade-offs and Mitigation and Adaptation Synergy

There can be negative trade-offs between adaptation and mitigation. Adaptation measures in one sector can negatively affect livelihoods in other sectors. For example, river fisheries can be negatively affected from adaptations in other livelihood sectors upstream. In particular, irrigation's additional water needs, such as in the Ganges region, can reduce flows and affect seasonal spawning and fish productivity. Mitigation measures, such as reduced emissions from deforestation, can threaten the land rights and livelihoods of rural people and undermine efforts to improve food security and sustainable development.

It is possible to reduce trade-off risks by promoting diverse and flexible livelihood and food production strategies, flexible and adaptable institutions, food security risk reduction initiatives and planned food security adaptation to climate change. In many cases, adaptation, mitigation and food security enhancement and rural development can go hand in hand. Unlike other sectors, adequate agriculture and forestry strategies can simultaneously increase adaptive capacity and mitigate climate change. For example, increasing soil organic matter in cropping systems, agroforestry and mixed-species forestry can improve soil fertility and soil moisture holding capacity, reduce impact of droughts or floods, reduce vulnerability and sequester carbon.

Although the most vulnerable countries should focus on food security and adaptation, they also should look for synergies with mitigation whenever possible. Adaptation and mitigation and their synergies are often location specific, although some patterns are based on elements such as climate, soil type, farming system and level of development.

IPCC estimates that the global technical mitigation potential for agriculture (excluding forestry and fossil fuel offsets from biomass, and including all gasses) will be between 5500 and 6000 Mt CO_2-equivalent per year by 2030, 89 percent of which are assumed to be from carbon sequestration in soils. The assessment of mitigation potential remains a major tool for priority setting at the national level.

Mitigation in the natural resources sector should focus on its five major components, namely: livestock, forestry, rangeland, agriculture and fisheries. The classical mitigation options in the agricultural sector includes forest-related measures of reducing deforestation and forest degradation and increasing afforestation and reforestation, along with forest management interventions to maintain or increase forest carbon density, and efforts to increase carbon stocks in wood products and enhance fuel substitution.

Soil carbon sequestration is one of the most promising options with a wide range of synergies. By increasing carbon concentrations in the soil through better management practices, this option offers benefits for biodiversity, soil fertility and productivity, and soil water storage capacity. Further, it stabilizes and increases food production and optimizes the use of synthetic fertilizer inputs, reversing land degradation and restoring the "health" of ecological processes. Fertilizers, pesticides and monoculture production have failed to optimize soil carbon sequestration or to moderate GHGs. Any attempts to increase production by increasing mineral nitrogen use need to be evaluated with respect to the fertilizer's efficiency and N_2O emissions. Experience from long term studies has shown that nitrogen fertilizers do not support organic matter build-up. Fertilizer evaluations also must include off-site effects such as water contamination and off-site N_2O emission, particularly in the most advanced countries. On the other hand, integrated crop and animal production, use of intermediate and catch crops and cover crops, compost application, crop rotation and diversification, and zero or reduced tillage have potential to improve soil carbon sequestration and reduce GHG emissions.

Livestock is responsible for significant GHG emissions. Mitigation options to reduce these emissions include: improving livestock waste management through covered lagoons, improving ruminant livestock management through improved diet, nutrients and increased feed digestibility, improving animal genetics, and increasing reproduction efficiency.

For the most vulnerable people as well as regions, the potential for implementation of mitigation measures is rather low and adaptation is the major concern. On the other hand, farming systems with reduced external inputs that are based on recycling nutrients and using natural processes to provide sufficient crop growth reduce dependence on purchasing fertilizers and other inputs. In the long run, these systems are a valid mitigation option that may enhance adaptation synchronously and that need to be developed locally.

In this respect, mitigation is perceived very differently for countries (mostly developed) that have an obligation to reduce their emissions and those that increasingly suffer from climate changes affecting climate variability patterns. However, international mechanisms that could channel international financial resources to the most vulnerable in developing countries provide a new opportunity that is still very far from affecting the lives of smallholders. Indeed, some mitigation measures may even disrupt traditional food production systems thereby compromising their food security.

Preventing activities known to contribute to global warming is the simplest and most cost-effective approach to avoid negative impacts of human activities on the climate and food production systems. Evaluation standards are needed to ensure mitigation strategies have no negative impacts on food security. For instance, clear guidelines would help resolve some of the conflicts between rural income from bioenergy and food security, taking into account likely short- and long-term impacts of individual decisions and national policies, and their effect on other resources such as water and on price trends.

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