INTERNATIONAL COFFEE ORGANIZATION
ORGANIZACIÓN INTERNACIONAL DEL CAFÉ
ORGANIZAÇÃO INTERNACIONAL DO CAFÉ
ORGANISATION INTERNATIONALE DU CAFÉ

ICC 103-6 Rev. 1

16 December 2009
Original: English

E

International Coffee Council
103rd Session
23 – 25 September 2009
London, England

Climate change and coffee

Background

This document contains a report on the effects of climate change on producing countries. The following Annexes are included in this document:

Annex I:	The impact of climate change on coffee: the views of stakeholders
Annex II:	Organizations providing funds for mitigation and adaptation to climate change
Annex III:	Ongoing research projects into the impact of climate change on agriculture
Annex IV:	References

Action

The Council is requested to note this document.

CLIMATE CHANGE AND COFFEE

More human beings derive their livelihood from agriculture than from any other economic activity; the majority are self-employed subsistence farmers living in the tropics. Despite growing urbanization, 75% of the world's poor live in rural areas, and agriculture remains the largest single contributor to their livelihoods. Agricultural development is therefore of vital importance to the alleviation of poverty in the developing world, both directly (by offering employment) and indirectly (by generating jobs away from the farm and pushing down food prices). It is not surprising then that agriculture has received a great deal of attention in recent times when action for tackling climate change has been placed at very top of the world's political agenda.

The challenges and uncertainties of climate change are tremendous, but should not be an excuse for inaction. Even if the greenhouse effects of CO_2 emissions were to be offset by a cooling down of the sun, as has been the case over the past decade, many scientists believe that we have passed the point of 'sustainability' for the earth's resources, and the consequences of human behaviour are already being felt throughout the planet. Climate change action represents both a potentially catastrophic scenario for all living species if humans don't change their ways, and a call for vigorous action towards a greener, more efficient economic model.

It is in this sense that the response to climate change cannot be limited to isolated actions randomly undertaken by national or international agencies. For actions to be effective in the long term, they must be integrated within the overall development strategy of a sector or even a whole country. Just as countries need resources to track weather patterns, make forecasts and assess potential risks, so farmers need access to technologies for adaptation, weather-related risk management financial tools and participation in carbon sequestration mechanisms. A critical input in this new concept of development is the production and dissemination of climate change information, particularly when addressing user-end concerns such as those of coffee farmers.

This is the objective of this study on the relations among climate change, coffee and development. Information on the generalities of climate change is abundant and readily accessible, so will not be explored in depth herein. In line with most of the scientific community, climate change is presumed to be happening although acknowledgement is made of the great degree of uncertainty in the prediction of future weather patterns.

1. Climate change and agriculture

According to the Intergovernmental Panel on Climate Change (IPCC), the adverse impacts of climate change on agriculture will occur predominantly in the tropics and subtropics, particularly sub-Saharan Africa and, to a lesser extent, South Asia. This means that coffee producing regions have been identified as being at a high risk and need to make extra efforts to prepare for the future. Before addressing specific threats to the coffee sector and possible adaptation strategies, the main components of climate analysis are briefly described.

Trying to predict global future weather patterns is extremely complex, in light of the vast range of data available. Given the complex relationships between crops, atmospheric composition and temperature, combined with the complexities of world agricultural policies and trade, making predictions about the effects of climate change is necessarily a tentative process, the results of which should be treated with due caution. For purposes of this study, the most important factor is how these projections will impact on crops.

1.1 Measurement of the impact of climate change on agriculture

A number of tools are used to understand potential effects of climate change on agriculture. These range from large-scale models representing the global climate, agriculture and food trade systems as they are now and extrapolated into the future, to small, farm-level or laboratory experiments used to study the responses of plant physiology to individual climatic drivers. A more comprehensive discussion of the issues involved in measuring the effects of climate change on agriculture can be found in Peskett (2007).

The most common approach is to build global climate change models, which produce projections about future climates based on current understanding of the drivers of climate change while associating the results of these models to potential impacts on crops. Three main scenarios (relating to future green house emissions, green house gas concentrations in the atmosphere and temperature changes) are fed into the projections for crop response models. From the results obtained potential impact on agriculture is then evaluated, and matched with other models so as to separate the specific impacts of climate change from other variables or influences.

In addition to large-scale modelling, scientists also isolate in the laboratory one or several crops and submit them to controlled experiments, changing the composition of water, temperature, CO2 concentrations and other variables present in the earth’s soil and atmosphere. These are usually referred to as controlled field experiments.

Finally, statistical analysis of the impact of past climates on crops is also used to estimate future responses.

Integrated climate-crop models are currently being developed in order to try to overcome the shortcomings of the approaches outlined above, including the fact that crops will probably react to climate change in complex ways and be affected by exogenous variables, such as hydrological cycles.

1.2 Model limitations and assumptions

Significant uncertainties exist in our comprehension of the effects of climate change on agriculture. Large-scale models necessarily simplify certain parameters representing complex phenomena, even though such simplifications may have considerable implications for the outcomes.

Major areas of uncertainty include:

- drivers used in climate change and agriculture models, such as levels of future emissions, changes in crop yields and responses of the climate system;
- assumptions regarding socio-economic processes, such as how humans will respond to climate change;
- regional biases due to greater availability of information (e.g. precipitation patterns) on model inputs in developed countries;
- temporal scale issues related to lack of detailed coverage of sub-seasonal variations in climate and weather;
- need to resolve differences between large-scale global climate models, which generally have a resolution of over 100 km, and the small scale of most farming systems, which are generally less than 10 km;
- relationships between climate change and soil degradation;
- water availability;
- crop responses to atmospheric composition, especially the influence of atmospheric CO_2 concentration on crops; and
- prediction of the effects of extreme events on agriculture is currently very complicated and poorly developed in most large-scale models.

1.3 Outputs

Combining the models and scenarios outlined above allows for the projection of a number of different variables in relation to climate change over the next century. Most modelling studies focus on a set of different parameters relating to agricultural crops, because of their importance in the world economy and their sensitivity to climate change. In general, model outputs include projections of:

- changes in yields due to alterations in seasonal climates;
- changes in production potential in relation to factors such as yields, available land suitable for agriculture and lengthened/shortened growing seasons;
- responses of crops to changes in atmospheric composition, such as concentrations of carbon dioxide;
- changes in prices resulting from climate change;

- changes in patterns of trade resulting from climate change;
- changes in the number of people at risk of hunger as a result of climate change, normally measured as the number of people whose incomes allow them to purchase cereals; and
- water runoff and related water stress.

1.4 A crucial externality for agriculture – El Niño climatic events

A very important climatic event, with serious implications for coffee production is the El Niño Phenomenon. The term El Niño (Spanish for 'the Christ Child') was originally used by fishermen to refer to the Pacific Ocean warm currents near the coasts of Peru and Ecuador that appeared periodically around Christmas time and lasted for a few months. Due to those currents, the availability of fish became much less abundant than usual. At the present time the same name is used for the large-scale warming of surface waters of the Pacific Ocean every 3-6 years, which usually lasts for 9-12 months, but may continue for up to 18 months, and dramatically affects the weather worldwide.

El Niño events happen irregularly. Their strength is estimated in surface atmospheric pressure anomalies and anomalies of land and sea surface temperatures.

The El Niño phenomenon dramatically affects the weather in many parts of the world. It is therefore important to predict its appearance. Various climate models, seasonal forecasting models, ocean-atmosphere coupled models, and statistical models attempt to predict El Niño as a part of interannual climate variability. Predicting El Niño has been possible only since the 1980s, when the power of computers became sufficient to cope with very complicated large-scale ocean-atmosphere interactions.

The strongest El Niño events of the 20th century occurred in 1982/83 and in 1997/98. The effects of 1982/83 included significant storms throughout the southwest United States and one of Australia's worst droughts of the century. According to the World Meteorological Organization, the 1997/98 El Niño was a major factor in the record high temperatures observed in 1997. The impact of the 1997/98 El Niño was felt in many parts of the world. Droughts occurred in the Western Pacific Islands and Indonesia as well as in Mexico and Central America. In Indonesia drought caused uncontrollable forest fires and floods, while warm weather led to a bad fisheries season in Peru, and extreme rainfall and mud slides in southern California. Corals in the Pacific Ocean were bleached by warmer than average water, and shipping through the Panama Canal was restricted by below-average rainfall.

A very clear example of the consequences of the El Niño's effect on coffee production can be seen by studying its impact on Colombia. El Niño events in the Andean region of Colombia cause a decrease in the amount of rain and an increase in solar brilliance and temperature.

The phenomenon in some regions causes decreased coffee production due to reduced availability of water on the ground, especially in low-lying areas with less than 1,500 mm/year precipitation levels, low retention of moisture and solar exposure of crops. During El Niño episodes, there is a high risk of loss of coffee (occurrence of black beans, small beans and other defects) since the lack of water at critical stages of development of the fruit affects bean quality. Also, increases have been recorded in coffee berry borer infestation levels that affect the quality of coffee.

1.5 Climate change scenarios

For purposes of predicting climate change, scientists from the IPCC have devised a set of scenarios of how the future might unfold, excluding so-called ‘surprise’ scenarios where drastic change takes place due to a completely unexpected factor. Four qualitative storylines of future possible worlds (A1, A2, B1 and B2) define four equally valid scenario families. The storylines describe developments in many different social, economic, technological, environmental and policy dimensions.

The A1 storyline and scenario family are based on fast economic growth, slow population growth, and the swift introduction of new and more efficient technologies. Major underlying themes include convergence among regions, capacity-building and increased social and cultural interactions, with substantial declines in regional disparities in per capita income.

The A2 storyline and scenario family are based on a very heterogeneous pattern of development. The emphasis is on self-reliance and the preservation of local identities. Population growth is high, since fertility patterns change very slowly. Per capita economic growth and technological change are more fragmented and less rapid than in other storylines.

The B1 storyline and scenario family are based on a convergent world, characterized by with the same low population growth as in the A1 storyline, but with fast changes in economic structures towards a service and information economy, as well as the introduction of clean and resource-efficient technologies. Global solutions to economic, social, and environmental sustainability are emphasized, but without additional climate initiatives.

The B2 storyline and scenario family are based on a world that emphasizes local solutions to economic, social, and environmental sustainability. This world is characterized by moderate population growth, intermediate economic development, and less speedy and more heterogeneous technological change than in the B1 and A1 storylines.

These four basic storylines are the basis for six scenario groups, A1F1 (fossil fuel intensive), A1B1 (balanced – i.e. not relying too much on any one source of energy), A1T (predominantly non-fossil fuel), A2, B1 and B2. In all, 40 different scenarios have been developed. Although all scenarios are equally valid and no probabilities of occurrence have been assigned, this study will focus on the four scenario groups that are most widely used, namely A1F1, A2, B1 and B2.

These scenarios form the primary drivers for emissions scenarios, which can be generated through modelling studies and used to make projections of temperature changes. The idea is to use each of those four scenarios and predict how crops would respond to climate change. When dealing with agriculture, attention must be paid to potential changes in yields, prices, patterns or trade, and the number of farmers at risk of hunger, dislocation, natural disaster, sudden drop in income, disease, loss of crops, as well as the deterioration in crop quality due to changes in water availability, soil degradation and all the other possible climatic variables affecting agriculture.

2. The coffee sector and climate change

Climatic variability is the main factor responsible for changes in coffee yields all over the world. Though adverse air temperatures, solar radiation and relative humidity influence many physiological processes of the coffee tree, thermal and rainfall conditions are considered to be the most important factors in defining potential yield.

Among almost 100 species of the *Coffea* genus, *Coffea arabica* L. (Arabica coffee) and *Coffea canephora* Pierre (Robusta coffee) economically dominate the world coffee trade, accounting for about 99% of world production.

Arabica coffee is native to the tropical forests of East Africa, at altitudes ranging from 1,500 to 2,800 m, between the latitudes of 4°N and 9°N. In this region, air temperature shows little seasonal fluctuation, with a mean annual air temperature between 18^{o} and 22^{o}C. Rainfall is well distributed, varying from 1,600 to more than 2,000 mm, with a dry season lasting three to four months coinciding with the coolest period. In this environment, Arabica coffee became established as an under-storey shrub.

Arabica coffee vegetates and fructifies very well in tropical highlands, such as the Southeast region of Brazil. It is usually affected in growth stages by environmental conditions, especially by photoperiodic variations and meteorological conditions, such as the distribution of rainfall and air temperature, which interfere in the crop phenology, and consequently in productivity and quality. For Arabica coffee, the optimum mean annual air temperature ranges from 18^{o} to 23^{o}C. Above 23^{o}C, the development and ripening of cherries are accelerated, often leading to loss of quality. Continuous exposure to daily temperatures as high as 30^{o}C could result not only in reduced growth but also in abnormalities such as yellowing of leaves. A relatively high air temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers. It should be noted, however, that selected cultivars under intensive management conditions have allowed

Arabica coffee plantations to be spread to marginal regions with mean annual air temperatures as high as 24^o to 25^{o}C, with satisfactory yields, such as in the Northeast and North regions of Brazil. On the other hand, in regions with a mean annual air temperature below 18^{o}C, growth is significantly hampered. Occurrence of frosts, even if sporadic, may strongly limit the economic viability of the crop.

Robusta coffee is native to the lowland forests of the Congo River basin, extending up to Lake Victoria in Uganda. This species developed as a mid-storey tree in a dense, equatorial rainforest. In that region, the annual mean temperature ranges from 23^o to 26^{o}C, without large oscillations, with abundant rainfall superior to 2,000 mm distributed over a 9 to 10 month period. High temperatures can be harmful, especially if the air is dry. Robusta is much less adaptable to lower temperatures than Arabica. Both leaves and fruits cannot withstand temperatures below 6^{o}C or long periods at 15^{o}C. As altitude is related to temperature, Robusta coffee can be grown between sea level and 800 m, whereas Arabica coffee grows better at higher altitudes and is often grown in hilly areas, as in Colombia and Central America. Robusta coffee grows better in areas with annual mean temperature between 22^o and 26^{o}C, as in the Republic of Congo, Angola, Madagascar, Côte d'Ivoire, Vietnam, Indonesia and Uganda. In Brazil, the main areas that cultivate the Robusta are the lowland areas of the states of Espírito Santo (Southeast) and Rondônia (North).

The relationships between climatic parameters and the agricultural production are complex, because environmental factors affect the growth and the development of the plants in different ways during the phenological phases of the coffee crop. Agro-meteorological models related to growth, development and productivity can supply information for the monitoring of soil water and yield forecasts based on the air temperature and water stress derived by a soil water balance during different crop growth stages, quantifying the effect of the available soil water on the decrease in the final yield. The process of photosynthesis becomes limited when water stress occurs, due to closing of the stoma and reduction in other physiological activities of the plant.

Other climatic factors can reduce productivity, such as adverse air temperatures during different growth stages. A study was conducted aimed at the development of an agro-meteorological model (Camargo et al., 2006) that monitors and assesses the quantitative influence of climatic variables, such as air temperature and soil water balance on the coffee crop phenology and yield for different Brazilian regions. This kind of model could be an efficient tool to assess the environmental effects of new technologies and future climate change scenarios.

2.1 Possible impacts on coffee production under different scenarios

Each of the scenarios described in Section 1.5 will have different impacts on coffee production and trade. The analysis below is derived from the work of Peskett (2007), which is primarily concerned with the cultivation of cereals, and has been accordingly adjusted to take into account some of the specific characteristics of coffee production.

2.1.1 A1F1 scenario

In the A1F1 scenario, world population rises to nine billion by 2050 and then falls to around seven billion by 2100. During this period, economic growth increases at about 3.5% per annum and per capita income rises to $76,000 in developed countries and $42,000 in developing countries. The ratio of average incomes diminishes to about 1.6, implying a more equitable world. In this scenario, crop yields are expected to decrease. However, depending on the effects of CO_2 'fertilization', this change may not be significant at a global average. Coffee production is also likely to decrease globally, particularly in Africa. Coffee prices vary inversely with production changes and this scenario generates the largest price rises out of all of the scenarios described here.

2.1.2 A2 scenario

In the A2 scenario, population grows at a very fast rate, increasing from around eight billion in 2020 to around 15 billion in 2100. Economic growth increases at around 2% per annum, a much lower rate than in A1F1. Average per capita income in developed countries is expected to reach around $37,000, compared to $7,300 in developing countries. Differences in income between developing and developed countries become narrower, but large differences remain. Agricultural yields are likely to decrease towards 2050, as happens in A1, but decreases become less marked as the end of the century approaches. As a result, coffee production would decrease by up to 10% compared to the reference case without climate change. Coffee price increases are likely to be high.

2.1.3 B1 scenario

Population growth in the B1 scenario follows a similar trend to A1, but economic growth increases at a lower rate. Average per capita income increases to $55,000 in developed countries and $29,000 in developing countries, implying lower growth rates than in the A1 scenario. Income ratios between developed and developing countries are significantly lower than current levels, implying a more equitable world. A fall in global coffee production is expected. However, this decline would be much less marked than in the A scenarios, mainly as a result of less extreme changes in temperature. As with other scenarios, the results are heavily influenced by the effects of CO_2 on crop yields. Coffee prices would increase gradually, but remain low.

2.1.4 B2 Scenario

In the B2 scenario, the world population rises gradually towards ten billion by 2100. Economic expansion is similar to the A2 scenario but differences between developed and developing countries are smaller (although still larger than in A1 and B1). Technological change is less rapid and more diverse than in the B1 and A1 storylines. Efforts to improve environmental protection and social equity focus on local and regional levels. Global decreases in crop yields are expected, although this again would depend on the CO_2 effect. The highest drops in yield are forecast for Africa and South America, although these are not as pronounced as in the A2 scenario. Global production is likely to fall, although not as much as in the A scenarios, leading to less extreme price rises.

2.2 Possible effects of climate change on coffee production

A great degree of uncertainty still exists with regard to how individual producing regions will be affected, and how climate change will impact overall coffee production. However, experts expect some changes to occur, and these they could be significant in some regions. Among the most likely are:

2.2.1 Quality

As temperature rises, coffee ripens more quickly, leading to a fall in quality. According to Dr Peter Baker, from CABI, if temperatures rise by 3^{o}C by the end of this century (some experts believe an increase of up to 5^{o}C is possible), the lower altitude limit for growing good quality Arabica coffee will rise by roughly 150 ft (46 m) per decade. This is 15 feet per year, meaning that areas that are currently too cold for growing coffee could become suitable. However, land use at higher altitudes is restricted in many countries due to competition from other crops, inadequate soil, restrictions on cultivation, inappropriate rainfall patterns, lack of irrigation or simply an absence of infrastructure.

2.2.2 Yields

Temperature increases affect different aspects of the metabolism of coffee trees, such as flowering, photosynthesis, respiration and product composition, which in turn adversely affect coffee yields. In addition, many of the adaptation strategies discussed below also reduce yields.

2.2.3 Pests and diseases

Temperature increases will favour the proliferation of certain pests and diseases, as well as permitting their dispersion to regions where they were previously not present. In the case of the coffee berry borer (*Hypothenemus hampei*), which is considered to be the most damaging pest affecting coffee production, Jaramillo et al. (2009) predict a maximum intrinsic rate of population growth of 8.5% for every 1°C increase. A study analysing the impact of climate change on coffee of nematodes (*Meloidoygne incognita*) and the leaf miner (*Leucoptera coffeella*) conducted in Brazil concluded that the infestation of coffee plantations by these pests under the future scenarios will increase when compared with the normal climatic conditions prevailing from 1961 to 1990. Similarly, a report from Colombia warns of the possible increased incidence of diseases, such as coffee rust (*Hemileia vastatrix*) and pink disease fungus (*Corticium salmonicolor*). As a result of the increased vulnerability of coffee plantations and the need to introduce more rigorous controls, production costs will tend to rise.

2.2.4 Irrigation

As aquifers become scarcer, there will be greater stress on their use, forcing stricter control measures. According to the IPCC Technical Paper No. VI: Climate change and water, "Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes (*very likely*) and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions (*likely*)". The report concludes that many semi-arid areas, such as southern Africa and north-eastern Brazil, are likely to experience a decrease of water resources due to climate change. On the other hand, more intense precipitation and variability will very likely increase the risks of both flooding and drought in many areas. In areas that do not currently require irrigation, higher temperatures may result in increased evapotranspiration and reduced moisture content in the soil. Such areas may require the implantation of costly irrigation infrastructure. In addition, the useful life of coffee trees subject to hydric stress is likely to be shortened.

2.2.5 Global output

As a result of all the changes in the environment, there is a distinct possibility that fewer parts of the world will be suitable for growing quality coffee. If this were to happen, current trends in concentration of production could become even more pronounced. This in turn could make global production more prone to high fluctuations, as any severe disruption in output from one of the major producers would drastically curtail global output.

2.3 Strategies for mitigation and adaptation

2.3.1 Mitigation

Mitigation of global warming involves taking actions to reduce greenhouse gas emissions and to enhance sinks aimed at reducing the extent of global warming. This is in distinction to adaptation to global warming which involves taking action to minimize the effects of global warming. Mitigation is effective at avoiding warming, but not at rapidly reversing it.

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. The Stern Review 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 fossil fuel emissions.

2.3.2 Adaptation

In the case of agriculture, given the far-ranging adverse impacts of climate change, adaptation must be an integral component of an effective strategy to address climate change, along with mitigation. As such, adaptation can be approached as an opportunity to rethink development, part of a comprehensive plan to combat poverty along the lines of the Millennium Development Goals. There is a real risk that progress already made in attaining those goals is drastically slowed or even reversed by climate change as pressure builds up on water availability, food security, agricultural production and many other key aspects of today's emerging economies.

Because of the current and projected climate disruption caused by high levels of greenhouse gas emissions by the industrialized nations, adaptation is a necessary strategy at all scales to complement climate change mitigation efforts since no certainty exists that all climate change can be mitigated. Indeed the odds are quite high that in the long run more warming is inevitable, given the geologic evidence of the most similar glacial/interglacial cycle that happened about 400,000 years ago.

Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damage. Extremes, variability, and rates of change are all key features in addressing vulnerability and adaptation to climate change, not simply changes in average climate conditions.

Human and natural systems will to some degree adapt autonomously to climate change. Planned adaptation can supplement autonomous adaptation, though there are more options and greater possibility for offering incentives in the case of adaptation of human systems than in the case of adaptation to protect natural systems.

2.3.3 Least developed countries

The ability of human systems to adapt to and cope with climate change generally depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources, management capabilities, and socio-political will. There is potential for more developed and less developed countries to enhance and/or acquire adaptive capabilities. Populations and communities are highly variable in their endowments with these attributes, and least developed countries are weak in this regard. As a result, they have less capacity to adapt and are more vulnerable to climate change damages, as well as being more vulnerable to other stresses. This condition is most extreme among the most disadvantaged people.

2.3.4 Mutual reinforcement

Many communities and regions that are vulnerable to climate change are also under pressure from forces such as population growth, resource depletion, and poverty. Policies that lessen pressures on resources, improve management of environmental risks, and increase the welfare of the poorest members of society can simultaneously advance sustainable development and equity, enhance adaptive capacity, and reduce vulnerability to climate and other stresses. Inclusion of climatic risks in the design and implementation of national and international development initiatives such as polar cities can promote equity and development that is more sustainable and that reduces vulnerability to climate change.

A study by the American National Centre for Policy Analysis (2009) argues that adaptation is more cost-effective than mitigation. Their report makes the following observations:

- By 2085, the contribution of (unmitigated) warming to the above listed problems is generally smaller than other factors unrelated to climate change.
- More important, these risks would be lowered much more effectively and economically by reducing current and future vulnerability to climate change rather than through its mitigation.
- Finally, adaptation would help developing countries cope with major problems now, and through 2085 and beyond, whereas generations would pass before anything less than draconian mitigation would have a discernible effect.

2.4 Adaptation for the coffee industry

Adaptation to climate change must occur through the prevention and removal of maladaptive practices. Maladaptation refers to adaptation measures that do not succeed in reducing vulnerability but increase it instead. Examples of measures that prevent or avoid maladaptation include better management of irrigation systems and improved building regulations on coasts and in floodplains.

Planning for climate change must involve consideration of climate-related risks including those which have slow onset, such as changes in temperature and precipitation leading to agricultural losses and drought and biodiversity losses, and those which happen more suddenly such as tropical storms and floods. Past and present experiences in dealing with climate variability and extreme events provide valuable information for reducing vulnerability and enhancing resilience to future climate-related adverse impacts.

For all regions there is a need to enhance technical capacity to assess, plan and integrate adaptation needs into sectoral development plans. Also necessary is to support integration of adaptation into sectoral policy, particularly in areas of water, agriculture, coastal zones and managing natural ecosystems. Needs-based regional technological transfer is an important area in United Nations efforts helping countries to adapt. This technical transfer can include 'hard' forms of technology, such as new irrigation systems or drought-resistant seeds, or 'soft' technologies, such as insurance schemes or crop rotation patterns; or they can of course involve a combination of hard and soft.

Another important adaptation strategy is 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. There are several actions that could make coffee producers better prepared for facing the potential consequences of climate change in their areas. Among the most important are:

- detailed monitoring of changes in climate and production by elaboration of maps classifying those areas more prone to the spread of specific pests according to the likely impact of climate change. Market mechanisms such as providing financial support to growers only if they choose recommended crops are already commencing to be used in some countries, providing the kind of governmental guidance needed to assure the long-term viability of the coffee industry;
- detailed mapping of likely climate change within each coffee region: The United Nations Framework Convention on Climate Change (UNFCCC) is enabling least developed countries to identify their immediate priorities for adaptation options via the National Adaptation Programmes of Action (NAPAs) which identify their urgent and most immediate needs, that is, those for which further delay could increase vulnerability or lead to increased costs in the future. Over 40 least developed countries have received funding under the Convention to prepare their NAPAs, drawing on existing information and community-level input to prioritize adaptation plans. As a result, many countries have already submitted their NAPAs to the UNFCCC Secretariat;
- migration: Production could shift northwards or southwards (latitudinal expansion) in search of more appropriate climate conditions. One likely scenario would be a southward move in Brazilian production, to areas where the likelihood of frosts is in the decline or might even disappear altogether. However, widespread latitudinal shifts will be difficult due to the susceptibility of both Arabica and Robusta coffee to changes in photoperiod, with effects ranging from a noticeable decrease of the growth phase to an inhibition of flower development. In addition, it should be noted that coffee is currently grown in areas of Nepal and China (Yunnan province) that lie outside the 'normal' tropical distribution range of coffee cultivation. As temperature increases, production may also move to areas of higher altitude (altitudinal expansion) whose climate will become more suitable for coffee plantation. However, both movements in geographical location and in altitude may be restricted by the factors mentioned in item 2.2.1 above;

- estimation of the impact on quality of coffee production: As temperatures go up, coffee will ripen more quickly, leading to a fall in quality. This means that areas currently favourable to the cultivation of coffee will no longer be so in 20 years, and others currently too cold may become suitable. This dislocation of existing areas towards new ones is highly problematic, given the increasingly high competition for fertile land across all regions;
- a strategy to facilitate diversification out of coffee when necessary: Diversification has been on the agenda for many years now, but has proven particularly challenging, mainly because of lack of adequate substitutes. It is expected however that with increasing pressure on food crops, more land that is currently used for coffee production might find itself subject to competition from profitable crops;
- evaluation of available adaptation techniques, such as shade management systems: Although originally a shade tree, current coffee plantations can prosper without shade in zones with adequate climate and soils. However, when production has been taken to areas with less than desirable conditions, or that will be affected by climate change, the use of shading management is highly advisable, the main effects being the decrease in air temperature fluctuations by as much as 3^{o} – 4^{o}C, decrease in wind speeds and increase in air humidity. Generally speaking, shading has been adopted to avoid large reductions in night temperatures at high elevations, or in high latitudes such as Paraná State in Brazil;
- planting at high densities, vegetated soil and irrigation: With all these the main aim is to maintain and/or increase organic matter and soil water retention capacity, thereby enhancing the viability cultivation under adverse climatic conditions; and
- genetic breeding: The main objectives when it comes to genetic manipulation are those of developing higher yields, increased quality and strength, and longevity. Brazil and Colombia have been at the forefront of research in this domain, especially when it came to producing plants resistant to coffee leaf rust. It is thus essential that genetic improvement based on selective breeding of Arabica and Robusta species contributes to the long-term sustainability of coffee cultivation in potentially affected lands. In some cases, research has focused on developing varieties that could cope well with higher temperatures and remain highly productive at the same time. An interesting example is the programme for genetic improvement conducted by the *Instituto Agronômico de Campinas* (IAC) that is currently working on the possibility of transferring the characteristics of Robusta to Arabica coffee, such as resistance to pests, vigour, and above all, higher resistance to higher temperatures. Equally important is research on varieties that are less water demanding.

THE IMPACT OF CLIMATE CHANGE ON COFFEE: THE VIEWS OF STAKEHOLDERS

This Annex aims at allowing the stakeholders in the coffee sector, especially growers, to present their views on climate change. The material below is a collection of statements by non-governmental organizations (NGOs), producer associations, certification schemes and other leaders in the sector that are witnessing first-hand the consequences of climate change.

Brazil

During recent decades, Brazilian coffee production has shifted northwards, away from areas prone to frosts and in search of more benign climates. However, as a result of temperature increases and a reduction in frosts, coffee planting in the southern parts of the country is once again becoming desirable. As a matter of fact, temperatures consistently above the historical average have been registered by the country's meteorological agencies since the 1990s. Overall, scientists agree that, given the rise in temperatures, coffee planting will become increasingly viable in the southern states such as Paraná, Santa Catarina and Rio Grande do Sul, formerly considered too prone to the risk of frosts. During the 1990s, researchers from that region began to notice how overall agricultural productivity began to fell. High temperatures in October during successive years, when blossoming takes place, provoked the early loss of flowers, preventing the formation of the cherry in some cases.

According to the Brazilian Agricultural Research Agency EMBRAPA, a one degree increase in temperature could reduce by 200,000 square kilometres the current areas with climatic potential for coffee plantation. A three degree increase would remove a further 320,000 square kilometres, while a catastrophic increase of 5.8 degrees would wipe out another 310,000.

Colombia

Production costs are likely to increase due to new climatic conditions favouring the proliferation of insects, plagues and pathogens. Thus, although many pests are naturally limited by their present predators, an unstable climate can alter this assessment and foster conditions favourable to the proliferation of pathogens and insects, which will serve as inoculum for epidemics and epizootics populations. For example, in the case of the coffee berry borer, drier environments may affect the presence of the fungus *Beauveria bassiana*, reducing its effectiveness in inhibiting natural or artificial infections and promoting an increase of the populations of this pest. Similarly, an increase of rainfall during the year can counteract the restrictive effect of dry periods on the proliferation of pathogens, thus enabling the continuity of a life-cycle that otherwise would be interrupted. The same effect can occur as a result of higher temperatures. Continuous life cycles in organisms with high reproduction capacity may result in a rate of exponential growth of their populations and permanent damage to plantations. Finally, the increase in temperature in altitude and latitude in mountain regions will allow the spread of diseases to regions where it was not present earlier. Likewise, production can be affected adversely due to the incidence of diseases such as the coffee leaf rust, the pink disease (*Corticium salmonicolor*) and radical ulcers (*Rosellinia*) among others, whose proliferation is facilitated by the persistence of rain and the occurrence of a high relative humidity in the environment. Water deficiency is not common in most coffee areas of Colombia and thus irrigation is not needed. However, increases in average temperature cause high evaporation, soil water losses and higher rates of perspiration, thus increasing water requirements. If this were the case, many farmers would have to introduce some sort of infrastructure for irrigation, inevitable increasing their production costs.

There is no doubt that in the likelihood of significant global warming, chances are that in some regions coffee plantations would have to be transferred to higher altitudes, seeking more suitable environmental conditions for production. There is great interest in acquiring as much knowledge on the methodologies and use of impact scenarios to allow the assessment of the implications of climate change on the growth and development of the coffee sector.

Costa Rica

Costa Rican coffee farmers are facing threats from climate change but the rising temperatures are also expanding high-altitude regions where the country's most prized beans are grown. In Costa Rica, the temperature increases may help transform mountainous land that was once too chilly for delicate coffee trees into prime coffee-planting territory.

The strictly hard-bean Arabica coffee sought by specialty roasters is only found at high altitudes, so the shift could mean more opportunities for a country already known for its quality coffee. According to an agronomist of the Coopedota coffee cooperative, coffee can now be grown at 2,000 m, whereas before plants have not survived above 1,800 m.

India

Arabica farms in India are already experiencing the negative effects of global warming. In the Coorg region, some areas have seen rainfall drop by one-third, from 106 inches per year to 70 inches, dramatically changing the ecosystem and growing conditions. With higher temperatures, too, infestation of Arabica plants by the white stem borer has destroyed up to 35% of the crop, and Robusta plants, immune to that pest, have been hit instead by the coffee berry borer. Growers who had never given a thought to irrigation in such a wet climate have had to dig deep, high-volume wells, lowering the water table in the region. The Indian government has paid farmers to monitor the life cycle of the borers so that a means to fighting them effectively can be designed.

Kenya

In Kenya, the total area for coffee and tea cultivation is expected to remain unchanged but to migrate upwards. The land now used around Mount Kenya for tea production would all become useless for tea, and production would have to move up the mountain. That area is now forested, and the forests would likely be cut down, accelerating local and global warming. In growing areas already well suited to coffee and tea cultivation, the effects of global warming are many. The soil tends to dry more quickly, leading to cracking that can impact the smaller roots and soil organisms that support the health of the coffee tree. Coffee evolved under the canopy of larger trees, and so, in Arabica, the outer layer of the leaf cannot tolerate heat stress and it may wilt. Both of these effects make the plant more vulnerable to pathogens, especially exotic pathogens that may move into the area as it heats up. In terms of quality, higher temperatures may cause the flowering period to expand, stretching out the fruiting period, with a resulting decrease in quality.

Mexico

According to the President of the National Union of Coffee Producers, Eleuterio González Martínez, coffee production in the country is in risk by climatic change and the advance of pests. In an interview the coffee leader asserted that “with climatic change there is no longer a clear divide as to what culture is in a greater degree of risk”. Mr Gonzalez explained that previously optimal areas for the coffee production were between 600 m and 1,200 m of altitude above sea level, but now that border no longer exists. Latest reports have shown that coffees trees as high as 1,200 m are being affected by the coffee berry borer pest. That is to say, where before it was considered free from risk, “with climate change, all altitudes are at risk in coffee production". He also emphasized that there is no programme of insuring small producers, although all of them are threatened by climate change.

Peru

Rising temperatures and erratic weather patterns are changing historic trends in coffee growing areas, a region closely tied to the impact of climate change because of its rapidly melting tropical glaciers. Farmers have reported that warmer temperatures are responsible for their early start this year – about a month earlier than last. They are also reporting high-altitude plants are maturing at times more typical of their low-land counterparts.

Traditionally, Peruvian coffee growers start picking their crop in April, some six months before the global Arabica harvest. Its different growing season has given Peru, the world's sixth largest exporter of coffee, a unique comparative advantage. If the season continues to move earlier, farmers worry they could lose their privileged position. Peruvian growers have said the scarcity of rains this year in some coffee-producing areas is the result of rising global temperatures.

There is already an in-depth study being carried out by the German Agency for Technical Cooperation (GTZ) and Cafédirect aimed at making adaptation to climate change available to small producers. Research is taking place in four major coffee growing areas, with extensive interviews to coffee growers as well as local agronomists. On the whole, the main changes reported so far are:

Temperature: increases in temperature matched by sudden cold fronts provoking frost and hail.

Rainfall: reduction in rainfall levels, prolonged droughts and reduced availability of water. In some areas total levels have not been affected, but its distribution has, with torrential rains causing floods and land movements.

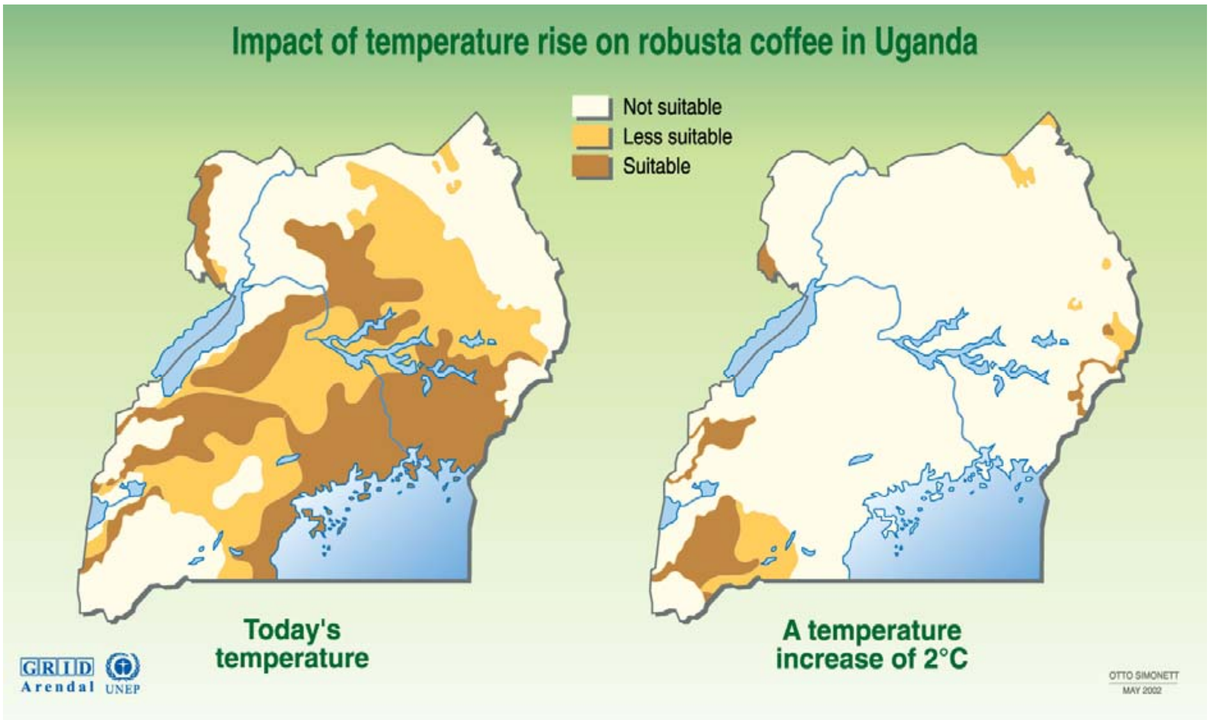
Winds: stronger winds have been responsible for the destruction of trees, roads and general infrastructure, as well as causing serious damage to coffee plantations.

Tanzania

An opposite example of the migration of prime coffee-growing areas is illustrated by Tanzania. There, where coffee contributes significantly to the GNP, the Organization for Economic Co-Operation and Development has collected scientific models of the changes that would occur when the current warming trend continues through the next few decades. Here, though, increased temperatures are expected to increase coffee yields by nearly 20%. This is very good news, not only for coffee growers but for the nation’s GNP, so Tanzania has a complex strategy for reacting to global warming, taking advantage of the benefits to exports while adapting to forecast losses in local staple crops such as corn.

Uganda

Perhaps in no country can the potential negative consequences of global warming be felt more than Uganda. A report published by Oxfam warns of the threat of a drastic reduction in the country’s land suitable for coffee cultivation. The report, called “Turning up the heat, Climate Change and Poverty in Uganda” states that “if average global temperatures rise by two degrees or more, then most of Uganda is likely to cease to be suitable for coffee. This may happen in 40 years or perhaps as little as 30.” It also makes clear that there are signs already of erratic rainfall patterns in the country. According to Oxfam, the devastation caused by the floods and landslides is already a cause for concern, especially when scientific experts warn that the current change in climatic conditions is just the beginning of these sorts of natural disasters.



Source: Otto Simonett, Potential impacts of global warming, GRID-Geneva, case studies on climatic change. Geneva, 1989.

The increase in erratic rainfall in the March to July rainy season has brought droughts and reductions in crop yields and plant varieties. But the rainfall towards the end of the year is more intense and destructive, Oxfam said, bringing floods, landslides and soil erosion. As such, Uganda's "coffee crop is in danger of extinction if temperatures rise too far".

On the positive side, however, some farmers have apparently begun to implement mitigation strategies such as growing more trees to create a cool shade for coffee, mulching or covering soil with grass to retain irrigation water, and digging long terraces in the ground to capture rainwater. How effective these measures will prove remains to be seen.

ANNEX II

ORGANIZATIONS PROVIDING FUNDS FOR MITIGATION AND ADAPTATION TO CLIMATE CHANGE

The following is a table with a comprehensive list of those organizations providing funds for mitigation and adaptation to climate change, including any amounts disbursed up to date on such programmes.

Name and link	**Type**	**Administered by**	**Areas of focus**	**Number of projects**	**Total funds disbursed to date (US$ millions)**
Adaptation Fund	Multilateral	Adaptation Fund Board	Adaptation	0	0.0
Clean Technology Fund	Multilateral	The World Bank	Mitigation – general	0	0.0
Cool Earth Partnership	Bilateral	Government of Japan	Adaptation, Mitigation - general	0	.0
Environmental Transformation Fund – International Window	Bilateral	Government of the United Kingdom	Adaptation, Mitigation - general	0	0.0
Forest Carbon Partnership Facility	Multilateral	The World Bank	Mitigation – REDD	0	0.0
Forest Investment Program	Multilateral	The World bank	Mitigation – REDD	0	0.0
GEF Trust Fund - Climate Change focal area	Multilateral	The Global Environment Facility (GEF)	Adaptation, Mitigation - general	591	2,388.7
Global Climate Change Alliance	Bilateral	The European Commission	Adaptation, Mitigation - general, Mitigation – REDD	0	0.0
International Climate Initiative	Bilateral	Government of Germany	Adaptation, Mitigation - general	128	347.2
International Forest Carbon Initiative	Bilateral	Government of Australia	Mitigation – REDD	0	0.0
Least Developed Countries Fund	Multilateral	The Global Environment Facility (GEF)	Adaptation	62	47.5
MDG Achievement Fund – Environment and Climate Change thematic window	Multilateral	UNDP	Adaptation, Mitigation - general	16	85.5
Pilot Program for Climate Resilience	Multilateral	The World Bank	Adaptation	0	0.0
Scaling-Up Renewable Energy Program for Low Income Countries	Multilateral	The World Bank	Mitigation – general	0	0.0
Special Climate Change Fund	Multilateral	The Global Environment Facility (GEF)	Adaptation	14	59.8
Strategic Climate Fund	Multilateral	The World Bank	Adaptation, Mitigation - general, Mitigation – REDD	0	0.0
Strategic Priority on Adaptation	Multilateral	The Global Environment Facility (GEF)	Adaptation	22	50.0
UN-REDD Programme	Multilateral	UNDP	Mitigation – REDD	0	0.0

ONGOING RESEARCH PROJECTS INTO THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

Projects currently under implementation to research the implications of climate change on agriculture include:

- Energy Conservation in Small Sector Tea Processing Units in South India, funded by the Global Environment Facility (GEF) Trust Fund – Climate Change focal area (mitigation efforts), US$1.0 million;
- Obtaining Biofuels and Non-wood Cellulose Fiber from Agricultural Residues/Waste in Peru, GEF Trust Fund – Climate Change focal area (GEF), US$1.0 million; and
- Adaptation to the effects of drought and climate change in Agro-ecological Zone 1 and 2 in Zambia, Least Developed Countries Fund (LDCF), US$3.5 million.

REFERENCES

American National Centre for Policy Analysis. 10 cool global warming policies, study # 321, June 2009

Arnell, N.W. Climate change and drought. *Options Mediterannéenes*, Series A, No. 80, 2004

Asian Development Bank. The Economics of Climate Change in Southeast Asia: A Regional Review, April 2009

Baker, Peter; Haggar Jeremy. Global Warming: the impact on global coffee. SCAA Conference handout, Long Beach, May 2007

Barnett. P. et al. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, 2005, 438

Baron, C. et al. From GCM grid cell to agricultural plot: scale issues affecting modelling of climate impact, *Philosophical Transactions of the Royal Society*, 2005

Betts, Richard A. Integrated approaches to climate-crop modelling: needs and challenges. *Philosophical Transactions of the Royal Society*, 2005

Bucker Moraes, Wanderson. Influência das mudanças climáticas na distribuição geográfica da *Cercospora coffeicola* Brasil. Simpósio de pesquisa dos Cafés do Brasil, 2009

Camargo M. et al. Calibration of an agro-meteorological model for predicting coffee (Coffea arabica L.) productivity in São Paulo State, Brazil, 2006

Camargo, Marcelo B. P. The impact of climatic variability in coffee crop. Instituto Agronômico de Campinas, Brazil, 2009

Cammack, Diana. Understanding the political economy of climate change is vital to tackling it. ODI Opinion 92, December 2007

Cintra de Jesus Junior, Waldir. Aquecimento global e o potencial impacto na cultura do cafeeiro. Simpósio de pesquisa dos Cafés do Brasil, 2009

Dias, Paulo C.; Araujo, Wagner L.; Moraes, Gustavo A.B.K; Barrosa, Raimundo S.; and DaMatta, Fábio M. Morphological and physiological responses of two coffee progenies to soil water availability. Universidade Federal de Viçosa, Brazil, 2007

Dresner, Simon. The Principles of Sustainability. Earthscan. London 2008

Department for International Development (DFID). Degrees of separation. Climate Change: Shared challenges, shared opportunities. London 2008

Erda L., et al. Climate change impacts on crop yield and quality with CO_2 fertilization in China. Phil. Trans. R. Soc. B, 2005

Food and Agriculture Organization of the United Nations (FAO). FAO's response to climate change. www.fao.org/climatechange, 2009

Fischer G. and H. T. van Velthuizen. GAEZ Global Agro-Ecological Zones. Soil Data Derived from WISE for Use in Global and Regional AEZ Studies. FAO/IIASA/ISRIC Report IR-97-025, 1999

Fischer, G, H. van Velthuizen, M. Shah, and F.O. Nachtergaele. *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results*. Research Report RR-02-02. International Institute for Applied Systems Analysis, Laxenburg, Austria, 2002

Fischer, G. et al. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080. Phil. Trans. Royal. Soc. B, 2005

Intergovernmental Panel on Climate Change. Emissions scenarios. Cambridge University Press, UK, 2000

Intergovernmental Panel on Climate Change Third Assessment Report (TAR). Climate Change 2001 http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm

Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4). Climate Change 2007 http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm

Intergovernmental Panel on Climate Change Working Group. Climate Change and Water Technical Paper VI, June 2008

Jaramillo, Juliana et al. Thermal Tolerance of the Coffee Berry Borer *Hypothenemus hampei*: Predictions of Climate Change Impact on a Tropical Insect Pest. University of Bristol, 2009

National Federation of Coffee Growers of Colombia (FEDECAFÉ). Impact of Climate Change in Coffee Production in Colombia. ICO Survey on Climate Change, May 2009

Nicol, Alan; Kaur, Nanki. Climate change: Getting adaptation right. ODI Opinion paper 117, November 2008

Parry, Martin L. et al. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14, 2004

Peskett, Leo. A rough guide to climate change and agriculture, Overseas Development Institute, March 2007

Titus, Anand; Pereira, Geeta N. The Impact of Climate Change on Coffee. INeedCoffee blog, www.ineedcoffee.com, 2009

Schiermeier, Q. The costs of global warming. *Nature*, 439, 2006

Silvestrini, Milene et al. Genetic diversity of a Coffea Germplasm Collection assessed by RAPD markers. In *Genetic Resources and Crop Evolution*, Volume 55, Number 6, September, 2008

Slingo, J. M. Simulation of the impact of high temperature stress on annual crop yields, www.elsevier.com/locate/agrformet, 2005

Stern, Nicholas. The Stern Review on the Economics of Climate Change, 2006

Stern, Nicholas. A blueprint for a safer planet. How to manage climate change and create a new era of progress and prosperity. The Bodley Head Ltd. London 2009

Stern, Nicholas. Key elements of a global deal on climate change. London School of Economics, 2009

United Nations Framework Convention on Climate Change. Impacts, vulnerabilities and adaptation in developing countries, 2007

Warren, R. *Impacts of Global Climate Change at Different Annual Mean Global Temperature Increases*, in Schellnhuber, H. J.; Cramer, W.; Nakicenovich, N.; Wigley, T.; and Yohe, G. (Eds) Avoiding Dangerous Climate Change, Cambridge University Press, 2006.