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Coffee and Climate Change

Impacts and options for adaption in Brazil, Guatemala, Tanzania and Vietnam

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Introduction

Gustav Paulig Ltd., Joh. Johannson Kaffe AS, Löfbergs Lila AB, Neumann Gruppe GmbH, Tchibo GmbH, Fondazione Giuseppe e Pericle Lavazza Onlus, and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of German Federal Ministry for Economic Cooperation and Development (BMZ) are implementing a supra regional Development Partnership with a focus on coffee and climate change. The objective of the initiative for *coffee and climate* is that producers and service providers along selected green coffee supply chains in key coffee regions have access to adequate knowledge and instruments that enable them to apply and finance effective climate change adaption and mitigation strategies. In order to be better prepared for the impacts of climate change, scientific research on a regional basis is necessary. Therefore short country portfolios on coffee and climate change had been developed for the four pilot countries Brazil, Vietnam, Tanzania and Guatemala.

For the present work several stakeholders at international level and national level in the four pilot countries were contacted (see Annex I). They provided information on the national coffee sector, climate change data and impact scenarios as well as research studies on climate change impacts on coffee production and trade, so far available.

All available information was studied and systematised to give an overview of perceived and expected climate change impacts on the national coffee sector in each of the four pilot countries. Relevant stakeholders and climate change initiatives at national and international level were screened and some potential partners for strategic alliances or other forms of collaboration in the framework of the *coffee and climate initiative* were identified. In order to support the project's main objective to develop a toolbox of adaptation and mitigation measures the authors furthermore identified based on existing knowledge and data the climate vulnerability of the coffee sector in each country. Consequently, they highlighted some important adaptation needs and identified potential mitigation options.

I. Summary of findings

Stakeholders in the coffee value chains in all four countries already perceive changes in coffee production that can be linked with changing climate conditions, although only two of the countries can count on specific climate predictions. In Guatemala and Brazil, where scientific institutions provide suitability maps, large changes in the distribution of the coffee are expected over the next forty years with a smaller net loss in the total area suitable for coffee production. These predictions serve very well to start the development of adequate adaptation strategies. In Vietnam climate impact scenarios, are accessible for agriculture, but there are no estimates of impacts on Robusta cultivation, while Vietnam is the world's largest Robusta producer. Nevertheless, the institutional framework in Vietnam appears to be very supportive of climate change initiatives and representatives at governmental and academic institutions are highly motivated to cooperate. In Tanzania climate change data based on international research are generally available, but coffee impact scenarios only exist for the neighbouring countries of Kenya and Uganda. Also the institutional framework is rather weak. Consequently, the coffee and climate initiative should invest in building institutional capacities in Tanzania and also in Vietnam as well as in generating baseline information.

Without question, all four pilot countries are still suffering from climate change impacts and are expected to experience more or less severe changes in the suitability of their current coffee cultivation areas. Surprisingly there are few practical adaptation and mitigation measures being implemented to cope with climate change. The only coffee specific adaptation actions are in Guatemala and Central America, and some agricultural initiatives in Tanzania. Nevertheless, the experiences and lessons learnt from existing public and private initiatives that aim at practical implementation such as AdapCC, Coffee under Pressure or the co-operation project between Starbucks and Conservation International should be considered well when designing a toolbox for climate change in the coffee sector.

General impacts of climate change on coffee

Temperature and rainfall conditions are considered to be important factors in defining potential coffee yield. Both factors interfere in the crop phenology, and consequently in productivity and quality. The Arabica coffee plant responds sensitively to increasing temperatures, specifically during blossoming and fructification. Scientific literature is varying concerning marginal temperatures for Arabica. Marcelo Camargo from the Agronomic Institute of the University of Campinas in Brazil (IAC) states that mean temperatures above 23°C hinder the development and ripening of cherries and a continuous exposure to daily temperatures as high as 30°C could result in reduced growth or even in yellowing and loss of leaves. The FAO EcoCrop model gives information on optimal and absolute temperatures for coffee Arabica, ranging from 14°C to 28°C and 10°C to 30°C, respectively. Besides the direct impacts of high temperatures on the coffee crop the increase of pests and diseases is supposed to be a consequence of increasing temperatures. Raquel

Ghini and other scientists at Embrapa in Brazil studied the impact of climate change on the distribution of nematodes and leaf miner and expect an increasing occurrence. Also water stress affects the physiological activity of the Arabica plant causing a reduction in photosynthesis.

Robusta coffee is better adapted to slightly higher temperatures, but is much less adaptable to lower temperatures than Arabica. The Food and Agriculture Organization of the United Nations (FAO) Ecocrop model determines the optimal and absolute temperatures for Robusta, ranging from 20°C to 30°C and 12°C to 36°C, respectively. Much less literature is available concerning the impacts of temperatures and rainfall distribution on the Robusta plant. This may also have led to less concern about the impacts of climate change on Robusta, but could also be due to the lower trading volume on the world's coffee market (30%) compared to Arabica (70%).

A factor that is not well understood is the response of coffee to increased carbon dioxide concentrations that are also part of climate change. Many plants respond favourably to increased CO_2 concentrations, especially contributing to increased water use efficiency. This may partially offset some of the negative consequences of increased water stress related to changing temperature and rainfall. Researchers in Brazil and at CATIE are initiating research to elucidate the real potential for the amelioration from the CO_2 fertilisation effect of climate changes impacts on the growth of the coffee.

Nevertheless, increasing mean and maximum temperatures and changing distribution of rainfall are expected, and undoubtedly will affect coffee production. In addition, coffee plantations are frequently affected by more severe and more frequently occurring extreme weather events. Specifically for tropical regions an increase in extreme weather events is predicted. Scientific research and participatory assessments show, that many of the current coffee growing regions are already suffering from these changing conditions and are very likely to be affected in the near and long-term future. This might have severe consequences, not only for the farmers, but for all actors of the coffee value chain as for the production costs, the coffee price and world market conditions.

Climate change impacts on coffee in Guatemala

Guatemala is projected to experience an increase in temperature of between 2°C–2.5°C by 2050 and a reduction in rainfall in the July-August-September period, the later obviously is critical for agricultural productivity. There is also a history of damage from severe weather events associated with hurricanes in the Caribbean causing loss in coffee production and processing infrastructure. Although the effects are less well documented, El Nino conditions lead to droughts in the region which particularly affect producers in the east of the country In general it is expected these extremes are likely to become more accentuated.

The changes in suitability for coffee production across the country vary, with loss of suitability for coffee in Eastern and Southern Guatemala and all areas below 1,000 masl, while Central and Western Guatemala maintain suitability, with the possibility of new areas becoming suitable for coffee in the northern Sierras that are not currently coffee growing areas. These changes are subject to revision depending on improvements in the modelling of the response of coffee to climate change to take into account response to increase in CO_2, socioeconomic factors, and climate variability. Work to improve these models is being undertaken between Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) and Centro Internacional de Agricultura Tropical (CIAT).

There are several initiatives to promote adaptation to climate change among coffee producers in Central America and at least two in Guatemala: Coffee Under Pressure (CUP) collaboration between Catholic Relief Services (CRS), CIAT and funded by Green Mountain Coffee Roasters (GMCR); and collaboration between Asociación Nacional del Café (ANACAFE) and Universidad del Valle. These projects currently concentrate on development of adaptation plans and promoting sustainable production practices. The CUP project analyses livelihoods analysis and models of suitability for coffee and other crops. Potentially this creates a strong integrated analysis of the threats to livelihoods and their capacity and options to adapt. How this can be translated into effects on adaptation is still being evaluated. Nevertheless, it is considered that more scientific research is required to develop adaptation technologies that go beyond simply reinforcing sustainable production practices.

Mitigation of the impacts to climate change has also been analysed in the region by ANACAFE, SAN, Universidad del Valle and CATIE. Options can be divided into reducing the contribution to climate change from green house gas emissions – primarily as result of nitrogen fertiliser use – or reducing the carbon footprint from coffee production. There are also options for sequestering carbon through reforestation on coffee farms, but at present there is no process to recognise the carbon conserved in shaded coffee agroforests.

Climate change impacts on coffee in Brazil

Brazil is one of the leading countries concerning regional climate modelling and climate change forecasts with high resolution of 50km. Excellent data and climate change scenarios until the end of this Century are available for the whole South American continent due to the fact that Brazil is running Regional Climate Models (RCM) nested into Global Climate Models (GCM), such as Hadley Centre HadAM3P in UK. The leading institutions are CPTEC (Centro de Previsao de Tempo e Estudos Climáticos) and INPE (National Institute of Spatial Research) with excellent capacities. Brazil published its second National Communication to the UNFCCC in October 2010. For southern Brazil mean annual temperatures are expected to increase above 4°C in summer and 2°C to 5°C in winter until the end of the Century. An increase of rainfall of above 20% in Southeast Brazil in form of more intense and more frequent extreme events is expected. Furthermore, impact scenarios forecast increasing evapotranspiration, water scarcity and an increasing number of areas with high climate risk, leading to less suitability for agricultural production. In order to predict climate change impacts on agricultural production CPTEC simulated the climate outlook for each Brazilian municipality in 2020, 2050 and 2070 for the Intergovernmental Panel on Climate Change (IPCC) A2 and B2 scenarios. Based on these predictions, Hilton S. Pinto and Eduardo D. Assad, at Embrapa and Unicamp, developed impact scenarios for nine important agriculture crops. According to their studies Arabica coffee is the crop, which will suffer most evident geographical redistribution. It is likely to lose up to 33% of current area in Sao Paulo and Minas Gerais, the two main coffee producing states in Brazil and increases in suitable area in Paraná, Santa Caterina and Rio Grande do Sul. Due to temperature increase the risk of frost in southern parts will decrease, thus becoming more suitable for coffee cultivation than previously. Despite the predicted increase in the South there will be an overall loss of suitable area for coffee cultivation. Based on available impact scenarios Marcelo B. Camargo proposes adaptation measures for coffee cultivation that range from shade management (arborisation), planting at higher densities, vegetated soil, irrigation, genetic breeding for pest management and other measures. Despite the excellent research work, no practical implementation of adaptation or mitigation measures in coffee sector in Brazil could have been identified. Hence, it is urgently required to start the implementation of adequate adaptation measures that may prevent serious economic losses. All necessary baseline data are available and the existing institutional framework and excellent capacities serve very well to realise adaptation in practice efficiently. In the North eastern municipalities of Pintadas a pilot project aimed at strengthening the adaptive capacity of communities has successfully combined adaptation with poverty alleviation by installing efficient irrigation systems. The experiences of the pilot project can be transferred to the coffee sector in other Brazilian regions. An ongoing cooperation between Brazil and Germany aims at the evaluation of results from this project and the potential to scale it up. This initiative can be a valuable partner for the present initiative on coffee and climate in order to design a toolbox for adaptation and mitigation practices in the coffee sector.

Climate change impacts on coffee in Tanzania

Past climate tendencies in Tanzania have been for steadily rising temperatures, decreasing rainfall and periodic droughts and excess rainfall associated with El Nino/La Nina cycles. Nevertheless models of future climate indicate an increased rainfall in both rainy seasons in the bimodal Northern Highlands, but probably some intensification of the dry season in the unimodal southern highlands, with a slight decrease in total rainfall.

The National Adaptation Plan quotes a study that estimates the impacts of climate change on coffee production and found that an increase in temperature of 2°C and higher rainfall would increase productivity by 16–18%, but with a 4°C increase in temperature production would become limited in the southern highlands. This contrasts with findings from Kenya and Uganda that indicate that climate change would lead to a significant redistribution of coffee growing areas with the minimum altitude for Arabica production increasing by up to 400 m, and Robusta cultivation moving to higher rainfall zones. Surveys of farmers show a very strong belief that climate is changing with greater irregularity of rainfall patterns and less rainfall leading to lower productivity. Changes in the altitude suitable for coffee production could obviously lead to considerable socio-economic impacts as farmers have to change their livelihoods, and environmental impacts as coffee production needs to expand at higher altitude areas competing with forestry and natural ecosystems (e.g. on Kilimanjaro).

The National Coffee Development Strategy aims to double coffee production by 2020, but does not consider the potential threat of climate change and climate variability to the success of that strategy, despite the known impacts of La Nina droughts on coffee productivity. At present there appear to be very few initiatives on adaptation and mitigation of climate change in the coffee sector of Tanzania, although there are agricultural adaptation projects in execution such as that coordinated by the Natural Resources Institute (NRI) and the University of Dar Es Salam.

Climate change impacts on coffee in Vietnam

Vietnam published its second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2010 with strong support from international institutions such United Nations Environment Plan (UNEP) and Global Environment Facility (GEF). Hence, the access to climate change data and impact scenarios for Vietnam is very good. According to General Circulation Models (GCM) the temperature in Vietnam is expected to increase by 1.4°C to 4.2°C by 2090s. The number of hot days (above 25°C) is expected to increase by 23 to 55% by 2090s, mainly in the wet season. For the Central Highlands, where coffee is grown, the number of hot days is even expected to rise to 94 in 2020, 134 in 2050 and 230 in 2100. The impact on Robusta coffee is not yet analysed but need to be considered. Furthermore, GCM indicate increasing rainfalls (-1 to +33% by 2090s), mainly in the wet season, but this is expected to be offset by predicted decrease of rainfall in the dry season (-62 to 23% by 2090s). The total rainfall is expected to increase by 2 to 14% by 2090s, mainly due to increasing extreme weather events from June to October.

National impact scenarios predict serious impacts on water resources, costal zones and the agricultural production map of Vietnam. River flows in the South are expected to decline. Groundwater is expected to drop up to 11m compared to the current level. Evapotranspiration, also in the Central Highlands, is expected to increase and the demand for irrigation in agriculture is calculated to be two- to threefold compared to current demand.

Vietnam is the world's largest producer of Robusta coffee. Robusta, covering 95% of the total production, is grown on more than 500,000 ha, mainly in the Central Highlands. The Vietnamese coffee sector has the highest yields and productivity (3.5 t/ha) worldwide. But this is due to intensive monoculture associated with deforestation, land degradation, water over-exploitation and the intensive use of fertiliser (2t/ha/year). Unsustainable cultivation practices make coffee plantations and farmers highly vulnerable to currently perceived and future climate change. The main problem is the over-irrigation and inefficient water use.

Irrigation is required during the dry season from December to April in order to achieve a 270 days growth period for optimal yield. Dave D'Haeze and other researchers studied the irrigation practices and found out that irrigation currently uses between 1,500 and 3,000 m^3 of water per ha per year. Three waterings are applied every year in order to break bud dormancy and induce fruit setting. Each watering uses between 600 to 900 litres per tree. The scientists state that this enormous amount of water is far too much and recommend reducing it to only 320 litres per tree and watering. Efficient irrigation will probably be one of the most critical factors in the near future given the climate change impact scenarios on water resources that predict a decline in rainfall, river flows and the drop of groundwater level, specifically in the Central Highland coffee cultivation area.

Vietnam is currently suffering from damage caused by the unusual extreme drought that affected the country in 2009–2010. Supported by FAO the Vietnamese government institutions have developed national policies to confront the impacts of this severe drought and designed strategies to reduce the risk of future drought events. According to latest press releases the coffee sector is already suffering from climate variability as the 2010–2011 harvest output is expected to decline by 20% compared with previous harvest due to extreme drought period and delayed rainfalls.

Numerous national and international climate change activities exist. The Ministry for Agriculture is implementing the Action Plan Framework on Climate Change Adaptation in Agriculture, but without any specific focus on coffee production, although this is the second most important agriculture product. Few coffee research institutions are working on climate change issues, and so far data on impacts and suitability scenarios are not available at all. The proposed adaptation measures for the coffee sector range from efficient irrigation and water management strategies, the application of sustainable cultivation practices and diversification of the production system and farmers' income. In order to develop a toolkit for adaptation practices the various climate change activities and institutions involved in the issue should be involved in the activities of the present coffee and climate initiative. There is a high interest and willingness to cooperate among all actors that were interviewed in the framework of the present study.

Climate change mitigation and adaptation in the coffee sector

Monitoring climate change in coffee growing regions

One of the limitations to understanding the impacts of climate variability on coffee production is the lack of precise meteorological data from coffee growing areas. This is critical for the development of climate-based insurance amongst other aspects of adaptation. We would recommend that the Programme establish simple meteorological stations in each of the regions where it works monitoring maximum and minimum temperature and precipitation. Different indicators should be reviewed with local experts in each country, but it would be useful to have a minimum set compiled across all countries where the project works, which would to some degree compensate for lack of long time series. Such information would need to be correlated to the productivity of coffee plantations, unfortunately long series of data – ideally over twenty years – are required to generate conclusions, but it is never too late to start.

Adaptation strategies

As is illustrated in the country profiles there are a number of initiatives to promote adaptation in the sector, covering a lot of important strategic elements. Some approaches focus on the farmers and their organisations and are more holistic in their strategies (AdapCC, innovations project) while others are more technical or specific in approach (CafAdpt, index based insurance), or look to combine these approaches (coffee under pressure). Although initiatives to promote the principles of sustainable production are an essential pre-requisite to achieve adaptation to climate change, they are not a sufficient response to buffer the magnitude of impacts that are expected. Investment is required from public and private sources to develop technologies that will enable coffee producers to better adapt to climate change. These processes have been started by CATIE/CIRAD/CIAT in Central America and University of Campinas/Embrapa in Brazil. The strategies for adaptation to climate change typically include the following elements all of which may be considered necessary to achieve the ultimate goal of sustaining coffee producers and the industry in the face of climate change:

- Community-based analysis of climate risks and opportunities
- Sustainable production techniques, such as shade management, new varieties better adapted to future climate conditions, conservation of soil and water sources, diversification of the production system and income sources
- Improved access to climate information for coffee producers
- Weather insurance products
- Financing to invest in adaptation and mitigation
- Payment for environmental services
- Organisation among small-scale farmers
- Value chain adaptation strategies.

Climate modules and codes

The Sustainable Agriculture Network and the Common Code for the Coffee Community have developed climate modules or add-ons to their normal standards. The two are similar in the processes they wish to reinforce namely the development of climate adaptation and mitigation plans for the farm and associated community, the promotion of management practices that should reduce greenhouse gas emissions and/or increase carbon sequestration, and the promotion of sustainable production practices that should increase the resilience to climate change.

Mitigation strategies

Mitigation can be divided into two concepts:

i. Reducing the contribution of coffee production to greenhouse gas emissions, this is primarily a function of the carbon footprint of coffee production.
ii. Sequestration of carbon in the shade trees or forest areas of the coffee farms, the conservation of existing trees could potentially be recognised under REDD+, while planting of new trees on land previously without trees have established protocols as mitigation against other emissions.

Studies of carbon footprints from coffee production indicate that on-farm emissions, and in particular nitrogen fertilisation account for about 40% of the carbon footprint of the whole coffee chain (PCF, 2008). Pressure or incentives to reduce the carbon footprint of coffee production currently come primarily from the industry and indirectly consumers. Recently Coopedota in Costa Rica announced their coffee as carbon neutral (**www.coopedota.com**).

Recommendations for the coffee and climate initiative

1. Although it is relatively clear the general effects of climate change on Arabica coffee production, this is not the case for Robusta coffee. Specific studies are required to determine the factors that may affect Robusta and where these may have most impact.
2. The project should explore options to reinforce efforts of research projects in Central America and Brazil to develop technologies to enable the adaptation of coffee production to future climatic conditions, as well as how to build on the results of these initiatives for adaptation of production systems in East Africa and South East Asia.
3. There is need to define climate variables for monitoring in producer areas to determine the actual nature of climate variability and its impact on coffee productivity and quality.
4. Engage or initiate research and validation of shade for climate resilience, adaptation and mitigation in countries where shade is not traditional, i.e. Brazil, Vietnam and Tanzania, through interchanges with regions where shade is traditional e.g. Central America and India. It is important that any trials should be well designed and managed as otherwise introduction of poorly managed shade can lead to rapid declines in productivity.
5. Given that climate variability and extremes are likely to be a considerable part of climate change, it would seem that greater effort should be put into testing and resolving the outstanding issues around the viability of weather insurance.
6. Training, facilitation and financing are required to scale up the adoption of the SAN climate module, the 4°C climate code and the adoption of the climate adaptation and mitigation measures in general to increase the resilience of coffee producers to climate change.
7. We consider that it is necessary to validate the effects of the mitigation aspects of the climate modules in order to gain credibility and so that compliance with these criteria can bring economic and market benefits to farmers.
8. Also both systems promote farmers maintaining some register of Greenhouse Gas (GHG) emissions. Tools need to be developed to enable farmers to keep reasonable measures, nevertheless we consider that it is probably necessary to develop a specialist service to process this information to provide reliable orientation as to the tendencies in GHG emissions, this could include the calculation of a farm carbon balance or footprint.
9. There is certain confusion in the industry on the relationship between the carbon footprint of the coffee chain and the apparently high emissions from on-farm against the carbon stocks and potential sinks from shaded coffee production. A synthesis of the information available should be conducted to try to resolve the relationship between these two processes and evaluate the potential for on-farm sinks to compensate emissions and contribute to a climate friendly carbon neutral coffee industry.
10. The programme has the opportunity to facilitate value chain adaptation strategies to manage variations in the supply of coffee due to climate change so as to not affect the long-term relationships between actors.

II. General information on possible climate change impacts in coffee crop

Impacts on the coffee Arabica plant

Thermal and rainfall conditions are considered to be the most important factors in defining potential coffee yield. Arabica coffee vegetates and fructifies very well in tropical highlands. It is native to the tropical forests of East Africa at altitudes ranging from 1,500 to 2,800m, where air temperature shows little seasonal fluctuation and rainfall is well distributed over the year. The distribution of rainfall and air temperature interfere in the crop phenology, and consequently in productivity and quality. Above 23°C, the development and ripening of cherries are accelerated, often leading to loss of quality. Continuous exposure to daily temperatures as high as 30°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. The process of photosynthesis becomes limited when water stress occurs, due to closing of the stomata and reduction in other physiological activities of the plant (Camargo, 2009). 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°C –25°C, with satisfactory yields, such as in the Northeast and North regions of Brazil (Fazuoli et al, 2007; Bergo et al, 2008). On the other hand, in regions with a mean annual air temperature below 18°C, growth is largely depressed. Occurrence of frosts, even if sporadic, may strongly limit the economic success of the crop (Camargo, 2009).

As regards water needs, the coffee plant requires moist soil during the period of vegetative growth and fructification, and drier soil in the periods of fruit maturing and harvest.

A quality problem could arise, from the faster plant growth that will lead to lower coffee fruit quality. Besides, high maximum temperatures during summer months may cause an excessive fruit ripening, against fruit quality. Coffee trees are resistant to high summer temperature and drought, but the increase of extreme conditions can be responsible for physiological stresses, such as the reduction of photosynthetic efficiency. Other critical phases are flowering, in relation with the breaking of bud dormancy break, and grain fill. Moreover high temperature and dry conditions during the reproductive phase can be critical for the optimum coffee production and quality. The setting of adequate air temperature limits for coffee is decisive for the distribution and economic exploitation of the crop (Camargo, 2009).

The scenarios on climate change of the International Panel on Climate Change (IPCC) predict for most parts of the Central American region an increase in mean annual temperature between 1°C–2°C until 2050. Dry seasons are expected to become even drier and precipitation is predicted to reduce, in some areas up to 30%, and to be distributed less regularly (IPCC, 2007). Consequently, the optimal climate conditions for Arabica coffee cultivation in most of the current production regions are likely to change. In addition, higher temperatures improve living conditions for pests and diseases. Increasing pest attacks lead to the loss of quality of the coffee beans or even to the destruction of yield and plants.

Impacts on the coffee Robusta plant

Robusta coffee is native to the lowland forests of the Congo River basin; with extend up to Lake Victoria in Uganda. This species developed as a midstorey tree in a dense, equatorial rainforest. In that region, the annual mean temperature ranges from 23°C to 26°C, without large oscillations, with abundant rainfall superior to 2000 mm distributed over a nine to ten month period. High temperatures can be harmful, especially if the air is dry (Coste, 1992). Robusta is much less adaptable to lower temperatures than Arabica. Both leaves and fruits do not withstand temperatures below 6°C or long periods at 15°C. As altitude relates to temperature, Robusta coffee can be grown between sea level and 800m, 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 among 22°C to 26°C, as in the Republic of Congo, Angola, Madagascar, Ivory Coast, Vietnam, Indonesia and Uganda. In Brazil the main areas that cultivate the Robusta are the lowlands areas of the Espirito Santo and Rondonia states (Camargo, 2009).

Robusta coffee (Coffea canephora), as its name suggest, is less sensitive to climate changes. With its origins in the low equatorial regions of the Congo basin, with a hot and humid climate, the plant adapts well too much higher temperatures, with annual averages of 22°C to 26°C. However the coffee plant, in general, is far less tolerant of the cold. Temperatures of -3.5°C provoke damage to leaf tissue and trunks. Other publications consider temperature below 5°C lethal. These levels can be practically lethal to the plant, depending on the topographic conditions of the plantation. The crop is more vulnerable to frost when located in valleys, where the air builds up on cold nights (Camargo, 2009).

The EcoCrop model of FAO summarises optimal and absolute conditions for Arabica and Robusta coffee as follows:

Table 1 Optimal and absolute growing conditions for Arabica and Robusta coffee

	Arabica				Robusta			
	Optimal		Absolute		Optimal		Absolute	
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
Temperature	14	28	10	34	20	30	12	36
Rainfall	1,400	2,400	750	4,200	1,700	3,000	900	4,000
Soil pH	5.5	7	4.3	8.4	5	6.3	4	8

Source: EcoCrop/FAO, 2011, ***http://fao.org/ecocrop***

Impacts on the coffee industry

The already perceived and for the future predicted impacts of climate change on coffee production will not only threat small-scale farmers as they are at risk of losing their yield and family income. Moreover, all actors of the value chain, including the consumer will be affected. Reduced areas suitable for production will influence the world coffee market, especially for high quality or gourmet coffees or brands with denomination of origin status, and will increase the pressure on the price.

More coffee may need to be grown under irrigation, thereby increasing pressure on scarce water resources. All the foregoing will increase the cost of production whereas in the future fewer parts of the world may be suitable for coffee production. If so then the already evident growth in concentration could become even more pronounced, bringing with it an increased risk of high volatility. For example if an extreme event should severely curtail the output of one of the major producers (Läderach et al., 2010).

Leo Peskett from the Overseas Development Institute related the IPCC scenarios (A1F1, A2, B1, B2) with the international coffee market and found out that under all scenarios global coffee production will fall leading to significant price rises. In consequence, the competition for high quality products might become more serious, keeping in mind the steadily growing demand for certified high quality and environmentally friendly coffee. Some market actors surely will be able to benefit from rising prices, but it is obvious, that on the other hand this will create a lot of climate change losers, among them small-scale farmers, whose livelihoods heavily rely on the income from coffee production (ICC, 2009).

Climate change impact assessment tools

The climatic variability is the main factor responsible for the oscillations and variation of the coffee grain yield in the world. The relationships between the climatic parameters and the agricultural production are quite complex, because environmental factors affect the growth and the development of the plants under different forms during the phenological phases of the coffee crop. Agro-meteorological models related to the growth, development and productivity can supply information for the soil water monitoring and yield forecast 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 of the final yield. The processes of photosynthesis become limited when water stress occurs, due to closing of the stomata and reduction in other physiological activities in the plant. Other climatic factors can reduce the productivity, such as adverse air temperatures happened during different growth stages. An agro-meteorological study was conducted aiming to develop 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. That kind of model could be an efficient tool to assess the environmental effects of new technologies, and future climate change scenarios.

Especially Brazilian scientists since many years are studying the impacts of climatic variability and climatic events on quality and yield of the coffee beans. They assessed the impacts of pests and diseases, frost attacks, heat waves and water stress or water shortages on the fruit, mainly of Arabica coffee. In Vietnam, where mainly Robusta is grown and intensive irrigation is applied, scientists started assessing the demand for irrigation and are developing more efficient irrigation systems. But there is still a high level of uncertainties, first of all regarding future climate change modelling and secondly regarding the real impacts that will affect coffee yield and quality in the future. Harvest output, productivity and fruit quality depend on a complex system of more or less interrelated environmental, technological and social factors. Temperature and rainfall distribution are just two of them. In addition, the fertilisation impact of additional CO_2 in the atmosphere needs to be considered, when forecasting climate change impacts on coffee production. Although some institutions started investigations on that issue, up to now very few information is available.

Drought and high and low temperatures are undoubtedly the major threats to agricultural crop production, and the possibility to develop projections of drought occurrence at the regional scale is a necessary step toward the definition of suitable adaptation strategies for the coffee sector. In deriving drought projections from regional climate scenarios, the capability of climate models to reproduce the key feature of the hydrological regime should be examined. In addition, from a risk analysis standpoint there is a pressing need to quantify uncertainties in the projections and provide probabilistic assessments of the impacts of climate change, including frost (Camargo, 2009).

1. Country profile: Guatemala

Summary of findings

i. Guatemala is projected to experience an increase in temperature of between 2°C–2.5°C by 2050 and a reduction in rainfall in the July, August, September period, the latter obviously is critical for agricultural productivity.

ii. The changes in suitability for coffee production across the country vary, with loss of suitability for coffee in Eastern and Southern Guatemala and all areas below 1,000 masl, while Central and Western Guatemala maintain suitability, with the possibility of new areas becoming suitable for coffee that are not currently.

iii. These changes are subject to revision depending on improvements in the modelling of the response of coffee to climate change to take into account response to increase in CO_2, socio-economic factors, and climate variability.

iv. There are several initiatives to promote adaptation to climate change among coffee producers in Central America and at least two in Guatemala, these currently concentrate on development of adaptation plans and promoting sustainable production practices. It is considered that more scientific research is required to develop adaptation technologies.

v. Mitigation of the impacts to climate change can be divided into reducing the contribution to climate change from green house gas emissions – primarily as result of nitrogen fertiliser use – or reducing the carbon footprint from coffee production. There are also options for sequestering carbon through reforestation on coffee farms, but at present no process to recognise the carbon conserved in shaded coffee agroforests.

1.1 Projections of future climate change

The following summarises the predictions of change in climate presented in the first national communication on climate change in 2002.

Predicted climate changes

Temperature increases – it is probable that the temperature will increase by the year 2050 between 1.5°C (optimistic scenario) and 4.5°C (pessimistic scenario) with the month of May being the hottest one with temperatures exceeding 28°C; an expansion of the areas with higher temperatures is to be expected at the expense of the one where currently there are lower temperatures such as the mountainous areas.

Precipitation reduction – all three scenarios (optimistic, moderate, pessimistic) point to an average reduction in precipitations by the year 2050 for the trimester July, September with the month of August presenting the most severe reduction.

Climate variability

In recent years (between 2001 and 2007) storms and droughts have had the highest human and economic impact in Guatemala, with losses for the period 1997–2006 averaging 0.51% of GDP – 485,662 people (around 5% of the country's population) have been affected by storms (three events) with the cost of the damages reaching US$1 billion and 113,596 people (around 1% of the country's population) have been affected by droughts (1 event) with the cost of damages reaching US$14 million. The damage inflicted by Hurricane Stan alone amounted to economic losses totalling 3.1% of GDP in 2004 According to the Guatemalan Ministry of Agriculture, Hurricane Stan, which hit the country in 2005, damaged an agricultural area of 720,000 hectares. The crop losses were estimated to be 50% in the case of yellow maize, 80% for black beans, 30% for white maize, 90% for banana, sorghum and sesame and 5% for sugar cane. It is also estimated that in some areas of the western departments, 100% of the small livestock died as a consequence of the disaster (UNDP, 2009). The UNDP report makes no mention of losses from the coffee sector, although reports from ANACAFE and Federación de Cooperativas Agrícolas de Productores de Café de Guatemala R.L (FECOCAGUA) at the time indicate a loss of 20% in coffee production from the Pacific slope region amounting to $4 million of losses. Comisión Económica para América Latina y el Caribe 2005 report a 3.3% reduction in the expected coffee production for 2005 due to Stan.

Current projections of climate change cannot account for climate variability; nevertheless, there is reason to believe that climate variability will increase (Elsner et al 2008) and indications that the frequency and duration of the El Nino/ La Nina cycles have become more pronounced (Gergis & Fowler, 2009). It is probable that it is years of extreme climatic conditions that will actually eliminate areas in coffee production. This could happen in a number of different ways.

a. In La Nina years hurricanes and persistent tropical storms are favoured and primarily cause flooding, landslides and erosion. During Hurricane Stan the Pacific Slope of Guatemala and Chiapas was affected, road infrastructure was destroyed just prior to the harvest, and there were some direct losses on coffee farms of wet mills and coffee plantations. In areas not affected by these physical impacts the persistent rainfall, and high humidity can lead to fruit fall and accentuate outbreaks of diseases such as Pellicularia koleroga, which normally only have localised effects.

b. In El Nino years there are two effects firstly drought due to reduced rainfall in the wet season and then a longer subsequent dry season leading to complete defoliation of coffee (and even shade trees) and die back of plants (as witnessed in S Nicaragua in 2006–07, after less than 1,000 mm of rain fell in 2006 and the dry season extended into a seventh month). The second effect at higher altitudes is increased persistence and intensity of cold fronts in the northern winter (Conde et al., 2008); this could limit the upward movement of coffee in response to increased average temperatures.

1.2 Impacts of climate change

Guatemala has a higher vulnerability in Latin America in general to climate change, especially in the areas of risk of extreme weather events (70%), dependence on rain-fed agriculture (95%), and employment dependent on agriculture (40%) (UNDP, 2009).

Impact on agriculture

The main crops cultivated in Guatemala are corn, beans, rice, sorghum and wheat (UNDP 2009). According to climate change scenarios to analyse the vulnerability of basic grain production to climate change in Guatemala for the year 2030, increases in temperature of 1.7°C (optimistic scenario), 1.2°C (normal scenario) and 2.4°C (pessimistic scenario) along with variation in precipitation ranging from average 6% increases (optimistic scenario) to 18% decrease (pessimistic scenario) for corn, beans and rice will mainly lead to yield decreases as follows: i) yield increases for corn of up to 15% or yield decreases of up to 34% depending of the zone; ii) dramatic yield decreases of up to 66% for beans for zone three of the valley of Asuncion Mita Jutiapa and Monjas Jalapa or modest yield increases of up to 3% for the farmlands of Amatitlan, San Jose Pinula, Palencia and Villa Nueva and iii) yield decreases of up to 27% for the lower areas of the Polochic river basin.

Effects on coffee

The projections of changes in altitude suitable for growing Arabica coffee from Laderach and Eitzinger (n.d.) in Mesoamerica, coincide in that the lower limit would rise from 600–700 masl to about 1,000 masl. The upper limits are affected by the land area available for production, which in the case of Nicaragua is very limited, i.e. there is very little land above 1,800 masl. Even in Chiapas it was estimated that the area of high suitability for coffee production would be reduced from 265,000 ha to just 6000 ha (Schroth et al., 2010). Thus it is probable that the projections for Guatemala would be very similar, and probably closer to Chiapas, as high elevation land is present.

Table 2 Changes in altitudinal range apt for Arabica coffee production (minimum 30% suitability) interpreted from Laderach and Eitzinger (n.d.) and Schroth et al., (2010).

Country	Actual		2050	
	Min.	*Max.*	*Min.*	*Max.*
Chiapas/ Mexico	700 m	1,950	1,000	2,150
Nicaragua*	600	1,600	1,000	n/d

*There is effectively no land for production above 1,800 masl in Nicaragua, so it is not possible to calculate a future upper altitudinal limit.

The preliminary Mesoamerican (Central America plus Mexico) distribution maps from Laderach et al., (2010) indicate that although low altitude areas in Guatemala would lose suitability for coffee production, there is substantial area where suitability would increase, especially around the high plateau of central and western Guatemala, some of this area is currently not a coffee growing region. A visual interpretation of the maps summarises the effects by department are as follows, these impressions should be verified using more precise means:

i. The primary areas that would uniformly lose suitability for coffee are the eastern departments of Jalapa, Santa Rosa, Jutiapa and Chiquimula
ii. The lower coffee growing areas along the Pacific volcanic range (San Marcos, Quetzaltenango, Retalhuleu, Suchitepequez and Escuintla) and also Alta Verapaz, would also lose suitability, but not the high altitude areas
iii. The departments that maintain conditions are Guatemala, Antigua, Chimaltengango, Solola and Huehuetenango
iv. Those areas that gain conditions suitable for coffee are Huehuetenango (higher into the Chuchumatane mountains), and also the high mountains of Quiche and Baja Verapaz
v. Map of change in suitability for coffee production in Mesoamerica (Source International Center for Tropical Agriculture, CIAT, A.Eitzinger@cgiar.org, 2010).

The table below shows areas for different degrees of change in suitability and climate for the coffee growing areas of Guatemala (Laderach et al., 2010). It should be noted that these changes are less severe than for other Central American countries plus Mexico. Honduras and Nicaragua suffer more severe changes in precipitation, and temperature and consequently loss of area suitable for coffee, but so too do Costa Rica and El Salvador with between a third and a half of the coffee area suffering severe loss of suitability for coffee. Guatemala is the only country with a significant area that gains suitability for coffee.

Table 3 Changes in area suitable for coffee production in Guatemala

Percentage of area with different degrees of change in suitability for coffee production			
>0% ie. +ve	-20% to 0	-40% to -20%	More than -40%
7.4%	54.2%	25.5%	12.9%
Percentage of area with likely change in precipitation			
>0% ie. +ve	-5% to 0	-10% to -5%	More than -10%
	82.6%	17.4%	
Percentage of area with likely temperature change			
	2.0–2.25°C	2.25–2.5°C	
	60.8%	39.2%	

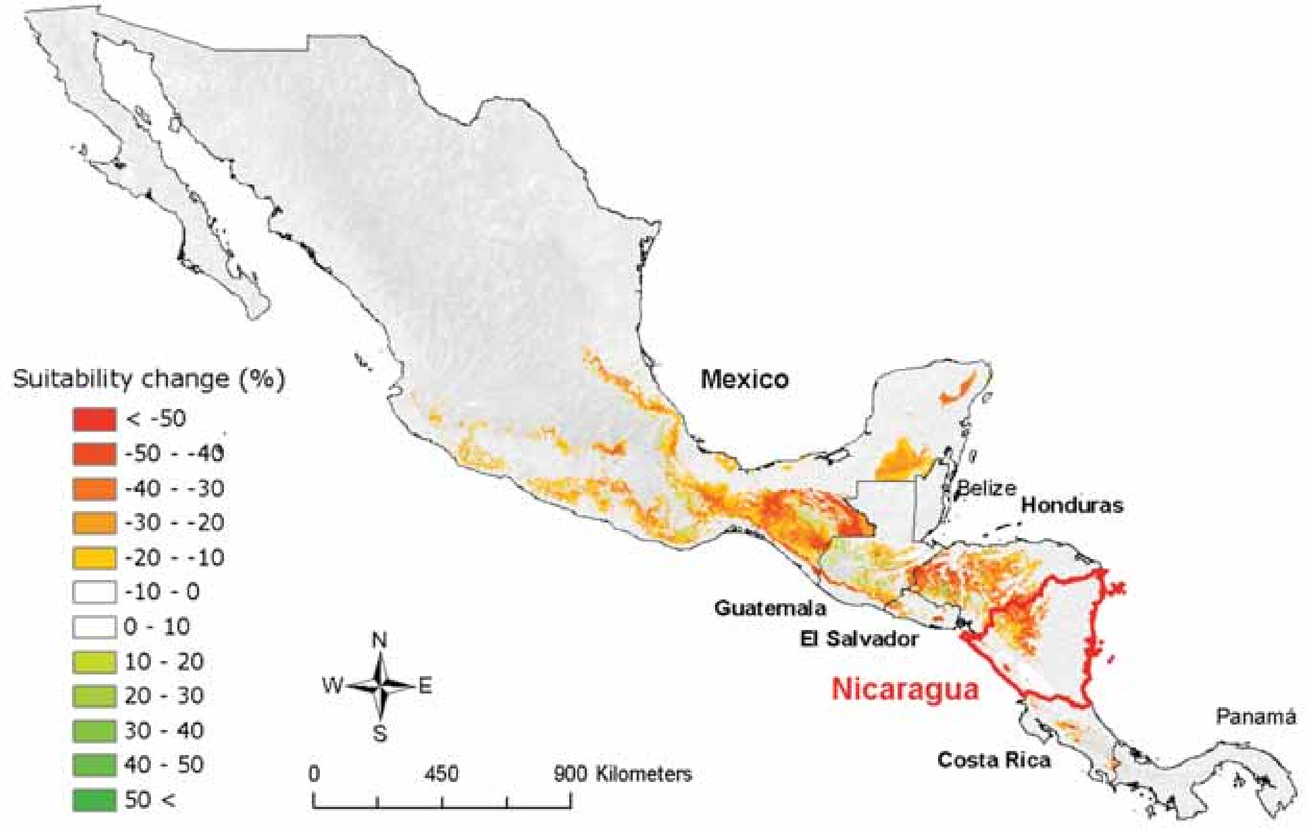

Figure 1 Map of change in suitability for coffee production in Mesoamerica, Source: International Center for Tropical Agriculture, CIAT, A.Eitzinger@cgiar.org, 2010

There are also two important caveats that may ameliorate the projections of impacts of climate change on coffee distribution, and one that may intensify them.

i. As mentioned above current climate models do not include climate variability, the models are based on projections of average climatic conditions, but do not take into account climate variability, and especially the El Niño/La Niña cycles that dominate the climate in the region. Thus the extremes of climatic conditions either excess rainfall or droughts are not well accounted for in these models, especially the possibility that these cycles may intensify. It will probably be extreme climatic events, whether drought or excess rain, that will actually be the cause of the loss of coffee plantations.

ii. The projections made are based on the climate conditions of the present distribution of coffee; however it is important to realise that current distribution is a function of the site productivity versus the costs of production. Thus the lower altitudinal limits indicated from the Laderach study are not the physical limits for Arabica coffee plant growth. In both Guatemala and Nicaragua coffee can be found at a lower elevation, with some commercial plantations down to 450 masl, and remnants of previously commercial coffee as low as 300 masl. This low elevation coffee has largely been abandoned because the lower and more variable productivity was not sufficient for it to be economically viable, but if coffee price rises were sustained this situation could rapidly change.

iii. The other consideration is that current models are based on response to temperature and rainfall, but do not consider the plants positive response increased concentrations of CO_2. To date there has been no published research to know the magnitude of this response for Arabica coffee, but there is the potential for effects increasing productivity and water use efficiency, which could ameliorate the effects of increased water stress with higher temperatures or lower rainfall.

At present we consider that the changes in coffee distribution developed by Laderach and Eitzinger (n.d.) represent the worst effects that could occur for the degree of climate change modelled (although the climate change predictions used are the average of a large number of models, and not the worst case scenarios), at least in the sense they do not include adaptation of the coffee plant, nor the economics of production.

Impacts and limitations to adaptation

A study between the Universidad del Valle and ANACAFE (Castellanos et al., 2008) on the perspectives of farmers indicates that 57% of farmers lost coffee in 2006, 27% due to excess rainfall and 26% due to lack of rain. Overall 39% of respondents were concerned about effects on coffee of drought, 30% heavy rains, and 23% hurricanes. Most considered the frequency of these events has increased, but little can be done a part from shade management in some cases (mostly for drought). A survey by Hanns R.Neumann Stiftung (HRNS) of farmers in 2010 conducted for the Coffee Climate initiative indicated weaker concerns about climate change than in some other countries, the main concerns were about the effects of excess rainfall and physical damage such as from landslides, and greater variability and more extremes in the climate.

Laderach et al., 2010 discuss the adaptation options in the face of climate change. Although suitability mapping indicate that there is potential for coffee to move higher to altitudes that are still suitable for coffee there may be other restrictions to this occurring. Firstly, much of the higher altitude land on the Pacific volcanic change is in forest protecting water and soil resources on very steep slopes, although much of this area is not formally protected it is questionable as to whether it would be appropriate to allow expansion of coffee. This was seen as a significant limitation and threat in analysis of the effects of climate change on coffee and forests in the Sierra Madre of Chiapas (Schroth et al., 2010). More detailed mapping should be undertaken to determine the true land area that would be suitable for coffee production between 1900 and 2100 masl.

At the other extreme is consideration of the environmental impacts of abandonment of coffee production at lower altitudes. Medina et al conducted an evaluation of the changes in coffee area during the coffee price crash between 2000 and 2004, and found that a third of coffee had been eliminated below 700 masl, most of this coffee had been under a diverse coffee agroforest system. If the area suitable to Arabica production to a higher altitude the considerable area under coffee agroforests between 700 and 1,100 masl could come under threat affecting biodiversity, carbon stocks, and soil and water conservation.

1.3 Initiatives for adaptation to climate change

AdapCC

The AdapCC project run by Cafédirect and GTZ (**www.adapCC.org**), promoted the development of adaptation strategies by coffee cooperatives in Nicaragua, Mexico and Peru. These strategies concentrated on improving disaster preparedness, promoting sustainable production practices – especially soil conservation, tree planting etc, and introducing solar driers to preserve coffee quality during the harvest. Mitigation measures included reforestation to offset emissions and reducing energy use in the mills. It also recognised the need for broader responses such as the development of coffee varieties with a broader adaptability to a range of climatic conditions.

Coffee Under Pressure

Coffee Under Pressure a project between Catholic Relief Services with scientific support from CIAT, and financed by Green Mountain Coffee Roasters, works in Mexico, Guatemala, Nicaragua and El Salvador. Models of changes in suitability for coffee production have been amplified to cover all Central America and Mexico. Subsequently communities have been studied to determine their vulnerability to climate change in three aspects:

i. Exposition which is the change in suitability for coffee production over the next forty years
ii. Sensibility which is the degree to which families livelihoods are likely to be affected by climate change
iii. Capacity of families to adapt to the consequences of climate change on their livelihoods.

The exposition is derived from the models of change in suitability. Sensibility and capacity for adaptation are obtained from family interviews of the livelihood strategies of coffee producers (Baca et al., 2010). The results of these analyses indicate that the differences in these parameters from family to family, even within a community, can be very great. The project has also mapped the probably changes in suitability for some thirty crops that could provide alternatives to coffee production, and which also contributes to the valuation of the capacity to adapt. Georeferencing of individual farms can permit individual evaluation of the probable change in suitability for coffee, and which other crops may maintain or improve in their suitability for that site. The tool is in development – but hopefully could become a publically available service.

Although fairly specific predictions can be made as regards to the changes in agroclimatic suitability of different crops, this does not take into account suitability of soil, type nor the economic viability of the product. However, the socioeconomic and livelihood capacities for adaptation are much more family and community specific. The development of adaptation strategies therefore requires local processes of identification of sensibility and needs to improve the capacity to adapt.

Climate insurance

The Government of Guatemala has one instrument in place that supports the agriculture sector in managing climate risks, GUATEINVIERTE. This is a programme (a fund) that guarantees lines of credit from private banks to the agriculture sector. As part of the guarantee scheme, the banks are required to request agricultural insurance coverage from borrowers. The programme can subsidise up to 70% of insurance premiums according to the crop and location of the farmer.

Over the past three years there has been an initiative by the Inter American Development Bank and World Bank to work with national governments and the Inter American Federation of Insurance companies to develop climate insurance for the agriculture sector. Part of this work is to validate index based climate insurance for coffee producers. CATIE with CIRAD have been contracted to evaluate whether a model can be developed for index based climate insurance for coffee in Nicaragua, initial results are expected by end of April 2011. It is understood that a similar project is being undertaken in Guatemala between La Ceiba Insurance, FEDECOCAGUA with technical assistance from the University of Berkley. From a personal interview with the general manager of La Ceiba it is apparent that although there is much interest, there are also many unresolved questions as to appropriate design for climate insurance and its financial viability. It has also been noted that farmers don't even insure infrastructure and equipment against loss, which is much more straight forward than crop productivity where attributing the cause of variations is considerably more complex.

At present it is not clear whether index based climate insurance for losses in production is technically viable. The climate response of coffee is complex as the factors that contribute to production accumulate over a period of eighteen months from the vegetative growth of the branches that will produce, through floral initiation and pollination, to the maturing of the fruits. Most limiting however, is a lack of long-term records of coffee productivity (over ten years) associated with equally long weather records that can effectively test the influences of climate on coffee productivity.

Innovation in adaptation to climate and market change for coffee value chains

This research and development project run by CATIE is working with coffee cooperatives and farmers in Nicaragua and Honduras to develop decision making capacity to confront climatic and market variations. At the on-farm level the project is working on integrated diversification of coffee farms to increase the resilience of the production systems, while at the cooperative level on developing risk management strategies on the marketing of coffee.

CafAdapt

This research project financed by Fondo Regional De Tecnología Agropecuaria (FONTAGRO) (BID) is the only research effort known in the region to develop adaptation of the coffee production system to climate change. It is conducted by a consortium led by CATIE, with CIRAD, CIAT, the Coffee Institutes of Honduras, and Costa Rica, and the Agrarian University of Nicaragua. Guatemala is not included because it is not eligible for funds from FONTAGRO, but the research being initiated is relevant for the whole region, if not across the world. In summary the project pretends to validate a physiological model of coffee production to integrate the effects of increased CO_2 with changes in temperature and rainfall to develop better predictions of the effects of climate change on productivity. Parallel the project will characterise the capacity of new coffee genetic materials (coffee hybrids produced in previous work) to adapt to a range of climatic conditions and temperature and water stress. Then the model will be validated to test the effects of a range of management options including the use of these new varieties as well as more conventional adaptation measures such as shade, fertilisation, irrigation etc. Subsequently the effects of these adaptation strategies will be mapped to see their potential to ameliorate the impacts on coffee distribution and production generated by current models. The understanding of the response of Arabica coffee to climate change, and whether coffee F1 hybrids are more resilient to climate change and variability, are results that would be relevant to coffee across the world.

1.4 Mitigation options

The Sustainable Agriculture Network climate module was designed through a project in Guatemala Rainforest Alliance, ANACAFE, Universidad del Valle, and Efico Foundation (Cuchet, 2010). The intervention works with some 370 farmers from five cooperatives and aims at developing the module, validating it through field measurements, training farmers and auditors in verification of the criteria and to raise awareness of this added value in the coffee chain. The climate module criteria have been reviewed through the multi-stakeholder processes that SAN uses for socialising and adjusting any new standard, which has now been published (SAN, 2011). The criteria are based on ensuring practices that should contribute to conservation of carbon stocks, limiting GHG emissions, and improving preparedness for extreme climate events both on the farm and in the community.

It is understood that the validation from field measurements have demonstrated carbon stocks of about 80tC per ha about half of which is in the trees and coffee (Cuchet, 2010), which is similar to other studies in the region. We consider that it is important to validate the impacts or differences of farms that are compliant with this standard to demonstrate the real impacts especially in terms of mitigation i.e. the impacts on carbon stocks and GHG emissions, or carbon footprint, at the farm level. We understand that the module does not pretend to demonstrate carbon neutrality, be a carbon footprint nor a lifecycle analysis. Nevertheless, we do think that to build the credibility of the certification it is necessary to demonstrate that farms that comply with the standard have larger carbon stocks or lower emissions than those that do not, or that the standard promotes improvements in these aspects. The impacts in terms of capacity to adapt to climate change will only be revealed with time.

Financing for mitigation through reforestation can be received through the Programme for Forest Incentives27 (PINFOR, Spanish acronym) promoted by the National Forest Institute (INAB) and aimed at stimulating the sustainable forest development in the country through investments in forestation and reforestation activities and management of natural forests. It consists of a cash payment from the government for reforestation or forest management projects and will be active until 2017. We understand that some coffee farmers have benefited from these payments but primarily for reforesting areas outside their coffee plantations.

We understand that ANACAFE's (Rosa Maria Aguilar, Environment Coordinator, ANACAFE, pers com) main aim in promoting these processes is to develop recognition of the environmental services provided by coffee, and the financial compensation for the provision of these environmental services either through direct payments or improved market access and conditions. In adaptation to climate change they perceive the need for more training of farmers to understand the implications of climate change and how to adapt.

1.5 Recommendations of priorities for adaptation and mitigation in Guatemala

Table 4 Recommendations of priorities for adaptation and mitigation in Guatemala

Themes	Potential collaborators
Training farmers to increase resilience to climate change in their production systems	ANACAFE, CATIE, Coops
Diversification strategies for areas leaving Arabica production	ANACAFE, CIAT, MAGA
Identification and validation of potential new areas for Arabica production	ANACAFE, CIAT
Validate climate insurance	FIDES, La Ceiba, CIRAD/CATIE, Univ Berkley
Determine Carbon Footprint/C neutrality	Universidad del Valle, CATIE, ANACAFE
Evaluate potential for compensation of environmental services	Universidad del Valle, CATIE, ANACAFE

2. Country profile: Brazil

Summary of findings

i. Excellent data on climate change available, Regional Circulation Models (RCM) developed by CREAS (Cenarios Regionalizados de Clima Futuro da America do Sul), high resolution scenarios (50 km), and running three regional models (Eta CCS, RegCM3 and HadRM3P) nested into GCM, e.g. Hadley Centre HadAM3P UK.

ii. Many sources for climate change data at international level like e.g. World Bank, FAO, UNEP country profiles at national/regional level.

iii. CPTEC (Centro de Previsao de Tempo e Estudos Climáticos/INPE) most important institution for climate change projections and assessments, excellent capacities.

iv. Second National Communication to the UNFCCC published in October 2010.

v. Most serious changes expected for Northeast Brazil/ Amazonas Region where tropical forest is predicted to turn into Savannah.

vi. For southern South America mean annual temperatures are expected to increase above 4°C in summer and 2°C to 5°C in winter.

vii. Increase of rainfall of above 20% in Southeast Brazil in form of more intense and more frequent extreme events expected.

viii. Impact scenarios forecast increasing evapotranspiration, water scarcity and an increasing number of areas with high climate risk, leading to less suitability for agricultural production.

ix. Embrapa, IAC and Unicamp are leading experts in climate change impact scenarios on coffee.

x. Based on agricultural risk zoning methodology, RCM and IPCC SRES A2 and B2 Arabica is likely to lose up to 33% in Sao Paulo and Minas Gerais.

xi. Coffee Arabica is the crop, which will suffer most evident geographical reconfiguration.

xii. Migration from Minas Gerais, Sao Paulo and Espirito Santos to Paraná, Santa Caterina and Rio Grande do Sul is expected (due to temperature increase risk of frost in southern parts will decrease, thus becoming more suitable).

xiii. Despite increase in the South overall loss of suitable area will overweigh.

xiv. Scientists predict loss of production in tonnes, suitable area in km2 and related economic loss based on 2003 figures.

xv. Studies on the impact of water stress on Arabica and Robusta is available, in addition, impact scenarios of increasing infestation of nematodes and leaf miner.

xvi. Despite excellent research work, no practical implementation of adaptation or mitigation measures in coffee sector was identified.

xvii. Proposed adaptation measures reach from shade management (arborisation), over planting at high densities, vegetated soil, irrigation, genetic breeding to pest management and others.

2.1 Past and future projections of climate change

As part of the regional project CREAS (Cenarios REgionalizados de Clima Futuro da America do Sul) (Marengo et al., 2009) regional climate change projections for the last half of the XXI Century have been produced for South America. Regional Climate Models (RCM) are promising tools, which, when nested into a Global Circulation Modul (GCM), permit the derivation of GCM-consistent climate change scenarios with more regional detail and a more trustworthy representation of processes active during heavy precipitation. Developing climate change scenarios at regional scale is, thus, an important component of understanding climate impacts under global warming conditions, with critical implications for climate change adaptation and mitigation. CREAS aims to provide high resolution climate change scenarios in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures. It runs three regional climate models (Eta CCS, RegCM3 and HadRM3P) with resolution of 50 km, nested in the public version of the atmospheric global model of the UK Met Office Hadley Centre HadAM3P (Marengo et al., 2009).

Past climate tendencies

The consequences of global warming can already be observed today. During the past decades, patterns of precipitation have changed significantly and temperatures have risen by 0.5°C. Between 2000 and 2007 floods and droughts have had highest human and economic impact, with losses averaging 0.04% of GDP. Over two million people were affected by two severe droughts. The first hurricane ever hit the Atlantic offshore coast in 2004 (**www.adaptationlearning.net/country-profiles/BR**).

Regional Climate Models (RCM) estimate temperature and precipitation

In the framework of CREAS three regional climate models were used to project climate change scenarios for the IPCC A2 high emission scenario[1] for 2071–2100. The projections show a consistent pattern of changes in circulation, rainfall and temperatures. Serious changes are predicted for Northeast Brazil, becoming hotter and drier as it already is. For southeastern South America an increase of rainfall is predicted (Marengo, 2009).

Rainfall[2]: Increased rainfall of above 20% is predicted over the western Amazon, extending all the way to southern Brazil and into the South Atlantic. This could be a partial consequence of an El-Niño like response in the three models.

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[1] The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by a world of independently operating, self-reliant nations, continuously increasing population, regionally oriented economic development, slower and more fragmented technological changes and improvements to per capita income.

[2] All fields shown on this section are presented as the projected changes in the future (2071–2100) relative to the present 1961–1990 as produced by the three RCMs.

Also GCM used for IPCC AR4 predict wetter conditions over southeastern South America. GCM and RCM projections of extremes suggest that this increase in rainfall in the future would be in the form of more intense and/or frequent rainfall extremes. In southern Brazil, the increase in mean precipitation is also associated with the increase in the wet day frequency and reductions in consecutive dry days (Marengo et al., 2009).

Temperature: All of South America is very likely to warm up during this century. The three regional models show temperature increases larger than 3°C in the entire tropical and sub-tropical South America. For southeastern South America mean temperatures above 4°C warmer in summer, and 2°C to 5°C warmer in winter are forecasted. In subtropical South America South of 20°S projected warming from the 3 RCM is consistent with Nuñez et al (2008) who found the warming larger in winter (3°C to 5°C) than in summer (3°C to 4°C). Increases in air temperature for the future are concomitant with changes in extreme short-term temperature extremes, mainly increases in the frequency of warm nights and warm days, and also reductions in the frequency of cold nights and cold days (Marengo, 2010).

Climate change impact scenarios

In order to forecast climate change impacts on agriculture production and other sectors researchers at the CPTEC (Brazilian Centre for Meteorology and Climate Studies), an agency linked to the INPE (National Institute of Spatial Research), simulated the future climate scenarios for Brazil (see Figure 2). In other words, they looked at the climatic outlook for each Brazilian municipality in 2020, 2050 and 2070 for the IPCC A2 and B2 scenarios. The forecasts were made by means of the PRECIS (Providing Regional Climates for Impact Studies) climate model, a computer programme developed by the Hadley Centre, in England – one of the main climate change research institutions in the world today. This system was chosen by the CPTEC as it works on smaller area scales, allowing one to ascertain the potential impact of the temperature rise on Brazilian agriculture until the end of the century and with a 50 km x 50 km resolution. Hence it “sees” what will happen even in small municipalities (Pinto, Assad, 2009).

Climate Change: pessimistic outlook A2: 3-4 ºC increase in mean annual temperature, increase of rainfall due to more intense and more irregular rainfalls, optimistic outlook B2: 2-3 ºC increase in mean annual temperature, increase in mean annual temperature, possible sea level rise

Possible impacts: increase in the urban flood frequency and landslides in hillside areas, affecting living, higher rates of evaporation and consecutive dry days, possible water imbalance, this can have negative impacts on subsistence farming, cattle management and agroindustry, food shortage and increasing prices for food, increase of heat waves leading to impacts on health and increasing use of hydropower with risk of electricity shortage, impacts on water quality and under-supply for the population, impacts on employment leading to social conflicts, threatening security and impacts on natural eco-systems (Mata Atlântica and costal zones), Source: **mundancasclimaticas.cptec.inpe.br**.

Water resources: The temperature rise is expected to provoke a growth in evapotranspiration (loss of water by evaporation from the soil and transpiration from plants) and, consequently, increased water deficiency and hence increased areas of high climate risk (Pinto, Assad, 2009).

Agriculture: With the exception of sites which presently suffer with frost, mainly in the southern region of Brazil and some parts of the southeast – and which therefore will feel some benefits from global warming – all the other locations will witness a reduction in their low risk areas for the majority of crops. Amongst the new products analysed, only sugarcane and cassava will not suffer such a reduction in area. The rise in temperature due to global warming could provoke seed crop losses of R$ 7.4 billion in 2020 – and up to R$ 14 billion in 2070 – generating drastic changes to the agricultural production map in Brazil (Pinto, Assad, 2008).

2.2 The coffee sector in Brazil

Summary of status of coffee sector in Brazil

Location: There are three main coffee growing areas in Brazil: Mogiana in Sao Paulo, Sul Minas in Minas Gerais and Cerrado in Sao Paulo. These areas feature moderate sunlight and rain. The temperatures are steady year-round at about 21°C, ideal to grow Arabica and Robusta coffee trees. The Mogiana region is the area along the border of São Paulo and Minas Gerais states north of São Paulo and is known for its rich red soil. The Sul Minas region is the heart of Brazil’s coffee country. The rugged, rolling hills of Sul Minas, are located in the southern part of Minas Gerais state northeast of São Paulo. The Cerrado region is a high, semi-arid plateau surrounding the city of Patrocinio, between São Paulo and Brasilia. This area is located in Brazil’s central high plains region. The Cerrado is a new and most promising coffee growing area because the dry weather during harvest in this region promotes a thorough and even drying of the coffee fruit. The Cerrado is one of the world’s most biologically rich savannas with over 10,000 species of plants of which about 45% are unique to this region. From a water basin perspective, the Cerrado is very important because it feeds three of the main South American water basins: the Amazon, Paraguay and São Francisco rivers. Of all the coffees growing in these regions, Brazilian Santos Bourbon is Brazil’s best well-known Specialty Coffee. Besides the main cultivation areas in Sao Paulo and Minas Gerais coffee is also grown in the states of Paraná, Espirito Santos and Bahia. In Brazil, the main areas that cultivate the Robusta are the lowland areas of the states of Espírito Santo (Southeast) and Rondônia (North).

In 2009 according to the International Coffee Organisation (ICO) coffee was produced on 2.092.909 hectare in Brazil.

Arabica coffee production in tons of São Paulo’s municipal districts in 2003, according to IBGE (2005), corresponding to 9% of national production. Arabica coffee is produced throughout the state of São Paulo, mainly in the East region (Pinto, Assad, 2007).

Arabica coffee production in tons of Minas Gerais’s municipal districts in 2003, according to IBGE (2005), contributing to 45% of national production. Arabica coffee is produced throughout the state of Minas Gerais, mainly in the southern region.

Production: Brazil is the world's largest coffee producer, accounting for 25% of the global supply. In addition, it is becoming a significant player in the specialty coffee industry. Bourbon, Typica, Caturra, and Mundo Novo coffees are grown in the states of Paraná, Espirito Santos, São Paulo, Minas Gerais, and Bahia (coffeeresearch.org). Arabica accounts for about 70% of total harvest. Robusta makes up the remaining 30%.

The coffee harvest in 2006 totalled 2.57 million tonnes, harvested over an area of 2.3 million hectares, according to the IBGE. Minas Gerais is the biggest coffee-producing state in the country (51.5% of the national production), followed by Espírito Santo (21.4%). The production value reached R$9 billion, 20% higher than the previous year. In 2009 according to ICO 26.247.124 bags of Arabica and 1.118.916 bags of Robusta were exported from Brazilian's coffee harvest.

The vast majority of coffee farms in Brazil are less than ten hectares in size. According to the Diagnóstico da Cafeicultura em Minas Gerais, 71% of farms are less than 10 hectares, 25% of farms had less than 50 hectares, and only 4% of farms were larger than 50 hectares.

Processing: Brazil processes its coffee by the wet, dry and semi-washed (pulped natural) methods. The vast majority of Brazil coffee beans are still processed via the dry method since Brazil is one of the few countries in the world that has the appropriate weather to do so successfully. Due to Brazil's distinct dry and wet seasons, the flowering and cherry maturation is homogeneous.

Climate change vulnerability of Brazilian coffee sector

High temperatures are known to disturb plant metabolism. Coffee cultivation in the open is the usual practice in Brazil, and this provokes leaf exposure to high irradiance and the absorption of much more energy than that usable by photosynthesis. Such conditions may cause an energy overcharge and to an overheating of leaves that, in extreme cases, can reach temperatures of 40°C or even above, especially if stomata are closed, as occurs on sunny days in unshaded crops (Maestri et al., 2001).

Coffee sector organisations

Embrapa Café: It coordinates the activities of the Brazilian Coffee Research and Development Consortium, which constitutes thirty-nine institutions of higher learning, research and extension, production and industrialisation of coffee. The Consortium maintains a close relationship with government organs such as the Deliberative Council of Coffee Policies, where actions and policies for the coffee business are defined. In this manner, Embrapa Coffee strives for the alliance of human and institutional resources in the country that are dedicated to the study and research in the technological and economical sustainability of the Brazilian coffee business. With Embrapa Coffee, Brazil acquires a national coordination of research efforts, thus enabling the country to consolidate and maintain its leadership in the world's coffee trade.

2.3 Expected changes in coffee production

Researchers from Embrapa and Unicamp are using *agricultural zoning*, a method that allows them to forecast climate impacts on agricultural crop production since many years. Hilton S. Pinto and Eduardo D. Assad are the most experienced scientists in this field of work. Their latest study published in 2008 works out the expected changes of agricultural production in Brazil due to global warming. They forecast changes in areas suitable for cultivation of nine main cash and food crops, among them coffee. According to their study Coffee Arabica is the crop, which will suffer the most evident geographic reconfiguration with the climate changes. Whereas today the main producers are Minas Gerais, Espírito Santo and São Paulo, in the future the crop could migrate to Paraná, Santa Catarina and Rio Grande do Sul. Coffee Arabica is likely to lose up to 33% of its low risk area in São Paulo and Minas Gerais. The southern region of Brazil, which, due to the high risk of frost, is presently more restrictive in terms of crops suited to the tropical climate, should witness a fall in this extreme event, thus becoming more suitable for planting coffee, but also for cassava and sugarcane. But as the region is likely to become more vulnerable to water shortages it is predicted to become unsuitable for soybean production (Pinto, Assad, 2008).

The forecasts for coffee Arabica confirm the simulations previously conducted by Unicamp and Embrapa, with the IPCC-2001 data. The crop could be hit either by water shortages or excessive heat in its traditional regions of plantation. The majority of the current planted area in the states of São Paulo and Minas Gerais will cease to offer appropriate cultivation conditions. On the other hand, there may be an increase in production in regions of Paraná, Santa Catarina and Rio Grande do Sul states. Despite this increase the overall losses for the crop will overweigh. Initially (2020), the loss in suitable area may not seem as severe in the B2 scenario (6.75%). But by 2050 the total area of suitable land for coffee may be cut by 18.3% and by 27.39% in 2070. Based on the figures from IBGE (Brazilian Institute for Geography and Statistics) for 2006 which confirm a production of 2.5 million tonnes worth R$ 9.3 billion, global warming is set to cause losses of at least R$ 600 million by 2020, R$ 1.7 billion by 2050 and R$ 2.57 billion by 2070 (B2). In the more pessimistic outlook (A2), the fall in low risk areas begins at 9.48% in 2020, reaching 17.1% by 2050 and 33% by 2070. This would correspond to losses of R$ 882 million, R$ 1.6 billion and R$ 3 billion, respectively (Pinto, Assad 2008).

Figures 2, 3 and 4 (below and opposite) show the maps of current and future coffee cultivation areas in Brazil developed by Pinto and Assad.

Based on the regional climate modelling the scientists were also able to predict future suitable coffee cultivation area in hectare and the number of municipalities that will be able to produce coffee under the optimistic or pessimistic outlook (see Table 5 overleaf).

Based on the same methodology and climate models Pinto and Assad elaborated climate risk zoning maps for coffee municipalities in the states of Sao Paulo and Minas Gerais. Figure 5 (overleaf) shows a comparison between current climate zoning for Arabica coffee in the State of São Paulo (upper right side) and three simulated situations, corresponding to increases of 15% in precipitation, based on values from 1961 to 1990, and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures.

Table 6 shows an estimate of suitable area, production and financial return for each climate scenario related to the following values: suitable area of 188,887km2 (in 2003), average production from 1994 to 2003 (349,911 ton) and a return of US$1,400 per ton.

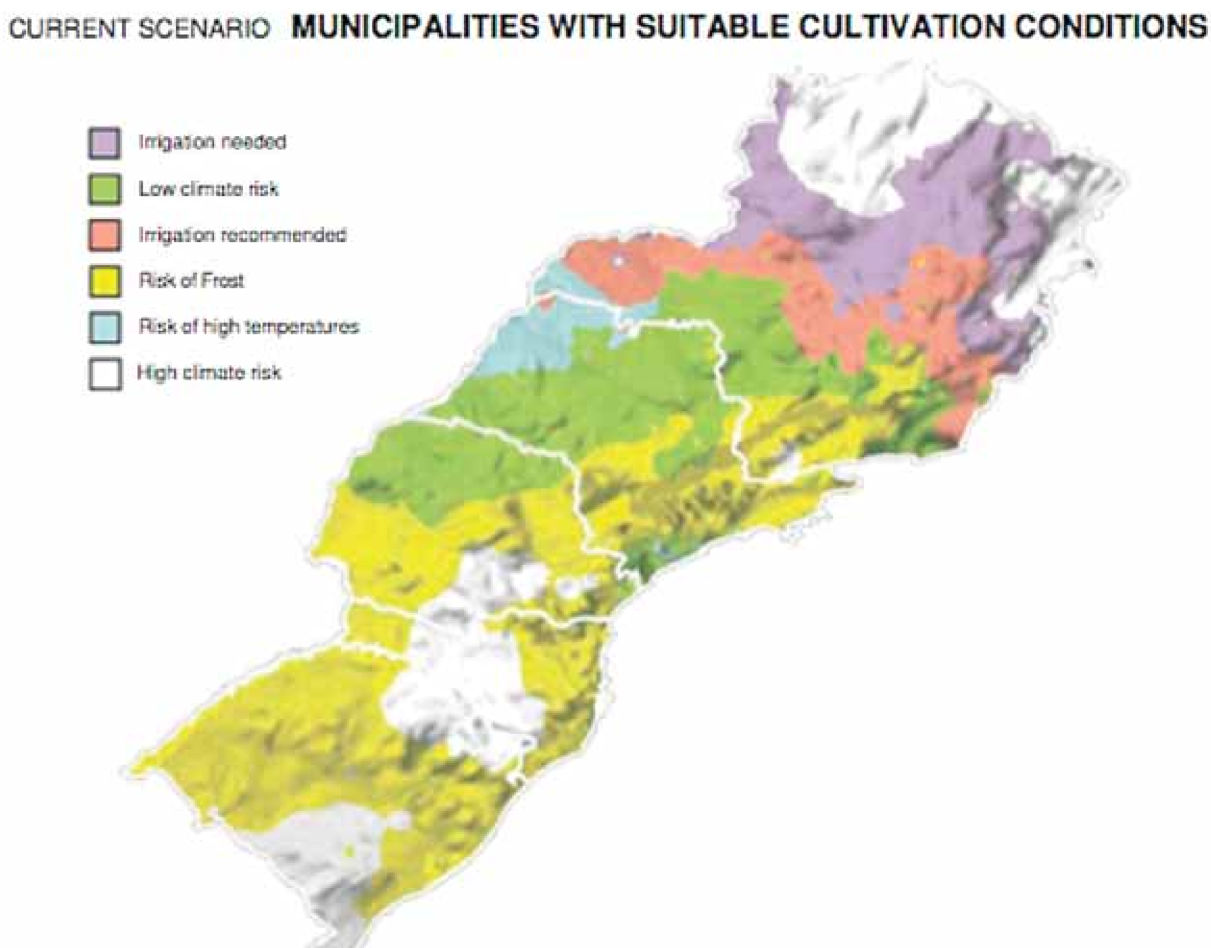

Figure 2 Current scenario for coffee cultivation on Brazil according to Pinto, Assad, 2008

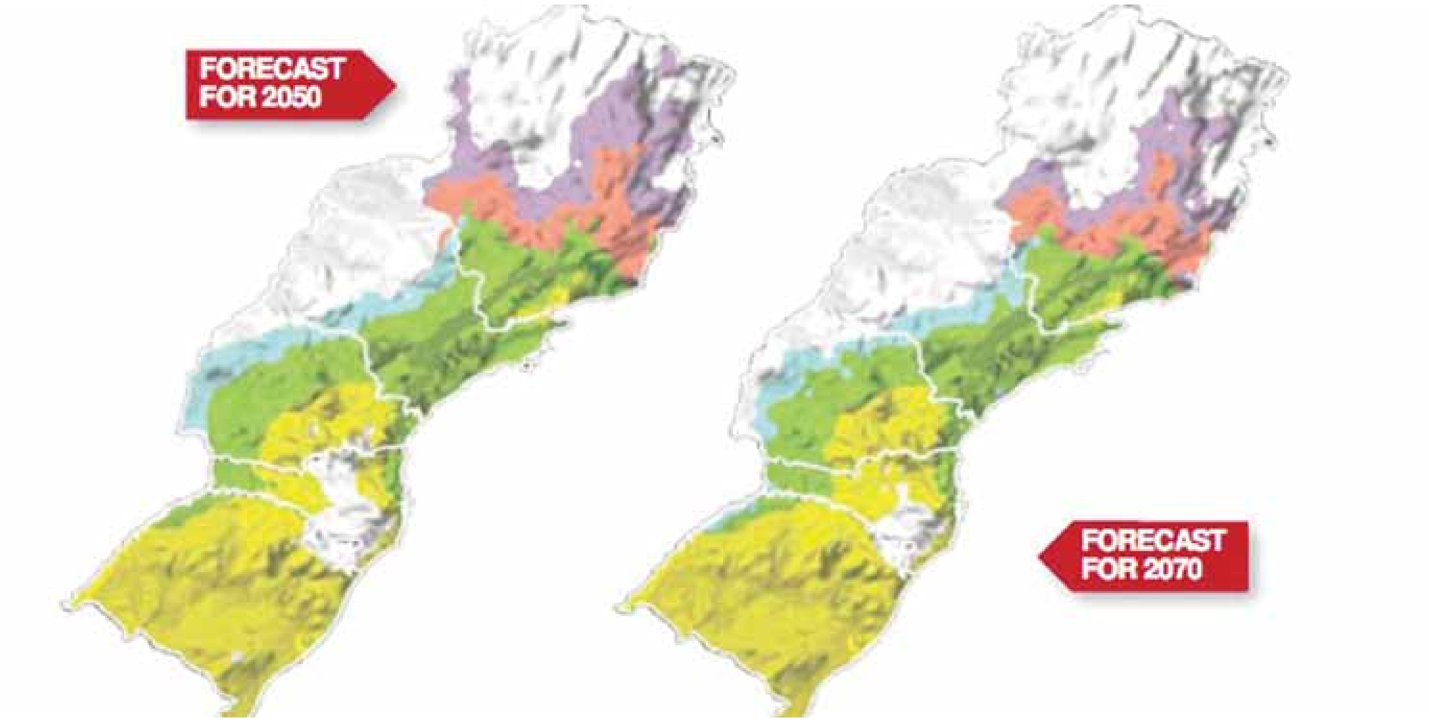

Figure 3 Optimistic outlook scenario for coffee cultivation according to Pint, Assad, 2008

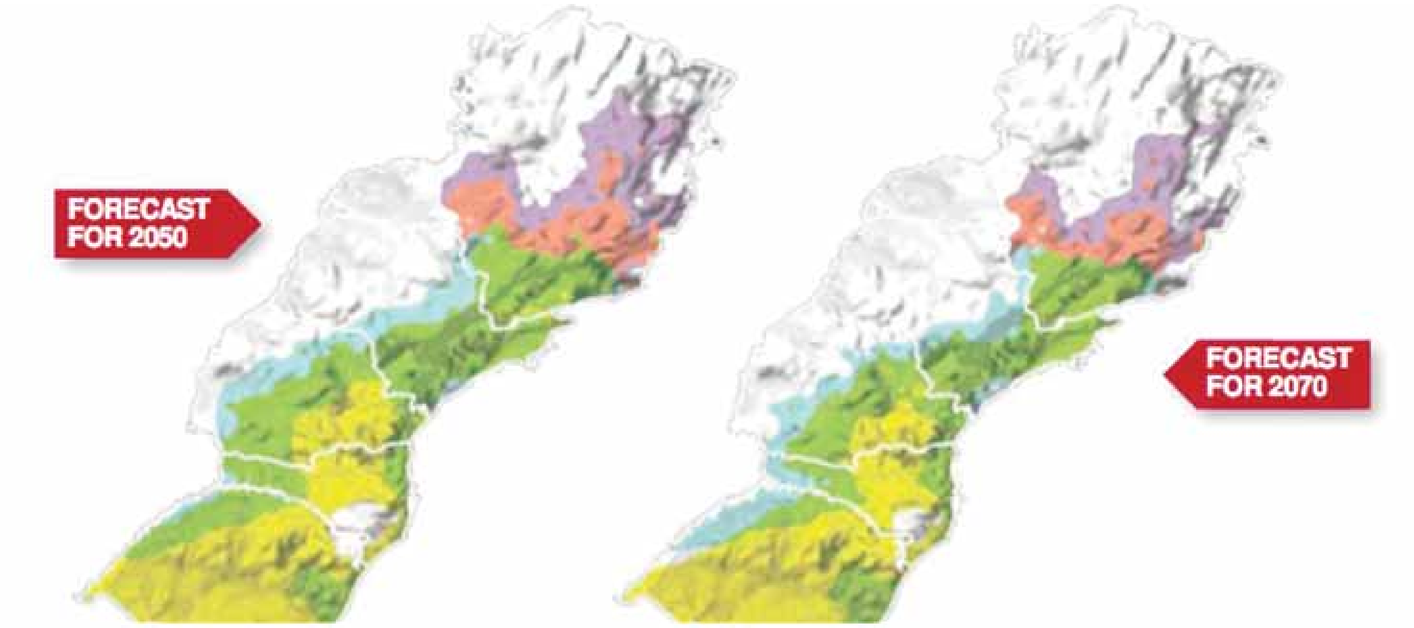

Figure 4 Pessimistic outlook scenario for coffee cultivation according to Pinto, Assad, 2008

Table 5 Alterations to the coffee Arabica plantations in southeast and southern Brazil (Source: Pinto, Assad, 2008)

State	Year	Current scenario – number of municipalities	Scenario B2 – number of municipalities	Scenario A2 – number of municipalities	Scenario B2 – Area (km²)	Scenario A2 – Area (km²)
MG	Current	649	–	–	–	–
MG	2020	–	357	309	103946	93412
MG	2050	–	310	252	85175	68522
MG	2070	–	267	191	70398	54302
SP	Current	380	–	–	–	–
SP	2020	–	374	351	138594	127649
SP	2050	–	304	257	113622	89992
SP	2070	–	267	192	97251	68006
PR	Current	216	–	–	–	–
PR	2020	–	278	239	106084	93531
PR	2050	–	221	152	90281	77002
PR	2070	–	195	113	81793	70616
SC	Current	0	–	–	–	–
SC	2020	–	96	132	16708	24173
SC	2050	–	128	166	23035	35111
SC	2070	–	134	148	26457	32384
RS	Current	0	–	–	–	–
RS	2020	–	27	96	3918	19681
RS	2050	–	69	231	11308	57444
RS	2070	–	77	177	10755	39935

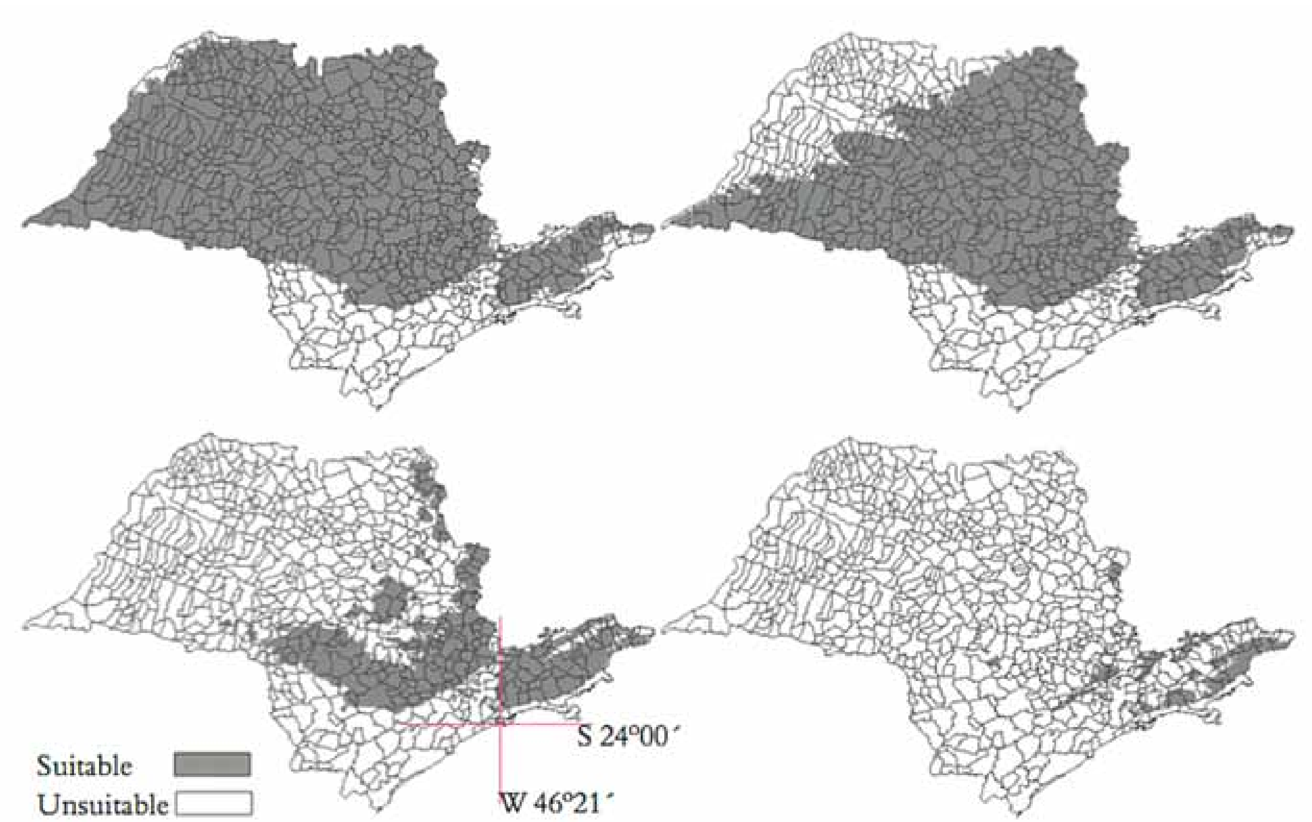

Figure 5 Climate risk zoning for coffee in Sao Paulo, source: Pinto, Assad, 2007

Table 6 Estimation of suitable area, production and financial return, Pinto, Assad, 2007

Temperature increase	Suitable area (km²)	Variation (%)	Production (ton)	Difference according to reference values	
				Production (ton)	Financial return (US$)
+1°C	145,202	-23.1	269,082	-80,829	-113,160,600
+3°C	75,455	-60.1	139,614	-210,297	-294,415,800
+5.8°C	8,439	-95.5	15,746	-334,165	-467,831,000

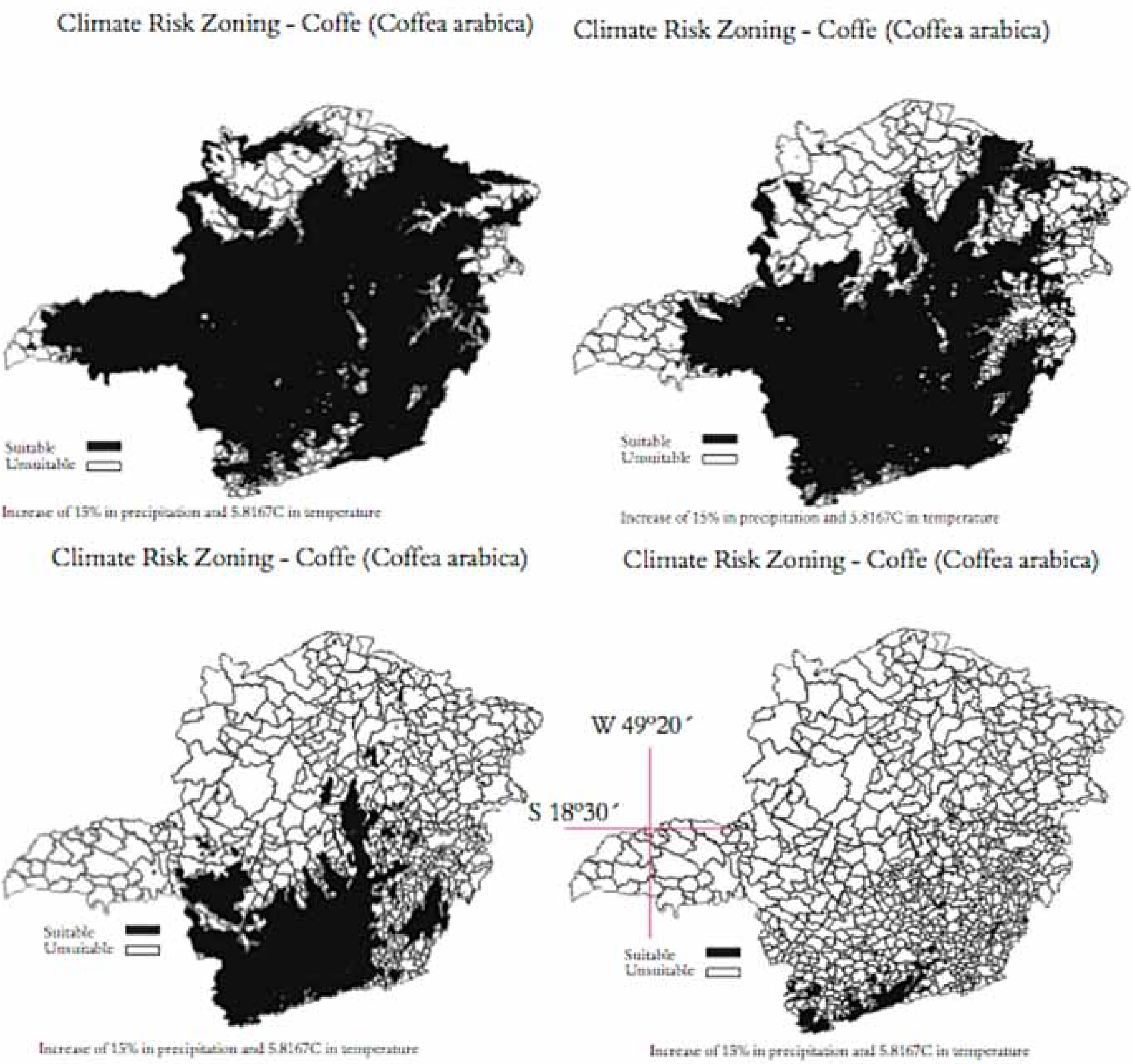

Figure 6 Climate risk zoning for coffee in Minas Gerais, source: Pinto, Assad, 2007

Figure 6 shows a comparison between current climate zoning for Arabica coffee in the State of Minas Gerais (upper left side) and three climate change scenarios, corresponding to increases of 15% in precipitation, based on values from 1961 to 1990, and 1°C (upper right side), 3°C (lower left side) and 5.8°C (lower right side), respectively, in average annual and monthly temperatures. The dimensions of suitable areas are inversely proportional to the increase of temperature, chiefly for values of 3°C and 5.8°C.

Table 7 shows an estimate of suitable area, production and financial return for each climate scenario related to the following values: suitable area of 445,174km^2 (in 2003), average production from 1994 to 2003 (1,572,465ton) and a price of US$1,400 per ton.

The Agroeconomic Institute of the University in Campinas in 2009 published the work of Marcelo Bento Paes de Camargo, who studied the optimal conditions for coffee Arabica production in the state of Sao Paulo. He determined that the coffee Arabica plant requires temperatures between 19°C and 22°C and less than 100 mm rainfall per month. Carmargo developed 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.

Coffee experts of Embrapa assessed the potential impact of climate change on the spatial distribution of coffee nematodes (races of *Meloidogyne incognita*) and leaf miner (*Leucoptera coffeella*), using a Geographic Information System (Ghini et al., 2008). Geographic distribution maps were prepared using models to predict the number of generations of the nematodes and leaf miner. Maps obtained in scenario A2 allowed prediction of an increased infestation of the nematode and of the pest, due to greater number of generations per month, than occurred under the climatological normal from 1961–1990. The number of generations also increased in the B2 scenario, but was lower than in the A2 scenario for both organisms. *Meloidogyne incognita* is one of the most important species of nematode that attacks coffee (*Coffea Arabica*) in Brazil. Root disease caused by the pathogen is more serious in sandy soil regions of the states of São Paulo, Paraná, and southern Minas Gerais. Symptoms include root necrosis, which reduces absorption of water and nutrients by the plant and contributes to decreased yield and even plant death. Leaf miner *Leucoptera coffeella*, considered the most important pest of coffee, occurs in all producing regions in Brazil. The main damage caused by the leaf miner in coffee plantations is a reduction in photosynthetic capacity because of leaf destruction (Gallo et al., 2002). Until 1970, it was considered a problem only during the dry period of the year. However, recently, the pest has occurred during the dry and rainy seasons, causing damage in the order of 37% in some regions of São Paulo (Gallo et al., 2002). Thus, global warming may result in an intensification of the importance of these problems. Decreased productivity occurs as incidence of the pest increases at different developmental stages of the crop, if supplementary control measures are not taken. The main control method is by chemical pesticides which, when applied indiscriminately, may cause biological imbalances, favoring outbreaks of mites (Gallo et al., 2002). A similar prediction was obtained for the races of *M. incognita* i.e., that the number of generations per year will increase in future scenarios. Due to the fact that this is a soil-borne plant pathogen, the most important control method consists in the adoption of preventive measures, avoiding the introduction of the nematode in the area. However, after its establishment, a control strategy must be implemented, because infestation seriously compromises productivity.

Da Silva studied the impact of water stress on the coffee quality in some Brazilian coffee regions. He found out, that the size of the fruit could be affected due to insufficient water supply, but that temperature is he more important factor influencing the chemical composition of the coffee bean, and hence taste and quality.

2.4 Proposed adaptation measures to climate change

Assessment of the impacts of climate change on pest infestations and disease epidemics in crops is needed as a basis for revising management practices to minimise crop losses as climatic conditions shift (Ghini, 2008).

Shading management system (Arborisation): Although native to shady environments, modern Arabica coffee cultivars in Brazil grow well without shade and even may show higher productions than those of shaded trees, particularly in zones with adequate climate and soils (DaMatta, 2004). The coffee cultivation was adapted and widespread for unshaded due to the highest latitudes (19–24°S) and lower altitudes (500–1,300 m) than the origin area. Great part of the Arabica coffee cultivation in traditional countries like Colombia, Costa Rica, Guatemala, El Salvador and Mexico can be found under arborisation system where the coffee plants are close to the microclimate of their natural habitat. However, in Brazil

Table 7 Estimation of suitable area, production and financial return, Pinto, Assad, 2007

Temperature increase	Suitable area (km^2)	Variation (%)	Production (ton)	Difference according to reference values	
				Production (ton)	Financial return (US$)
+1°C	332,561	-25.3	1,174,631	-397,834	-556,967,103
+3°C	139,007	-68.8	490,609	-1,081,856	-1,514,598,288
+5.8°C	15,249	-96.6	53,464	-1,519,001	-2,126,601,666

there is an increasing trend in expanding coffee cultivation to marginal lands where water shortages and unfavourable temperatures may significantly constrain crop production. Coffee plantations have been also expanded towards warmer regions with prolonged droughts. In these harsh environments, the use of shading management is highly advisable in order to allow economic yields (DaMatta & Rena, 2002) and make the environment more suitable for Arabica coffee. The main effects of shading on the coffee crop provides associated with decreased of the air temperature fluctuations by as much as 3°C–4°C (Camargo et al., 2008) and wind speeds, and increased air relative humidity. Shading has been adopted to avoid large reductions in night temperatures at high elevations, as in Kenya (Carr, 2001), or at high latitudes, as in Parana State (23–24°S), Southern Brazil (Caramori et al., 2003) in order to reduce frost damage. There are several possible tree species for use as arborisation, such as grevílea robusta, cedrinho, macadamia, rubber tree, banana prata, avocado, dwarfish coconut among others. The technique of the arborisation allows thinner shading, with a density of around 60 to 70 shading tree plants per hectare.

Planting at high densities: this agronomic practice is the latest trend in Brazilian coffee growth. New coffee cultivars, such as Tupi and Obatã, are of compact size and especially suitable for planting in smaller spacing among lines and among plants in the line (planting in row). So, this practice presents smaller productions per plant, but increasing the production per area. Besides, stressing less the coffee plant, allows maintaining it more grown leaves, providing a suitable microclimate, with lower air temperatures inside the plant, in relation to the external environment.

Vegetated soil: the good agricultural practice recommends maintaining during the rainy season vegetated soil with weed in the middle between lines handled with agriculture implements. Besides the good soil conservation practice, the maintenance vegetated soil reduces the soil and air temperatures and allows a better plant root system distribution because the superficial roots are affected by the high temperatures. This handling also increases the organic matter tenor and the soil water retention capacity making possible a more tolerant cultivation to the adverse climatic conditions.

Irrigation: this practice has been the main factor to allow the establishment of the coffee plant in Brazilian marginal areas of low altitude in that the mean air temperatures are high for the usual cultivation of the Arabica coffee.

Genetic breeding: The genetic improvement of Arabica and Robusta plants in the "Centro de Café Alcides Carvalho" (IAC) has always emphasised the development of material with high yields, quality, strength, and longevity. The cultivars developed at the IAC include Bourbon, Icatu, Mundo Novo, Acaiá, Catuaí, Obatã, Tupi, and Ouro Verde, which represent more than 90% of the Arabica coffee trees currently in production in Brazil. The cultivar Obatã is resistant to coffee leaf rust, compact size, suitable for planting in rows or at high densities, and especially good yield and quality. Bergo et al. (2008) evaluated forty cultivars of Arabica and Robusta coffee from 1994 to 2004 in Rio Branco region, state of Acre, Brazil, where the annual mean air temperature is close 25°C. The study was carried out in the experimental field of Embrapa-Acre, and authors concluded that the best yield performance was the Obatã cultivar with significant difference in relation to the other cultivars. Obatã presented a mean yield of forty-nine sacks per hectare of clean coffee. This is an example of genetic improvement based on selective breeding of species Arabica and Robusta and of how improvement can contribute to the sustainability of coffee cultivation even under marginal lands with unfavourable air temperature.

2.5 Climate change adaptation and mitigation initiatives in Brazil

At national level there are several policies and climate change programmes, e.g. the National Climate Change Programme developed by the Ministry of Science and Technology (**www.mct.gov.br/index.php/content/view/326984.html**). In this framework an Executive Group for Climate Change (GEx) was set up and the latest National Communication to the UNFCCC was elaborated. A National Climate Change Plan defines activities to confront climate change, focussing on mitigation policies and practices. RedeCLIMA is an excellent Brazilian research network on climate change.

The National Institute of Spatial Research (INPE) provides excellent data on climate change and impact and vulnerability assessments and proposes adaptation options. INPE uses a combination of regional climate change projections and vulnerability indices based on environmental, geographical-geophysical and social information. The emphasis is on climate extremes and their impacts on water resources and planning and natural disasters of meteorological origin at national scale, on what would be a first approach of mapping risks and vulnerabilities in Brazil.

Specific objectives of current projects, starting in 2010–2014:

- Development of future cc scenarios at regional scales, for various GHG emission scenarios, uncertainty assessments for XXI Century, (Eta CPTEC 40 and 20 km lat long forced by the HadCM3 and ECHAM4 global models, new runs of IPCC AR5, MBSCG-future developments)
- Enhancement of understanding the impacts of cc and identify main regions potentially to be affected by cc and vulnerabilities for population
- Vulnerability mapping for Brazil using GIS
- Generation of high quality scientific information to assist public policy in the areas of adaptation and mitigation.

Between 2006 and 2008, a pilot project aimed at strengthening adaptive capacity to vulnerabilities was implemented in the Northeastern municipality of Pintadas. The project provided a concrete example how community-based adaptation strategies may look like and combined adaptation with poverty alleviation measures by installing efficient irrigation systems.

Starting with 2008, a joint ongoing cooperation project between Brazil and Germany is now to assess practices and develop possible implementation strategies to transfer the Pintadas project's experience to other municipalities and regions, as well as to identify and multiply other successful adaptation projects in Brazil through dissemination and communication networks.

In Brazil, only few experiences exist with adaptation strategies and practices, despite the urgency of the problem. It is predicted that one of the most vulnerable regions regarding climate change will be the semi-arid North East (Marengo et al, 2007; Governo Federal, 2008). To address these problems, a number of NGO-initiatives now aim to understand what makes local adaptation projects successful.

Unfortunately, lack of financial means and support as well as capacity often prohibits development of such projects and/or communication of their results, thus impeding a collective learning for adaptation and adaptive capacity building. In recognition of this, an ongoing joint cooperation project between the German Federal Environment Agency and Centro Clima aims at identifying and multiplying successful adaptation projects in Brazil through dissemination and communication networks. Brazilian partners of the network-based NGO SouthSouthNorth (SSN, **www.southsouthnorth.org**) began in 2006 to identify potential adaptation projects in the region, which would combine community-based adaptation with poverty reduction. Two assessments showed that the implementation of efficient irrigation technologies in the semi-arid North East could provide ample benefits for smallholder farmers, both regarding increased family income (via increased agricultural productivity) and the building of adaptive capacity (regarding hydrological deficit and climate change) (Obermaier et al., 2009).

To decrease climatic risks for agriculture in Brazil, Department for agriculture started in 1996 an official programme of agricultural zoning to define planting calendars for principal economic crops like rice, bean, soybean, wheat, sorghum, cotton, coffee and fruits, based on meteorological parameters, updated every year (ASSAD, BRUNINI, CARMARGO, PINTO).

Oil tax: Brazil intents to fund climate change mitigation and adaption projects through a levy on domestic oil production. Izabella Teixeira, Brazil's Minister of Environment, told Reuters the fund is expected to receive around $132 million (R$ 226 million) in 2011, a figure that would climb with rising oil production. Brazil expected to substantially expand production after the recent discovery of massive offshore oil deposits.

The mitigation and adaption fund – known as the National Fund on Climate Change (FNMC) – would also be eligible to receive money from other sources, including international funds, according to Teixeira.

Teixeira also reiterated Brazil's commitments to reducing deforestation in the Amazon and cerrado ecosystems. She said figures to be released next month would show record-low forest loss in the Amazon over the past 12 months (**www.mongabay.com**).

Despite excellent research work, no practical implementation of adaptation or mitigation measures in coffee sector was identified.

3. Country profile: Tanzania

Summary of country findings

i. Past climate tendencies have been for steadily rising temperatures, decreasing rainfall and periodic droughts and excess rainfall from El Nino/La Nina cycles.

ii. Models of future climate indicate an increased rainfall in both rains in the Northern Highlands, and probably some intensification of the dry season in the Southern Highlands, with a decrease in total rainfall.

iii. Estimates of the impacts of climate change on coffee production found that an increase in temperature of 2°C and higher rainfall would increase productivity by 16–18%, but with a 4°C increase in temperature production would become limited in the southern highlands.

iv. Comparison with findings from Kenya and Uganda indicate that impacts of climate change could mean a significant redistribution of coffee growing areas with the minimum altitude for Arabica production increasing by up to 400 m, and Robusta cultivation move to higher rainfall zones.

v. Surveys of farmers show a very strong belief that climate is changing with rainfall patterns irregular and less rainfall leading to lower productivity.

vi. Changes in the altitude suitable for coffee production could obviously lead to considerable socio-economic impacts as farmers have to change their livelihoods, and environmental impacts as coffee production needs to expand at higher altitude areas competing with forestry and natural ecosystems (e.g. on Kilimanjaro).

vii. The National Coffee Development Strategy aims to double coffee production by 2020, but does not consider the potential threat of climate change and climate variability to the success of that strategy, despite the known impacts of La Nina droughts on coffee productivity.

viii. At present there appear to be very few initiatives on adaptation and mitigation of climate change in the coffee sector of Tanzania.

3.1 Past and future projections of changes in climate

Past climate tendencies

Mean annual temperature has increased by 1.0°C since 1960, an average rate of 0.23°C per decade (McSweeney et al,. n.d.). This increase in temperature has been most rapid in January and February and slowest in June, July, August and September. The frequency of cold days has not changed discernibly, despite the observed increases in mean temperature. The frequency of cold nights has, however, decreased significantly in all seasons.

Observations of rainfall over Tanzania show statistically significant decreasing trends in annual, and June, July, August, September and March, April, May rainfall. Annual rainfall has decreased at an average rate of 2.8 mm per month (3.3%) per decade. The greatest annual decreases have occurred in the southern most parts of Tanzania. March, April, May and June, July, August, September rainfalls have decreased by 4.0 and 0.8 mm per month per decade, respectively (3.0% and 6.0%).

One of the prime causes of climate variation has been the El Niño (often bringing extremely conditions), and La Niña bringing reduced rainfall and drought.

Global climate model estimates of future temperature

The National Vulnerability and Adaptation Assessment of Tanzania (Mwandosaya et al., 1998), cited in the Initial National Communication on Climate Change (2003) and the National Adaptation Plan (2009), is the basis for most of the projections of climate change impact in Tanzania. Nevertheless other studies broadly agree with this first assessment (ref).

The mean annual temperature is projected to increase by 1.0°C to 2.7°C by the 2060s, and 1.5°C to 4.5°C by the 2090s. The range of projections by the 2090s under any one emissions scenario is 1.5°C –2.0°C. The averaged effect indicate that mean annual temperatures are projected to rise by 2.2°C by 2100, with somewhat higher increases (2.6°C) over June, July and August, and lower values (1.9 °C) for December, January, February. Low standard deviations relative to the mean indicate good agreement across the 11 models.

All projections indicate increases in the frequency of days and nights that are considered 'hot' in current climate. Annually, projections indicate that 'hot' days will occur on 19–40% of days by the 2060s, and 19–65% of days by the 2090s. Nights that are considered 'hot' for the annual climate of 1970–99 are projected to increase more quickly than hot days, occurring on 30–68% of nights by the 2060s and 35–91% of nights by the 2090s. All projections indicate decreases in the frequency of days and nights that are considered 'cold' in current climate. These events are expected to become exceedingly rare, with cold days occurring on 0–4% of days and cold nights occurring on a maximum of 1% of days, and not at all under the two higher emissions scenarios, by the 2090s.

Global climate model estimates of change in precipitation

In terms of precipitation meanwhile, according to the MAGICC/SCENGEN analysis annual precipitation over the whole country is projected to increase by 10% by 2100, although seasonal declines of 6% are projected for June, July and August, and increasers of 16.7% for December, January, February.

- The models consistently project overall increases in the proportion of rainfall that falls in heavy events. The increases range from 1 to 14% in annual rainfall by the 2090s. Increases affect most of the country in the seasons January, February, March, April, May and September, August, November.
- The models consistently project increases in 1- and 5-day rainfall maxima by the 2090s of up to 24mm in 1-day events, and 4 to 37mm in 5-day events. The largest increases are seen in March, April, and May.

However the models disagree to a considerable extent on changes in the El Niño/La Niña cycles and their impacts on climate in Tanzania. Although other studies have found evidence for increased frequency and intensity of the El Niño/La Niña cycle at its origin in the eastern Pacific (Gergis

& Fowler 2009). As coffee has been affected particularly by the droughts brought by La Niña conditions leading to reduced harvests, this brings a considerable degree of uncertainty about the impacts of changes in climate variability on coffee production. The Tanzanian Coffee Board has recently issued a downward revision of the estimate for the 2011–12 coffee harvest due to the recent La Niña associated reduction in rainfall.

Models indicate differences in precipitation changes in different parts of the country, which provide some reference for the different coffee growing areas.

Northern sectors of the country would experience an increase in rainfall ranging from between 5% and 45% under doubling of carbon dioxide. For instance, the northeastern sector might experience an increase of 25–60% in the short rains and an increase of 20–45% in the long rains.

The *southern highlands* might similarly experience a decrease of 10%. Seasonal patterns in possible changes in rainfall could be complex. In the unimodal region, rainfall might decrease between 0% and 25% in central regions during October, November, and December, but increase by 15% in March, April, and May.

No specific mentions are made of the *Lake Victoria region of Kigera* where Robusta coffee is grown. Reference to the World Bank Climate Knowledge Portal indicates a small 2% increase in total rainfall for 2030–2049 with about 15% increase in the March/April/May rains, but a 3–5% decrease in the September, October and November rains.

3.2 Summary of status of coffee sector in Tanzania

The Tanzanian Coffee Development Strategy 2011–2016 (Tanzanian Coffee Board, 2010) aims to increase coffee production from a current average of 50,000 tonnes to 100,000 tonnes by 2020, through increasing productivity and some expansion of area. Annual production has fluctuated between 33,000 to 68,000 tonnes over the past 30 years. The primary means for promoting this increase in production is through renewal of coffee plantations with higher productivity varieties and improved management. It is estimated that total production could be increased by 50% just through improved management of existing plantations. Although climate fluctuations are recognised as a threat in the SWOT analysis presented, the potential threat of climate change to achieving the aim of doubling national production is not explored further.

A study of the status of the coffee sector in Tanzania by BACAS (2005) found the following information relevant to adaptation in the coffee:

- Coffee production has been somewhat unstable over the past decade since the fall in prices in 1990s and then again early 2000s. The variability seems to be in part economically driven (but also latterly climatically driven – current authors' perspective).
- Coffee plantations are mostly intercropped with bananas in the north and west resulting in low plant densities and low productivities; bananas are the main crop. Also plants are old and replanting rates low. Only in the southern highlands is coffee the main crop, planted at higher densities and with greater rates of replanting.
- Management is minimal with only farmers in southern highlands applying fertiliser or other agrochemicals, even then less than half of producers do so.
- Research and training needs were recommended in production of new varieties resistant to pest and diseases and drought; improved soil fertility including use of green manures; good intercrop management; nursery management and; improved organisational and marketing abilities among producers.

Coffee sector organisations

Analyses of the adaptation capacity have recognised the importance of organisational structures to facilitate the processes of adaptation. Lema and Kapange (2006) provide the following review of farmer organisations in Tanzania.

> "In relation to coffee research there are several such farmers' organisations, some resulting from the old cooperative sector, such as the Kilimanjaro Native Cooperative Union (KNCU) and Tanganyika Coffee Growers Association (TCGA), others from the newly developing specialty markets overseas such as the Association of Kilimanjaro Speciality Coffee Growers (AKSCG). Representatives of some of these FOs have become board members of privatised coffee research bodies such as the Tanzania Coffee Research Institute (TACRI)".

Nevertheless many farmers are not organised or the organisations only market the coffee in the national auction system without providing other services (Wengrzyk pers com).

Tanzania Coffee Research Institute

Tanzania Coffee Research Institute (TACRI), has a substantial research capacity especially in coffee breeding, as well as coffee management (nutrition, IPM) and some capacity for technology transfer to farmers (TACRI, 2008), but not a full extension service. The long term climate and production data held by the institute demonstrate a high correlation between rainfall and coffee productivity over the past thirty years, but no general trend. The institute has sub-stations in the major coffee growing areas of the country and should be a vital resource for any future adaptation strategy. A major activity of the sub-stations is the propagation and distribution of improved varieties and clones to improve productivity. One station in Kilimanjaro, is promoting the planting of Albizia shade trees to counteract the effects of climate change.

3.3 Changes in coffee production

According to the Initial National Communication to UNFCC (Rep of Tanzania, 2003) coffee production is projected to experience increases in yield. In order to assess the impact of climate change on coffee production, two areas which represent the major producers in the north-eastern (Lyamungo) and southern parts of the country (Mbozi-Mbeya) were selected. At $2xCO_2$ the temperature increases between 2°C and 4°C in the two areas. Also, the rainfall increase is by 37% in the north-eastern and the decrease is by 10% in the southern parts. Since the increase of 2°C in both areas is within the optimal values for coffee growth then the major determining factor will be the rainfall. An increase in rainfall will imply an increase in the yield. In the southern areas the decrease in rainfall is minimal and will not affect the yield. For Lyamungo, located within an area of bimodal rainfall, coffee yields are expected to increase by 18%, and for Mbozi, where rainfall is unimodal, the coffee yield is expected to increase by 16%. These results take into account the effect of the increase in pests and diseases due to increases in temperature and changes in precipitation in these areas. Increased pests and diseases would reduce yield by 20% on average. An increase of 4°C in those areas would significantly reduce coffee production. At this increase in temperature (4°C) in the southern areas, where annual rainfall at 2 x CO_2 is predicted to decrease during short rains, irrigation would need to be encouraged to supplement the effect of reduced rainfall and the loss of moisture. Otherwise, drought and disease resistant coffee varieties will need to be developed and farmers sensitised to use them if coffee is to remain a major cash crop in such areas. Coffee is likely to be grown successfully where rainfall will increase i.e. in the northern, north-eastern and south-eastern parts.

Other agricultural crops

Modelling of effects of climate change on maize show that the average yield decrease over the entire country would decline by 33%, but simulations produced decreases as high as 84% in the central regions of Dodoma and Tabora. Yields in the northeastern highlands decreased by 22% and in the Lake Victoria region by 17%. The southern highland areas of Mbeya and Songea were estimated to have decreases of 10–15%. These results suggest that climate change may significantly influence future maize yields in Tanzania, reducing them in all zones that were studied, relative to baseline levels. These reductions are due mainly to increases in temperature that shorten the length of the growing season and to decreases in rainfall. Consequently, the continued reliance on maize as a staple crop over wide areas of the country could be at risk.

A study by Thorton et al., (2006) analysing agricultural impacts of climate change estimated a reduced of over 20% in the length of growing period by 2050 in the “Mixed rainfed highland perennial systems of the Great Lakes region of East Africa”, which could significantly affect the viability of coffee production in this region.

Coffee and climate change predictions for Kenya

Studies of the impact of climate change on coffee production in Kenya by CIAT (2010) were based on the following climate projections for the coffee zones:

- The increase of temperatures for specific districts by 2050 is between 2.2°C and 2.4°C.
- Precipitation for specific districts will increase by 135 to 205 mm by 2050.
- The maximum number of cumulative dry month will stay constant at 4 months.
- The overall climate will become less seasonal in terms of variability through the year in temperature and less seasonal in precipitation.

The optimum coffee-producing zone is currently at an altitude between 1,400 and 1,600 masl and will by 2050 increase to an altitude between 1,600 and 1,800 masl (Table 8). Compared with today, by 2050 areas at altitudes around 1,200 masl will suffer the highest decrease in suitability and the areas around 2,000 masl the highest increase in suitability.

By 2050, the decrease of precipitation of driest month and increase of minimum temperature of the coldest month are main negative factors driving suitability together with increasing precipitation of the coldest quarter, which, however, has less weight, suggesting that the decrease in dry season rainfall combined with higher evaporative demand would lead to drought stress at lower altitudes.

Table 8 Changes in altitudinal range for coffee in Kenya (Interpreted from CIAT 2010)

	Current	2050
Lower altitudinal limit masl	1,000	1,400
Upper altitudinal limit masl	2,100	2,300

Overall these changes in climate are similar to those predicted for Northern Tanzania, thus we may expect similar effects upon the coffee growing regions of this as to those predicted for Kenya. If the changes in altitude suitable for coffee production are extrapolated to Kilimanjaro, the lower half of the coffee producing zone will leave coffee production and coffee production will need to expand to higher altitudes competing with the existing forestry based land-uses.

Coffee in Uganda

The Robusta coffee growing area of Tanzania west of Lake Victoria is really an extension of the coffee growing region of Uganda. A projection of the impacts of climate change on Robusta in Uganda indicates that Robusta coffee would retreat to the higher elevations in the south-west of Uganda bordering on Rwanda are partially Tanzania. This would suggest that the Robusta growing area of Tanzania would also move away from the areas adjacent to Lake Victoria closer to the Rwandan border. However, it is not clear what the scientific basis is of the prediction for Uganda, so any extrapolation must also be considered speculative.

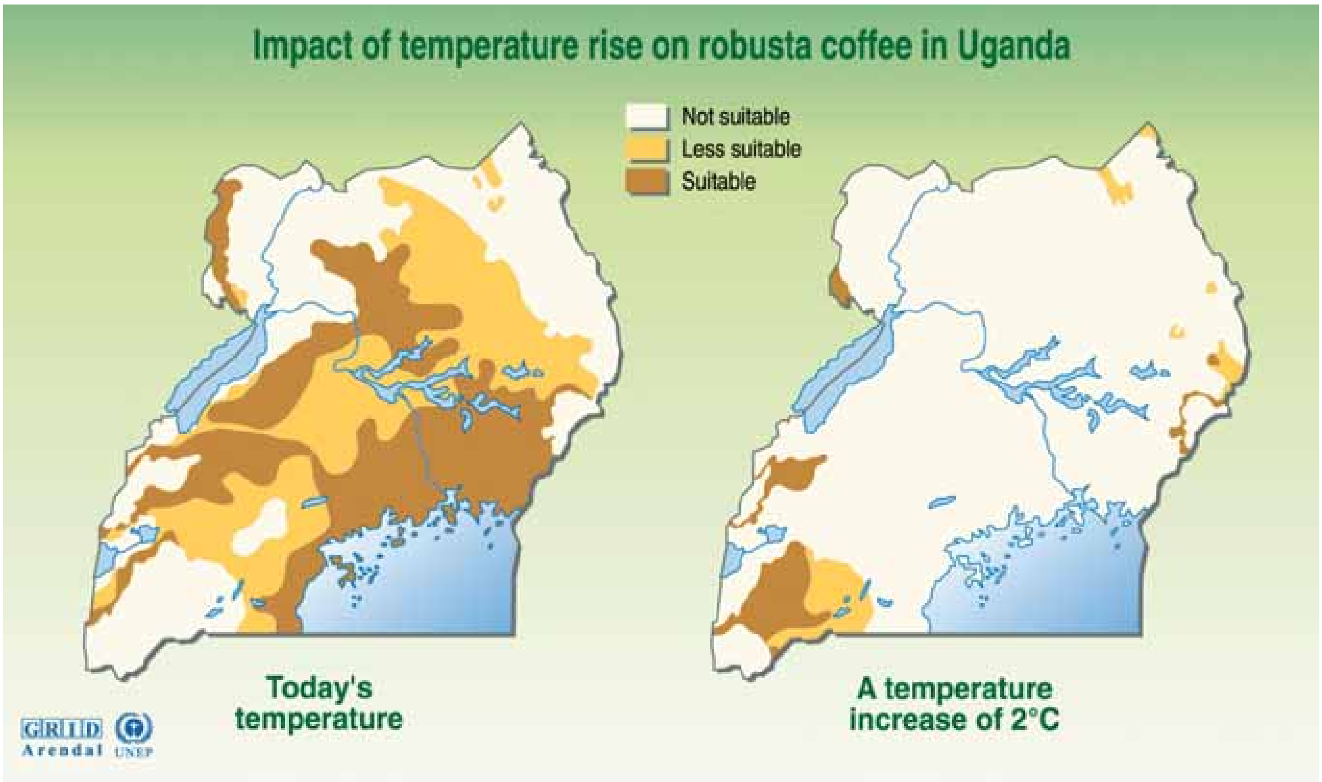

Figure 7 Potential impacts of global warming, GRID-Geneva, case studies on climactic change. Geneva, 1989.
Source: Otto Simonett, 2002

Conclusions regarding impacts on coffee in Tanzania

The studies present a certain degree of contradiction in their findings, but they need to be interpreted in the context in which they were undertaken. The estimates of impacts from the National Climate Change Communication were based on the impacts of climate change on coffee at two specific sites in the middle of the zone apt for coffee production (1,600 masl at Mbozi, and 1,200 masl at Lyamungo). It is probable that at these sites coffee production may not be affected by climate change. But Arabica coffee producers at lower altitudes may well find coffee production unviable in the future, and the coffee at these altitude may lose some of its quality characteristics. Across the tropics forecasts have been for coffee production to move to higher altitudes or latitudes due to the increases in temperature, which are a certain feature of climate change. To make a quantitative estimate of the impacts of climate change on Tanzanian coffee would require mapping of the altitudinal distribution of coffee in the main producing regions. Changes due to rainfall are more uncertain due to less agreement between the models, especially as regards climate variability associated with the El Nino/La Nina cycle. Unfortunately it will be the extreme events, of flood or drought that determine the viable range of perennial crops such as coffee.

There have also been some surveys of coffee farmer's opinions on climate change. A survey of AdapCC in 2007 indicated farmers were convinced the climate was changing, they had access to some climate information, but there was no institutional support to respond but they had their own ideas. A more recent survey by the Hanns R. Neumann Stiftung in 2010 for this programme indicated that the majority of coffee farmers considered that the climate had changed, with more hot days, changes in the rainfall patterns becoming more unpredictable with rainfall erratic and in general no rainfall. This had led to a decline in yields, and more pests and diseases. Many farmers were introducing more shade to the coffee plantations, but some were reducing the area in coffee. It should be remembered that these strong opinions are probably reinforced by the current drought. The Tanzanian Coffee Board has announced that they expect coffee production for the coming year to be reduced by about 25% due to the drought (AllAfrica.com, 24 March 2011).

3.4 General adaptation measures

General recommendations on adaptation measures from the national adaptation programme include:

- Since some parts of the coffee growing areas like the southern parts will experience reduced rainfall it would be necessary to introduce crop varieties whose maturities varies widely and which have climate tolerance. In this case irrigation will be required to supplement moisture losses caused by raised temperature and reduced precipitation.
- Topsoil and nutrients by leaching in some parts of Tanzania will necessitate the application of minimum and reduced tillage technologies in combination with the planting of cover crops and green manure crops to restore nutrient loss. Mulching is important to coffee plants because it reduces evaporation and improves water retention by coffee plants.
- In areas where rainfall has been observed to decrease, like in the southern and central areas, cotton growing would not be suitable. Cotton growing would have to shift to the northern areas where rainfall availability would

be better. In such areas it would be advisable to grow drought resistant crops.

- Current traditional irrigation schemes will require substantial improvement to reduce water loss by evaporation and infiltration.
- Tillage methods and the incorporation of crop residues are other means of increasing the useful water supply for cropping.
- The costs of pests and disease control will rise because their occurrence will increase as temperatures and rainfall increase to favour their growth, survival and distribution; and
- Food programmes and other social security programmes in case there is crop failure need to be introduced to provide insurance against local food supply changes.

The greater use of shade may also be considered. Extrapolating from Central America where most coffee is shaded, there is unlikely to be a loss of production in the generally low productivity systems most producers use, and there could be benefits from the amelioration of climate and stress on the coffee. Nevertheless, research needs to be conducted on the most appropriate shade trees, and farmers trained in their management.

United States Agency International Development (USAID) considers the key institutions for enhancing climate resilience in Tanzania include the Tanzania Meteorology Agency (TMA), the Ministry of Agriculture, Food Security and Cooperatives (MAFSC), and regional institutions, such as the River Basin Management Offices and Regional and District government offices in charge of land use planning and investment promotion (Wengrzyk pers com).

3.5 Initiatives in adaptation and mitigation of climate change in Tanzania

The Adaptation Learning Mechanism of UNDP does not register adaptation projects related to coffee sector. Nevertheless a few projects have been identified with some relevance to the coffee sector. We understand that the Kilimanjaro Native Cooperative Union (KNCU) was considered for participation in the AdapCC project of CafeDirect, but has not yet initiated adaptation planning activities (AdapCC website). Also the climate change module of Rainforest Alliance SAN is also being validated in Tanzania. More substantial information was found on the following studies.

Carbon footprint of Tanzanian coffee

One of the few publically available estimates of the carbon footprint from coffee production is for coffee produced on Mt Kilimanjaro, certified by Rainforest Alliance and marketed by Tchibo (PCF, 2008). The study follows the PAS2050 method, the most recognised for calculating carbon footprints. Of the total footprint of 59.12 gCO_2e per cup, 32.45 gCO_2e was from on-farm with the majority (26.1 gCO_2e) from agrochemical use, primarily fertiliser production and N2O emissions. Despite the coffee being shade grown no estimation was made of carbon stocks in trees nor the soil, but it was assumed that the system was in balance as a mature coffee plantation – i.e. that the growth in the trees was compensated by the die-back or pruning of the same trees. Another considerable missing element recognised as important by the study, but that could not be estimated, was the methane emissions from the fermentation of the coffee and coffee waste disposal. The carbon balance of the tree-soil system and the methane emissions from processing are two important aspects that should be resolved in any future estimation of carbon footprints. It is not clear whether any recommendations or changes in management resulted from the study.

Climate change and impacts on Kilimanjaro

A more detailed analysis has been by the OECD (Agrawala et al., 2003) conducted of the impacts on Mt Kilimanjaro including the role of coffee production in mitigating those impacts. The following is a summary of their findings.

“Kilimanjaro is one of the main agricultural regions of Tanzania contributing approximately 30% of the country’s high quality *Arabica* coffee in 1985/1986 (O’KTING’ATI & KESSY., 1991). In addition to coffee the other cash crops are sugar cane, sisal, pyrethrum and cotton. Mt. Kilimanjaro is also important in terms of food crops such as bananas, beans, rice and millet. Most of this activity on the southern and (north) eastern slope of Mt. Kilimanjaro is performed by smallholders of the Chagga tribe, who use the vegetation zones in various ways (see Table 9), depending on the climatic conditions (cp. HEMP et al., 1999). On the southern slopes of the mountain, the area below the montane forest was traditionally divided into two zones. The upper part, the highland area of the irrigated banana belt in the submontane zone (“kihamba” land), was permanently cultivated and inhabited by the Chagga for reasons of suitable climate and defense against the Masai. The lower part, the “shamba” land of the colline savanna zone was cultivated seasonally and provided annual crops like maize, beans and finger millet as well as fodder for cattle.”

“Analysis of proxy data reveals that annual precipitation decreased by 150 mm, this means a lapse rate of 7.5 mm/year between about 1880 and 1900. Since 1935 there are actual daily rainfall records from the Lyamungu Coffee Research Institute which is located at an altitude of 1,200 meters in the submontane cultivated zone on the southern slope of Mt. Kilimanjaro. It appears that there is a decrease in precipitation since 1935 of about 11% or 177 mm (equivalent to 2.6 mm/year) at Lyamungu or a lapse rate of 2.6 mm per year. If this rate is extrapolated back to the year 1900 this would mean an annual loss of over 400 mm compared with the situation before 1880.”

“The Chagga home gardens (vihamba) are an old and very sustainable way of land use that meets several different demands. Besides crop production, the sparse tree layer provides people with fire wood, fodder and timber. However, the high demand for wood and the introduction of coffee varieties that are sun-tolerant endangers this effective system. In some areas of the mountain (e.g. on the eastern slopes) the trees in the banana fields are very scattered or already missing. Therefore it seems to be necessary, in order to reduce the pressure on the forest, to support the tree planting in the Chagga home gardens with their unique agro forestry system.

Table 9 Land-use in the different vegetation zones of Mount Kilimanjaro (adapted from Agrawala et al 2003)

Altitudinal zone (meters)	Land-use
Subalpine zone 2700–3200	Tussock grassland and giant lobelias are fringed by moorland zones into Erica bushland at steeper slopes.
Montane forest 1700–2700	Forest reserve, large plantations of pine, cypress and eucalyptus, shamba/ Taungya system of agric crops (potatoes, carrots, and cabbage grown with tree seedlings first three years.
Submontane coffee-banana zone 1000–1700	Intensively cultivated by the Chagga (population density 500 person per km^2), Tree layer provides firewood, fodder and shadow, banana trees with network of irrigation canals.
Colline savanna zone 700–1000	Small and large-scale farming of annual crops.

There could also be a programme that rewards farmers to have a certain share of their land covered with trees. As the banana belt is nearly as extensive as the forest reserve, this will certainly have major effects in terms of forest protection and water balance. In combination with new marketing and farming strategies for growing organic coffee using traditional methods an advertising campaign should be started. The campaign should point out that the consumer buys high quality ecologically grown coffee supporting not only sustainable land use and an old African cultural heritage but he is also protecting the rain forest. A certain share of the coffee prize should be used to run this environmental Chagga home garden programme. Government programmes and donor agencies should cover any additional programme costs instead of using financial resources for other expensive and in the long-term less effective projects such as dairying, which are not suitable for the Chagga home gardens. Coffee is the main cash crop. Lately, however, coffee has become less profitable due to traditional farming techniques and very low coffee prices. In the 1970s 35,000 tonnes of coffee were harvested annually in the region whereas today (2003) only 12,000 to 15,000 tonnes are produced. Still, coffee accounts for over 60% of the region's income and authorities plan to raise coffee production to over 45,000 tonnes. The most promising economic alternatives for the region currently appear to be the promotion of high *quality* organic coffee rather than necessarily increasing the *quantity* of production, the production of new cash crops such as passion fruits and flowers, as well as the improvement of eco-tourism and improvement of tourism infrastructure."

The above strategy is that proposed by Agrawala et al., (2003) at the time of the coffee price crash. It should be noted that in general increasing productivity is the most effective route to increasing income to families. In any case whether income is increased through premiums or productivity, or a combination, both require investment. Obviously current market conditions are distinct and increasing production of quality Arabica coffee is viable and in demand. Nevertheless there is also considerable demand for organic coffee. The socioeconomics of organic coffee is complex, it is often seen as appropriate for low-input but organised farmers, but also suffers from an image of being unproductive and to a degree uneconomic. Studies from Central America indicate that although this is often true there are also cases of productive profitable organic coffee production, the limitations of the majority of organic producers are a lack of capacity to invest rather than being organic per se (Soto and Haggar, 2010). It is not known to the authors to what degree the strategy proposed in this study has been implemented. Given the growing demand for organic coffee it may be worth analysing whether the limitations to organic producers in East Africa are similar to those in Central America.

Perceptions about impacts of climate change by farmers in Rungwe District, Mbeya region.

This is part of a larger project on Agricultural adaptation to climate change project run between Institute for Resource Assessment of the University of Dar Es Salaam, and Natural Resources Institute and funded by the Department for International Development (DFID)/International Development Research Centre (IDRC). One of the communities where the project works produces coffee, and the table below summarises farmer's perspectives on how climate change has affected the primary commercial crops of this region. There is also the perception among some participants that coffee is replacing tea at higher elevations (Lamboll pers com).

Table 10 The effects of changing climate and variability on their 3 main crops as mentioned by male farmers.

Element	What has changed	Tea	Coffee	Banana
Rain (*Mvua*)	1. In the past, rains started in the November 2. Currently rainfall is unpredictable 3. The short rains (*Vuli*) are shorter	1. Delayed rains means there is less of a tea leaf flush 2. Uncertainty as to when to apply fertiliser	1. Rain causes the flowers to rot* (*Mvua inapozidi huozesha maua*) 2. Hailstones spoil the berries (*Mvua ya mawe kuharibu mbegu*) 3. Diseases increase	1. Stunting 2. Banana weevil (*Bungua*) infestation through delayed rains 3. Delayed fertiliser application 4. Delayed rains come with strong winds causing plants to fall
Hot sun (*Jua kali*)	The dry season (*Kiangazi*) sets in earlier than expected or it used to previously (*Kinawahi*)	1. Harvest is reduced (*Mavuno hupungua*) 2. Leading to reduced income (*Halafu mapato hupungua*)	1. Young berries are scorched by the sun (*Mbegu changa huungua)* 2. Drying of the whole plant (*Kukauka kwa mibuni*)	1. Causes reduction of water in the plants (*Husababisha upungufu wa maji kwenye migomba*) 2. Drying of plant (*Migomba hukauka*) 3. Reduces harvest (*Mavuno hupungua*) 4. Plants become weak and fall (*Kunyong'onyea na kuanguka*) 5. Premature falling of young bunches (*Kukatika kwa vikonyo*)
Wind (*Upepo*)	Winds have increased (*Upepo umeongezeka*)	–	1. Branches break (*Huvunja matawi*) 2. Bananas fall on to the coffee plants (*Migomba huangukia mibuni*) 3. The plant is loosened in the soil (*Kulegezwa kwa shina kwenye udongo*) 4. Shedding of flowers and berries (*Kupukutisha maua na mbegu*)	1. Falling plants (*Kuangusha mimea*) 2. Reducing harvest (*Kupungua mavuno*) 3. Premature falling of young bunch (*Kukatika vikonyo*) *kuanguka kwa mikungu ambayo haijakomaa* 4. Causes hunger and reduces income (*Husababisha njaa na kupungua kipato*)
Cold (*Baridi*)	Some say the cold has increased (*Wengine wanasema baridi imeongezeka*) Others say it has decreased (*Wakati wengine wanasema imepungua*)	1. Less tea leaves flush (*Uchipuaji wa majani hupungua*) 2. Small leaves (*Majani husinyaa*)	1. Stunting of young trees (*Kusinyaa/kudumaa kwa mibuni michanga*) 2. Late ripening of berries (*Kuchelewa kuiva kwa kahawa*)	1. Late maturity (*Kuchelewa kukomaa*) 2. Stunting of leaves (*Kusinyaa kwa majani*) 3. Growth rate reduction (*Ukuaji wa polepole*) 4. Premature falling of young bunches (*Kukatika kwa vikonya*) *na kuanguka kwa mikungu ambayo haijakomaa* 5. Small size bunches (*Mikungu huwa midogo*)

* Farmers might have meant the spread of coffee berry disease is favoured by heavy rains and the young berried are affected.

3.6 Recommendations of priorities for adaptation and mitigation in Tanzania

Table 11 Recommendations of priorities for adaptation and mitigation in Tanzania

Themes	Potential collaborators
Determine the impacts of climate change on coffee	CIAT, CEEST, TACRI
Train farmers increase resilience to climate change	TACRI, IRA/NRI, Coops
Evaluate potential of shade for adaptation and mitigation	TACRI, NRI, National Universities
Participate in climate change learning alliances	IRA, NRI, Tanzanian Coffee Board, TACRI
Validate climate coffee modules	SAN, 4C, Coops
Develop adaptation strategies in coffee organisations	AdapCC, Coops, NRI/IRA

4. Country profile: Vietnam

Summary of findings

i. Climate change data available due to strong international support regarding preparation of Second National Communication to the UNFCCC, published in December 2010.

ii. Since 1960s mean annual temperature increased by 0.4°C, most rapidly in the dry season November – January and February – March and more rapid in the South of Vietnam.

iii. No consistent decrease or increase of rainfall patterns observed since 1960s.

iv. Vietnam is currently suffering from damages caused by the unusual extreme drought that affected the country in 2009–2010.

v. According to GCM temperature is expected to increase by 1.4°C to 4.2°C by 2090s, number of hot days (above 25°C) is expected to increase by 23 to 55% by 2090s, mainly in wet season, for the Central Highlands, where coffee is grown, number of hot days are expected to raise to 94 in 2020, 134 in 2050 and 230 in 2100, impact on Robusta is not yet analysed but should be considered well.

vi. GCM indicate increasing rainfalls (-1 to +33% by 2090s), mainly in wet season, but this is expected to be offset by predicted decrease of rainfall in dry season (-62 to 23% by 2090s), total rainfall is expected to increase by 2 to 14% by 2090s, mainly due to increasing extreme weather events from June to October.

vii. National impact scenarios predict serious impacts on water resources, costal zones and agricultural production map of Vietnam; river flows in the South are expected to decline, groundwater is expected to drop up to 11 m compared to the current level, evapotranspiration, even in the Central Highlands is expected to increase and demand for irrigation in agriculture is calculated to be two- to threefold compared to current demand, sea level is expected to rise by 0.18 to 0.56m, leading to saltwater intrusion, high risk of floods, serious social and economic damages and high pressure on land.

viii. Vietnam is the world's largest Robusta producer, coffee (mainly Robusta covering 95% of total production) is grown on more than 500,000 ha, mainly in the Central Highlands, high yield and productivity (3.5 t/ha) is due to intensive monoculture going hand in hand with deforestation, land degradation, water over-exploitation and intensive use of fertiliser.

ix. Intensive unsustainable cultivation practices make coffee plantations and farmers highly vulnerable to already perceived and in the near future expected climate change, main problem is over-irrigation and inefficient water use.

x. The 2010-2011 harvest output is expected to decline by 20% compared with previous harvest due to extreme drought period and delayed rainfalls.

xi. Numerous national and international climate change activities exist; the Ministry for Agriculture is implementing the Action Plan Framework on Climate Change Adaptation in Agriculture, but without any specific focus on coffee production.

xii. Few coffee research institutions are beginning to investigate in coffee and climate change issues, data on impacts and suitability scenarios are not available at all.

xiii. Proposed adaptation measures for the coffee sector range from efficient irrigation/water management strategies, over application of sustainable cultivation practices and diversification of the production system and farmers' income to profound research and capacity development.

xiv. In order to develop a toolkit for adaptation practices numerous climate change activities and institutions involved in the issue should absolutely be involved.

4.1 Past and future projections of climate change

Vietnam received international support for climate change research, specifically from UNEP and GEF for working out the National Communications to the UNFCCC. The second National Communication was published in December 2010. Hence, data on past and for the future expected climate change is available.

Vietnam's climate: The main coffee areas are located in the five provinces known as Central Highlands, where a moderate tropical climate is predominating. Monsoon circulations cause the majority of rainfall, bringing heavy rains from May to October in the North and South of the country, and from September to January in the central regions. Inter-annual variations are caused by El Niño Southern Oscillation, influencing the behaviour of the monsoon and generally bring warmer and drier than average winter conditions, whilst La Niña episodes bring cooler than average summers (McSweeney et al., UNDP Climate Change Country Profiles).

Past climate tendencies

Recent trends temperature: Since 1960 mean annual temperature has increased by 0.4°C, around 0.09°C per decade. The increasing rate is most rapid in dry season (November, Deceber, January and February, March, April) and slower in the wet season (May, June, July and August, September, October). Past warming has been more rapid in southern parts than in the central and the northern region (McSweeny). Coffee areas are located in the central regions. The frequency of hot days and hot nights has increased significantly since 1960 in every season. The average number of hot days per year has increased by 29 (+7.8%), most strongly in September, October, November (2.9 days per month ➔ +9.5%). The average number of hot nights per year increased by 49 (+13.3%), most strongly in JJA (5.1 days per month ➔ +16.3%) The number of cold days and nights has decreased significantly (11 and 35, respectively, mainly in December, January, February) (McSweeny).

Recent trends precipitation: Mean rainfall over Vietnam does not show any consistent increase or decrease since 1960 (McSweeny).

Unusual drought period in 2009–2010: Vietnam has been hit seriously by an unusual extreme drought period in 2009–2010.

Global Climate Model (GCM) estimates temperature and precipitation

Temperature: is projected to increase by 0.8°C to 2.7°C by 2060s and 1.4°C to 4.2°C by 2090s. The rate of warming is similar in all seasons and regions. All projections indicate a substantial increases in the frequency of hot days[3] (+ 17-41% by 2060s, 23-55% by 2090s, May, June, July) and nights (+ 25-51% by 2060s and 34-68% by 2090s, May, June, July) (McSweeny). For the Central Highlands, where coffee is grown the number of days above 25°C are expected to increase from 79 in the base year to 94 in 2020, to 134 in 2050, and to 230 in 2100 (2nd NC, 2010). The impact of increasing temperatures on Robusta coffee production needs to be considered well.

Precipitation: Projections from different models are broadly consistent in indicating increases in rainfall for Vietnam, mainly due to the projected increases in August, September, October rainfall (-1 to +33% by 2090s). But the additional amount of rainfall will partially be offset by projected decrease in dry season FMA (-62 to +23%). However, the proportion of the total rainfall that falls in heavy events is projected to increase by all models by an additional 2 to 14% by 2090s. This is mainly due to the expected increase in extreme weather events in August, September, October and May, June, July. In addition, all models project increases in the magnitude of 1- and 5-day rainfalls of up to 43mm and 52mm, respectively by 2090s (McSweeny).

Climate change impact scenarios

In the framework of the elaboration of the Second National Communication to the UNFCCC the Vietnamese government carried out impact scenarios for most affected sectors. The scenarios for future water availability and sea level rise need to be considered when planning adaptation strategies in the coffee sector as they will affect coffee production either directly or indirectly.

Water resources: The annual flows of rivers in the North are predicted to increase; in contrast, annual flows of southern rivers are expected to decrease. Flood flows tend to increase while flows during dry season are declining. The annual potential evapotranspiration rapidly scales up in the South and Mekong Delta region (2nd NC UNFCCC, 2010). Evapotranspiration in Central Highlands is expected to increase in 8.5% (1,726mm) between 2040–2059 and 14.47% (1,821mm) between 2080-2099 (Institute of Meteorology, Hydrology and Environment, MoNRE, 2010).

After 2020 the groundwater level may drop drastically due to overexploitation and the decrease in groundwater recharge during the dry season. In the South, if river flow decreases by 15 to 20% in the dry season, the corresponding groundwater level may drop by eleven meters below the current levels. The groundwater level may drop even lower in areas not subjected to tidal activities (2NC UNFCCC, 2010).

Coastal zones: Vietnam's coastal lowlands are vulnerable to sea-level rise. Sea-level in this region is projected by climate models to rise by the following levels by 2090s, relative to 1980–1999 sea-level (McSweeny):

- 0.18 to 0.43m under SRES B1
- 0.21 to 0.52m under SRES A1B
- 0.23 to 0.56m under SRES A2.

With rising sea level, the annual flood-ridden area will expand dramatically. The Mekong Delta will be most impacted, leading to the risk of saltwater intrusion of rivers and underground water resources. Until 2100 it is expected that climate change will affect approximately 4.4% of Vietnam's population, causing the loss of 5,469 km^2 of arable land leading to serious social and economic losses.

Furthermore, 168 km^2 of aquaculture area and 320 km^2 of forest land would be submerged (2nd NC UNFCCC, 2010). Sea level rise may have strong impacts on the agriculture map of Vietnam. And this will undoubtedly lead to high pressure on land, also for the Central Highlands where coffee is grown.

Agriculture: The water demand for agriculture may increase two or threefold compared with that of 2000. This will be exacerbated with the dropping groundwater level, salination and rising evapotranspiration. Tropical plants will tend to shift further north or towards higher altitudes, among them coffee. An increase of the incidence and spread of diseases is expected for plants, crops, animals and humankind (2nd NC UNFCCC, 2010).

4.2 The coffee sector in Vietnam

Summary of status of coffee sector in Vietnam

Location: Vietnam's coffee production is concentrated in five provinces known as Central Highlands: Dak Lak, Dong Noi, Gai Lai, Kun Tom and Lam Dong (Marsch, 2007).

With a production area of 234,000 ha (60% of the total coffee production in Vietnam) Dak Lak is the most important region. The Central Highlands are a basaltic area with moderate tropical climate. Coffee production ranges from 300m upwards, including some small areas up to 1,500m. But the majority of Robusta production is located at 300 to 500m altitude (Marsch, 2007). *2008: 530.900 ha, (source: statistical yearbook, 2008)*.

The climate in the Central Highlands is ideal for Robusta production. The dry season is typically four months and extends from mid-December until mid-April, coinciding nicely with flowering. During this period there is less than 25 mm rain per month. During the eighth month wet season from May to November, a monthly average of 200 mm is expected giving an average yearly rainfall of 1,600 to 1,800 mm. The average daily air temperature in the Robusta areas fluctuates between 18°C in December and 25°C in April. The maximum day temperature is 30°C in April and the minimum day temperature is 15°C in December (March 2007).

Production: Around 95% of Vietnam's coffee production is Robusta. The remaining 5% is Arabica coffee. Coffee is behind sugarcane the agricultural product with the second largest production rate.

[3] Days when temperatures exceed 25°C (2nd NC UNFCCC)

The Statistical Yearbook 2008 gives some figures:

Table 12 Coffee production in Vietnam

Year	Production in t
2006	985,300
2007	915,000
2008	1,055,800

The export value in 2010 for coffee amounted to 1.67 billion USD (Mr. Manh Nguyen Quoc, MARD). Since the 1980s coffee production grew rapidly from 8,400 tonnes with a growth rate of more than 26% per year. Most recent figures (VICOFA 2004, see figure 1) indicate that there were 506,500 ha of coffee planted in Vietnam in 2004. Robusta coffee was grown on 480,000 ha, representing 95 % of the total coffee planted. Only 26,500 ha were planted with Arabica coffee, representing 5% of the total coffee production (A. Marsch, FAO 2007).

Today Vietnam is with a share of approximately 10% the second largest coffee producer worldwide and with 40% the world's largest producer of Robusta coffee (Marsch, 2007).

85% of the production is held by small scale farmers. 45% of the rural households in the Central Highlands are involved in coffee production. Two-thirds of the farms are smaller than one hectare, and only 3% larger than three hectare (Marsch, 2007). The crop year for coffee in Vietnam starts with harvest in October and ends up in September the following year.

Cultivation practices: Intensive Robusta cultivation as monoculture crop is a success story in Vietnam. Farmers actually achieve over 3.5 tonnes/ha. Productivity and yields are much higher than in other South East Asian countries. Robusta can be very profitable if grown intensively, with large inputs of fertiliser (2 t per ha and year), water and labour (Marsch, 2007). D'Haeze found out in 2004, that e.g. in the Dak Lak coffee growing region the annual water requirements are between 1,500 and 3,000 m3 per hectare, based on 1,100 trees per hectare and three waterings of between 600 and 900 litres per tree (D'Haeze, 2004).

Climate change vulnerability of Vietnamese coffee sector

The other side of the coin is the high vulnerability of the production system to climate change and other environmental risks. Coffee cultivation in Vietnam goes hand in hand with deforestation, land degradation and depletion of water resources. The resilience of coffee monoculture production systems to e.g. soil erosion, increasing evapotranspiration, drought periods or devastating extreme weather events is very low.

The above described projections on temperature increase and changing precipitation patterns should be considered well against the background of irrigated Robusta production in Vietnam and the high dependence on the availability of groundwater or river flows. Water resources are essential for the high yields obtained in Vietnam. The basaltic soils of the Central Highland regions have provided sufficient water with their large stores of underground water, replenished annually by the monsoon rains. Overall rainfall volume has been sufficient for Robusta coffee, but the uneven yearly distribution requires irrigation to achieve the high yields. Water for coffee irrigation is acquired from 3 main sources: manmade ponds and reservoirs (20.8%), natural rivers, lakes and streams (28.5%) and from ground water (56.6%). According to local estimates water resources in Dak Lak are exploited up to 71% of their total capacity. More than 95% of the extracted water is used for irrigation of perennial crops, mainly coffee (March, 2007). According to the Second National Communication to the UNFCCC from 2010 serious impacts on water availability are expected until the end of the Century. For example the annual flows of southern rivers are expected to decrease in the dry season and the corresponding groundwater level may drop by eleven meters below current level. In addition, the annual evapotranspiration is expected to rapidly scale up in the Central Highlands and other regions (see figures above). The predicted impacts on the availability of water resources might have serious consequences for irrigated coffee production, specifically for irrigation based on rivers and groundwater. Future availability and demand should thus be analysed profoundly.

According to D'Heaze, irrigation is required during the dry season from December to April to receive a 270 days growth period for optimal production conditions in order to break flower bud dormancy and induce fruit setting (D'Heaze, 2003). During the dry season water is applied every 20–25 days with a field application depth of 100 mm. Preliminary investigations on farmers' fields suggest that the amount of water presently used, exceeds the crop water requirement and therefore endangers water resources in the region (D'haeze, 1999).

Box 1 Use of irrigation in Vietnam

D'haeze (2003) provides the following account of the importance of irrigation in Robusta fruit set. "The variability in water requirements for coffee is strictly related to flower bud development and fruit growth. After initiation of the flower buds, they grow for several months reaching an average length of 4–6mm, before becoming dormant by the end of the rainy season. Continuous water stress for 1–4 months in the next stage slowly breaks this dormancy. Subsequent relief of water stress by rainfall or irrigation stimulates the flower buds to grow again. During the first 7–8 days after this stimulus, the water content in the flower buds increases rapidly and they grow in length three-to-fourfold, developing to blossom. A period of water stress therefore seems to be mandatory for normal flower bud development (Alvim, 1960, 1973). Pollination and fertilisation is completed 24–48 hours after flower opening. From then the fruits undergo a rest period, remaining as so called 'pinheads', and crop water requirements decline. Sixty days after blossoming the fruits start swelling to reach their final size, hence increasing the crop water requirements again (Naidu, 2000). The latter period often coincides with the beginning of the rainy season in the Central Highlands, so that no further irrigation is required."

Coffee sector organisations

In Vietnam 95% of all coffee farms are private run today. The remaining 5% are still state owned. In addition, many of the collection, processing and export roles are still performed by state owned enterprises.

The key stakeholders of the sector are:

- Ministry for Agriculture and Rural Development (MARD): is key ministry for coffee sector. Some research and development institutions are managed under MARD: IPSARD (Institute for Policy and Strategy for Agriculture and Rural Development), Dak Lak agriculture extension centre, WASI (Western Agroforestry and Scientific Institute Dak Lak).
- VINACAFE: the state owned enterprise is the umbrella company under MARD and manages 59 state owned enterprises, including 40 state farms with 27,000 ha coffee plantations. The process of liberalising and privatising these enterprises is running.
- VBARD: the Vietnamese Bank of Agriculture and Rural Development is the main form of credit for coffee farmers.
- VICOFA: the Vietnam Coffee and Cocoa Association counts 110 members. It was formed in the late 1980s to help the government develop a coffee policy. VICOFA is presented as independent business association, but in reality it is government affiliated.
- 100 registered coffee exporters.
- Vicopex: Vietnam Coffee Trade Promotion and Agriculture Extension (no further information available).
- E.D.E Consulting: implements projects on sustainable coffee production worldwide, mainly on behalf of NKG, HRNS and others. Studies on irrigation of Robusta in Vietnam (D'Haeze).
- 4C (Common Code for the Coffee Community): international baseline standard for sustainable coffee production. The 4C regional office for South East Asia is located in Vietnam.
- Buon Ma Thuot Coffee Association: was set up in October 2010. Represents members involved in production and trading of green coffee. Closely linked with DOST.
- Dak Lak Department of Science & Technology (DOST): realises R&D projects involving various aspects of socio-economic development, and focusing on agriculture including coffee production.

4.3 Expected changes in coffee production

On 16 April 2011 Bloomberg published an article about the expected loss of coffee output in the 2010-2011 crop year. According to VICOFA the production will decline by over 20% compared to the previous harvest of 1.1 million tonnes: “We have had both droughts and rains and the unexpected rains lately have delayed the harvesting and affect the crops in many areas” Luong Van Tu, chairman of the Vietnam Coffee & Cocoa Association, said. The current coffee harvest was delayed by at least one month because of the rain. The International Coffee Organisation expects global coffee production to total 133 million bags for the crop year 2010-2011 because of smaller harvest in Brazil, ICO acting Executive Director Jose Sette said at a conference in Ho Chi Min City. The Vietnamese government plans to maintain coffee production at 1.1 million tons, or 17.5 million bags per crop year, because land available for plantation expansion is limited and the environment must be protected“ (Bloomberg, April 2011).

Although coffee is the second largest trading product in Vietnam and the MARD developed the Action Plan Framework for Adaptation to Climate Change in Agriculture 2008–2020, no specific activities are planned to address climate change risks for Vietnamese coffee production. In the framework of the present work, Mr. Manh Nguyen Quoc was contacted and stated “The Ministry of Agriculture and Rural Development has an Action Plan Framework for Adaptation to Climate Change in Agriculture 2010–20 with many sectors as: water resource, forestry, aquaculture, dyke management, livestock production, crop production, rural development, etc. In crop production we have some projects in the action plan for example: assessment of impact of climate change to crop production in general; changing crop structure to adapt with climate change; breeding new varieties to adapt to climate change, among others. These projects focus on some crop in low land as rice, maize, soybean, mainly in the Red river and Mekong river, the area impacted by sea level rise. In the action plan we have not any projects focussing only on coffee, though coffee is second product after rice on export value.” In addition he confirmed, that specific impact assessments of climate change on coffee production or any impacts scenarios are not available for Vietnam. “We have not any research on impacts of climate change to coffee production yet, but the coffee area of Vietnam is affected by climate change, specifically by droughts and we can provide the data on drought in the Central Highlands.”

Vietnam has been affected by an unusual drought period in 2009–2010. Also coffee growing regions in the Central Highlands were affected. In August 2010 responsible government institutions, international development cooperation and some NGOs met to analyse the situation and define activities to manage the existing damages and the risk of future droughts. Among the participants were MARD, UNDP, FAO, United Nations Educational, Scientific and Cultural Organization (UNESCO), World Bank, SNV, International Federation of Red Cross and Red Cresent Societies (IFRC), Save the Children, PACCOM. The stated that “This drought was not similar to the usual drought impacting Vietnam every year, so it could be related to climate change or the ENSO phenomenon. However, more research has to look into these issues.”

Also Mr. Truong Hong, Vice Director of WASI confirmed, that no detailed data have been collected referring the impacts of climate change on coffee production. He stated: ”WASI has many investigations on coffee production only. We have realised clearly that climate change has impacted the coffee production in Vietnam, particularly in Western highlands. Farmers have faced many difficulties in cultivation, rainy rules and dry season changed, decreasing yield and coffee quality. And I think this problem is more serious from now on, but no detailed data were collected according to the information now. There is no public or private initiatives, projects or programmes dealing with climate change issues related to the coffee growing areas in Vietnam.“

The only institution that already has started investigating in climate change aspects related to coffee is DOST (Dak Lak Department of Science and Technology). DOST provides fund for WASI to develop low water volume irrigation system as a solution for increasing water scarcity as a result of water overexploitation and chronic drought possibly from climate change in the region. Mr. Trinh Duc Minh states that "in December 2010, DOST organised a seminar on the impacts of climate change on agriculture production in the Central Highland of Vietnam, in which initial and general information on the matter was available, including coffee". Further information was not provided.

Besides governmental organisations all above mentioned actors were asked to provide any information on climate change research as well as existing mitigation and adaptation measures focusing on coffee production in Vietnam. But the German coffee and climate change initiative of the coffee industry and GIZ is touching new ground. Current and expected impacts on Robusta production in Vietnam need to be assessed and available climate change data and scenarios need to be analysed in order to develop impact scenarios for the coffee sector. The following chapters and the map of stakeholders (see Annex I) should be involved in any future climate change activities referring to the Vietnamese coffee sector.

4.4 Proposed adaptation measures to climate change

With regard to the above described situation and risks, some key areas to support the adaptation of Vietnamese coffee production to changing climate conditions can be identified:

Water management/irrigation: climate models predict less water availability in the Central Highlands where coffee is grown. Evapotranspiration is expected to increase, whereas groundwater level and natural river flows are predicted to decrease, specifically during dry season, when irrigation is essential for the development of the bud. On the other hand, D'Haeze found out that the currently used amounts of water for irrigation (600 to 900 litres per tree and watering) are leading to over-irrigation of up to 230%. Only 320 litres per tree at each watering were sufficient to achieve the same yield (D'Haeze, 2003). That means there is huge potential to improve the efficiency of water management and irrigation. Based on the results of the studies on irrigation from Dave D'Haeze and the by WASI developed low water volume irrigation system as a solution for increasing water scarcity. The water management should be analysed profoundly and measures to enhance efficiency should be identified in a participatory manner together with farmers.

Soil management: Closely linked with water scarcity is the issue of soil management. If groundwater level will decrease as much as predicted and evapotranspiration will increase, also the fertility and resilience of the soils would be affected seriously. Furthermore, one should keep in mind the impact that intensive fertilisation and mono-cropping will have on soil conditions over the years. All those factors certainly will increase the vulnerability of coffee plantations to climate change. Thus, measures to enhance the resilience of soils (organic fertilisation, planting trees and bushes or legumes that help to prevent from soil erosion and landslides, dead and living barriers, enhancement of water storage capacity of the soils, etc.) should be identified and implemented early enough to avoid serious damages and yield loss.

Diversification: Given the high dependence on coffee as a monoculture, farmers are very vulnerable to climate risks like e.g. prolonged drought periods or devastating rainfalls and storms. To reduce this risk and to enhance the resilience of the agriculture production system, options to diversify production and farmers' income should be identified. Diversification is the main tool that farmers have to reduce their individual farm risk. However, farm diversification is not always easy as there are often no clear profitable options and the financial costs of changing crops are high. The Government of Vietnam and MARD both support farm diversification and have an official diversification plan, which is disseminated from the provincial level down to the farm level. According to the FAO report from 2007 a range of diversification options are being promoted such as rubber, cashew, pepper or annual crops such as corn, cassava or cotton.

Sustainable coffee cultivation practices: related to above mentioned concerns regarding water and soil management, sustainable cultivation practices should be applied in general, including re-/aforestation and avoiding further deforestation, because this will further reduce the resilience of coffee plantations and the agro-eco-system as a whole. The application of standards like 4C or Rainforest Alliance, which also already integrate climate aspects, should be supported strongly.

Research: specifically regarding climate change impact scenarios on coffee cultivation will help a lot when designing adaptation strategies and instruments.

Capacity building and training: Farmers need to be linked with extension services that have the capacity to provide knowledge and instruments regarding climate change adaptation practices. The key problem arising for individual farmers is the lack of availability of technical information to help them make decisions on their production and processing. Farm diversification and individual farm risk management has not been a focus of Robusta extension (Marsch, 2007). In addition, government institutions should be supported with trainings and capacity building measures that enable them to integrate the coffee sector into existing and future national adaptation plans.

Financing and Insurances: Farmers' access to financial support and risk management systems need to be improved. The Vietnam Bank for Agriculture and Rural Development (VBARD) has been asked to give preferential credit if farmers wish to follow diversification plans set up by local people committees to diversify out of coffee, particularly in areas, which are not suitable for coffee.

Box 2 Proposed coffee strategy for Vietnam

"The challenge for the future of the Vietnam coffee industry is to develop appropriate perennial crop strategies with a good technical basis. To do this effectively the industry must address issues like farm risk management through farm diversification and appropriate farm extension, sustainability of water and land resources and effective and efficient use of inputs like fertiliser and labour." (Marsch, FAO, 2007)

4.5 Climate change adaptation and mitigation initiatives in Vietnam

International support programmes

UNFCCC

As a developing country, Vietnam has received financial assistance from the GEF through the UNEP for the preparation of National Communications under the UNFCCC. The development of the Second National Communication, published in December 2010, also received technical support from the United National Economic and Social Commission for Asia and the Pacific (UNESCAP). Hence, climate change data, impact scenarios on some key sectors, the country's greenhouse gas inventory are available for further use and analyses. Mitigation and adaptation options have been identified and are integrated in national policies and action plans to address climate change.

Climate Change Activities Matrix of World Bank

The World Bank, in collaboration with the Government of Vietnam, donors, and non-governmental organisations, has produced a matrix of climate change studies and activities in Vietnam. It is intended as a tool to facilitate collaboration and cooperation.

Drought Disaster Risk Management

FAO and UNDP have developed a project proposal, based on current situation and assessments from the FAO project in the Northern mountainous provinces and also from other assessments done in 2010. The project proposal has two different components: one focuses on emergency supply of rice for the short term, one focuses on capacity building for the medium and long term, for provincial as well as national level. It is targeted to be implemented in North, Central and South Vietnam. FAO is currently looking for funding and more input into the proposal from the ministry and other relevant stakeholders.

National support programmes

National Climate Change Research

Vietnam has a network of hydrological and meteorological stations, comprising of surface-based meteorological stations, upper-air meteorological stations, agro-meteorological stations, hydrological stations, marine meteorological stations, environmental observing stations, and air and water quality monitoring stations. However, the stations are distributed unevenly between regions, with varied station densities. There are currently 174 meteorological surface stations, 248 hydrological stations, seventeen marine meteorological stations and 393 independent rain gauge stations all over the country. Of the 174 surface-based meteorological stations, 145 stations have observation time series data for over thirty years, sixteen stations have data series for 20 to 30 years, and the rest have data records for below 20 years. Density is rather low in the Central Highlands. In an effort to strengthen hydro-meteorological capacity, the Government issued Decision 16/2007/QÑ-TTg dated 29 January 2007 on approving the Master Plan of the National Natural Resources and Environmental Observation Network until 2020. Vietnam has undertaken a substantial amount of research related to climate change and climate change response carried out by governmental agencies, science academies, universities, institutes and NGOs with international assistance at different levels and in various forms.

A number of specialised websites covering climate change issues, such as **www.noccop.org.vn**, **www.vacne.org.vn** and **www.nea.gov.vn** have been set up to provide timely global and national news updates (2nd NC UNFCCC, 2010).

National Target Programme to Respond to Climate Change (NTP)

In late 2008, the Government approved the National Target Programme to Respond to Climate Change (NTP) MARD and MONRE

Action Plan Framework for Adaptation to Climate Change in Agriculture 2008-2020 presented by MARD

Objective: To develop an action plan to enhance capability of mitigation and adaptation to climate change to minimise its adverse impacts and ensure sustainable development of the agriculture and rural development sector in the context of climate change and under the umbrella of the National Target Programme

VUFO-NGO Resource Centre: Vietnam Climate Change Working Group

The Vietnam NGO Climate Change Working Group was established in February 2008 to facilitate inter-agency coordination and foster discussions between NGOs on climate change. They developed guidelines for integrating disaster risk reduction and climate change adaptation into development programmes. The document is available at the website **www.ngocentre.org.vn/ccwg**. In cooperation with CARE International, they provide an excellent overview of globally applied adaptation tools, the Community Based Adaptation Toolkit **www.careclimatechange.org/tk/cba/en/**. This should absolutely be kept in mind when designing the planned toolkit for the coffee sector. In addition, the Climate Change Working Group, led by CARE International, offers co-ordination of capacity building and knowledge sharing activities on climate change issues.

Mitigation Options

The government identified in the framework of the 2nd National Communication to the UNFCCC three focal sectors for GHG mitigation options: agriculture, energy and LULUCF. GHG mitigation options in agriculture were assessed using statistical tools and methodologies in accordance with Dr. J. Sathaye's guidebook on GHG mitigation assessment. Five options for the agriculture sector (56.5 million tCO_2e) and eight options for LULUCF (3,022 million tCO_2e) were identified. GHG abatement and carbon sink expansion costs vary quite drastically, in agriculture sector from US$-10.9/$tCO_2$ and US$9.7/$tCO_2$, and in LULUCF sector, between US$0.4/$tCO_2$ and US$1.4/$tCO_2$ (2nd NC, 2010).

Among the mitigation options in agriculture one could be of high importance for the coffee communities in the Central Highlands: *Biogas replacing cooking coal* *in mountain areas*. Scenario assumptions: Coal is to be gradually replaced by gas for cooking as mountain areas households are equipped with 224,000 biogas tanks. The increase will be from 2,000 tanks in 2010 to 112,000 tanks in 2020 and finally 224,000 tanks in 2030. The GHG mitigation potential of this option is 5.2 million tCO_2 at an abatement cost of US$9.7/$tCO_2$.

III Strategies for adaption and mitigation of climate change in the coffee sector

Monitoring of climate change in coffee growing regions

One of the limitations to understanding the impacts of climate variability on coffee production is the lack of precise meteorological data from coffee growing areas. This is critical for the development of climate-based insurance amongst other aspects of adaptation. We would recommend that the initiative establish simple meteorological stations in each of the regions where it works monitoring maximum and minimum temperature and precipitation. Based on this information the following indicators of climate could be derived:

i. Number of days per year above the maximum optimal temperature for Arabica (28°C) and Robusta (30°C)
ii. Number of days per year below the minimum optimal temperature for Arabica (14°C) and Robusta (20°C)
iii. Absolute maximum and minimum temperatures during the year
iv. Total rainfall between flowering and harvest, relative to current and subsequent years harvest
v. Date of first rains and all flowering events.
vi. Temperature and rainfall on days of flowering
vii. Dates of extreme weather events such as hail storms or hurricanes/cyclones

These indicators should be reviewed with local experts in each country, but it would be useful to have a minimum set compiled across all countries where the project works, which would to some degree compensate for lack of long times series. Such information would need to be correlated to the productivity of coffee plantations, unfortunately long series of data – ideally over 20 years – are required to generate conclusions, but it is never too late to start.

Strategies for adaptation

Also there have been at least four policy briefs that propose integrated strategies to adaptation to climate change, which are summarised below.

As was illustrated in the country profiles there are a number of initiatives to promote adaptation in the sector, covering all if not most of these strategic elements. Some approaches focus on the farmers and their organisations and are more holistic in their strategies (AdappCC, Innovations project) while others are more technical or specific in approach (CafAdpt, Index based insurance), or look to combine these approaches (Coffee Under Pressure). Although initiatives to promote the principles of sustainable production are an essential pre-requisite to achieve adaptation to climate change, they are not a sufficient response to buffer the magnitude of impacts that are expected. Investment is required from public and private sources to develop technologies that will enable coffee producers to better adapt to climate change. These processes have been started by CATIE/CIRAD/CIAT in Central America, University of Campinas/ Embrapa in Brazil. The strategies for adaptation to climate change typically include the following

Table 13 Climate change adaptation policy recommendations from different authors

Hallie et al 2009	Morales et al 2010	Laderach et al 2010	Schepp, AdapCC 2010
Improved access to technical information and knowledge	Technical assistance	Capacity building	Building farmers' capacity to empower them to analyse their adaptation needs and to take action
	Climate information		Combining scientific climate change modelling with farmers' knowledge as basis to identify site-specific adaptation/ mitigation practices (ROA)
	Organic production	Development climate resistant varieties	Selection of more resistant crop varieties
	Reforestation	Diversification	Diversification
			Strengthening resilience of farmers' plantation, irrigation, technical adaptation, adoption of processing, etc
Financial support to enable investment in adaptation	Access to credit	Financial transfer tools	
	Insurance	Affordable crop insurance	
	Environmental service payments	Payments for environmental services	Access to carbon markets, generation of carbon credits, e.g. via reforestation
			Climate friendly certification
Social organisation to facilitate and administer the processes of adaptation	Organisational capacities		Building partnerships between private and public institutions along value chains to improve framework conditions
	Disaster preparedness		
	Fairtrade	Value chain strategies for adaptation	

elements all of which may be considered necessary to achieve the ultimate goal of sustaining coffee producers and the industry in the face of climate change.

Community based analysis of climate risks and opportunities

The AdapCC project developed and tested the process of the Risk and Opportunity Analysis (ROA). The main objective of the ROA process is the participatory identification of adaptation measures and strategies at the small-scale farmer level to cope with climate change. It allows to identify climate risks for small-scale production systems and to understand the root causes of being affected by climate variability or extreme weather events. The final product is supposed to be a site-specific strategy to adapt to climate change, which could be implemented by the affected producers themselves. The members of the small-scale producer organisation are contributing to the analysis, making decisions and becoming sensitised for the climate risks and the need to adapt. On the one hand ROA is an analysis and on the other hand it contains sessions of capacity building for all involved actors as well as sensitisation lessons.

Sustainable production techniques

Shade management: Undoubtedly as temperatures rise, higher altitude coffees that have little or no shade will require more shade and this will contribute to maintaining and sustaining productivity. What is in doubt is the degree that shade will ameliorate the impacts of increasing temperatures on lower altitude coffee that already has substantial shade. From the results of studies in Chiapas we can also expect the diversified shade does help protect (or reduces the probability of damage to) production systems from the physical damage of tropical storms causing floods and landslides.

Conservation of soil and water sources is also expected to improve the resilience of the cropping system. Without doubt elimination of contamination of water sources is obligatory to responsible social and environmental management and not increase vulnerability through affecting this critical resource. Another obvious adaptation is the introduction of irrigation, although it should be recognised that this may compete for water sources with other users, especially in drought years. For the same reason it is essential to ensure that any irrigation system is highly efficient in its use of water ideally using drip irrigation systems.

Diversification: Although it is recognised that this is a sensible strategy in the face of risks and uncertainty it should also be recognised that many small-scale coffee farms already have some level of diversification, and introducing new crops represent a considerable investment and risk in themselves. Ideally coffee should be replaced with other perennial crops that have similar ecological and productive characteristics, this may include cocoa or the replacement of Arabica coffee with Robusta as temperatures rise limiting the adaptability of Arabica coffee at lower altitudes.

Improved access to climate information: This includes short term information to facilitate preparedness for disasters e.g. a hurricane and medium term predictions over the coming 4-6 months to know whether the season will be wet or dry. Climate fluctuation in much of the tropics is dominated by the El Niño/La Niño cycle for which such predictions are reasonably reliable. However, such information must be presented in a way understandable by farmers (including no prediction is a certainty), and with orientation on how to respond.

Climate insurance

The climate response of coffee is complex and it remains to be seen if a viable climate insurance can be developed for coffee production, though this would be a very valuable tool and effort should be made to develop it. Nevertheless, even basic insurance of infrastructure from the effects of hurricanes, landslides or floods is generally absent and should be re-inforced.

Financing

Financing must be made available to coffee producers and millers to invest in adaptation of their farms and facilities to increase resilience to climate change, and eliminate their negative effects on adaptation capacity such as contamination of water sources. Also financing is necessary to invest in reducing greenhouse gas emissions (see mitigation below).

Payment for environmental services

Although shade coffee production, such as in most of Central America, does provide environmental services to local, national and the global community, the processes for generating payments depends heavily on national legislation and international procedures. Many times the administrative investment – particularly when divided across many small-scale producers – can be greater than the value of the service. Even when feasible the payments are very modest, - e.g. a payment of $50-70 per ha per year has been estimated for shaded coffee in Costa Rica where all the legal and institutional procedures are established. A first pilot project started in Piura/ Peru to combine financing of adaptation with generating carbon credits (mitigation) for a reforestation project. In the case of the AdapCC pilot group CEPICAFE in Peru a reforestation project on degraded community land around coffee areas was developed and validation was certified by Rainforest Alliance according to the CarbonFix Standard (see **www.carbonfix.info/RSP/**). CEPICAFE pre-sold certificates to buyers like Cafédirect and roasters and agreed to reinvest earnings in implementation of adaptation measures on the coffee plantations.

Organisation among small producers

This is vital to enable them to participate in adaptation and mitigation processes. The reinforcement or formation of producer organisations can require substantial investment but is fundamental to the success of other processes. It may be strategic for the programme to ally itself with other organisations in each country to facilitate these processes.

Value chain adaptation strategies

There is no doubt that climate change will affect the availability and quality of coffee to the markets, most particularly creating greater variability from year to year. This is a threat to the maintenance of long-term relationships from specific sources, and especially denominations of origin. This needs to be openly discussed between the actors in the value chains, to have a strategy to cope with variations in the supply without causing a breakdown in the relations, and identifying the contingencies for the financial implications this may have.

Climate modules and codes

Both the Sustainable Agriculture Network (SAN, 2011) and the Common Code for the Coffee Community (Linne, 2010) have developed climate modules or add-ons to their normal standards. The two are similar in the processes they wish to reinforce namely:

i. development of climate adaptation and mitigation plans for the farm and associated community
ii. promotion of management practices that should reduce greenhouse gas emissions and/or increase carbon sequestration
iii. promotion of sustainable production practices that should increase resilience to climate change
iv. preparedness for extreme weather events and natural disasters

The overall criteria of both schemes are eminently reasonable and well thought through, and it can reasonably be expected they will help farms to be better prepared for climate change and reduce their contribution to it. They provide an incentive to scale up the types of adaptation planning promoted in AdapCC, which contribute to resilience to climate change. The verification criteria of the 4°C scheme are much more explicit and precise than those of the SAN climate module, but as 4°C is for coffee and SAN for any crop it is easier to develop such specific criteria; it is presumed that SAN provide more specific criteria in the training of verifiers. Both schemes promote that farms should keep registers of their green house gas emissions, although not necessarily calculations of the carbon footprint per se. Both schemes are explicit in that compliance with their modules do not imply carbon neutrality nor are an assessment of carbon footprint. However, this does leave the doubt as to what impact these modules may achieve we recommend that efforts should be made to document the differences in compliant or non-compliant farms, or changes in farms that become compliant to reinforce the legitimacy of these climate modules.

Strategies for mitigation of climate change

Mitigation can be divided into two concepts:

- Reducing the contribution of coffee production to greenhouse gas emissions, this is primarily a function of the carbon footprint of coffee production.
- Sequestration of carbon in the shade trees or forest areas of the coffee farms, currently the conservation of existing trees has no process for recognition but planting of new trees could be considered as mitigating other emissions.

Studies of carbon footprints from coffee production indicate that on-farm emissions, and in particular nitrogen fertilisation account for about 40% of the carbon footprint of the whole coffee chain (PCF, 2008). Pressure or incentives to reduce the carbon footprint of coffee production currently come primarily from the industry and indirectly consumers. Recently Coopedota in Costa Rica announced their coffee as carbon neutral (**www.coopedota.com**). In this latter case investments were made to reduce green house gas emissions, primarily in the coffee milling stage by increasing energy efficiency and better treatment of waste products.

Currently the carbon foot-printing methods primarily PAS2050, do not consider the carbon in shade trees nor soil. There is much data on the quantities of carbon present in shaded coffee systems and especially in Guatemala (e.g. Medina et al., 2006), but there is no data on the carbon balance of these systems, or how much carbon they accumulate (or lose), each year that could be put against a carbon footprint of emissions. Furthermore this is likely to vary considerably. In new coffee plantations on previously un-forested ground the growth of the shade trees sequesters considerably more carbon than is emitted from agronomic practices (Noponen et al., 2010), however once the trees have matured and processes of shade regulation and tree replacement have started it is not clear what the carbon balance may be. Also changes in soil carbon can be a large contribution but much depends on the initial starting conditions, for example if shaded coffee is planted after annual crops soil carbon may increase, but if planted it replaces a high carbon tree-based system (even including the renewal of a previous shaded coffee system) soil carbon could decline (Haggar et al., 2011).

It is currently not clear what the potential balance between the greenhouse gas emissions and the potential for sequestration in soil and trees may be, and thus the potential trade-offs and costs of producing carbon neutral coffee. Nevertheless, most of the information exists to make this evaluation but in a dispersed form, but if brought together an initial assessment could be made.

IV Recommendations

1. Although it is clear the general effects of climate change on Arabica coffee production, this is not the case for Robusta coffee. Specific studies are required to determine the factors that may affect Robusta and where these may have most impact.
2. Project should explore options to reinforce efforts of research projects in Central America and Brazil to develop technology to enable the adaptation of coffee production to future climatic conditions, as well as how to build on the results of these initiatives for adaptation of production systems in East Africa and South East Asia.
3. Need to define climate variables for monitoring in producer areas to determine the actual nature of climate variability and its impact on coffee productivity and quality.
4. Engage or initiate research and validation of shade for climate resilience, adaptation and mitigation in countries where shade is not traditional, i.e. Brazil, Vietnam and Tanzania, through interchanges with regions where shade is traditional e.g. Central America and India. It is important that any trials should be well designed and managed as otherwise introduction of poorly managed shade can lead to rapid declines in productivity.
5. Given that climate variability and extremes are likely to be a considerable part of climate change, it would seem that greater effort should be put into testing and resolving the outstanding issues around the viability of climate insurance.
6. Training, facilitation and financing are required to scale up the adoption of the SAN Climate module, the 4°C climate code and the adoption of the climate adaptation and mitigation measures in general to increase the resilience of coffee producers to climate change.
7. We consider that it is necessary to validate the effects of the mitigation aspects of the climate modules in order to gain credibility and so that compliance with these criteria can bring economic and market benefits to farmers.
8. Also both systems promote farmers maintaining some register of GHG emissions. Tools need to be developed to enable farmers to keep reasonable measures, nevertheless we consider that it is probably necessary to develop a specialist service to process this information to provide reliable orientation as to the tendencies in GHG emissions, this could include the calculation of a farm carbon balance or footprint.
9. There is certain confusion in the industry on the relationship between the carbon footprint of the coffee chain and the apparently high emissions from on-farm against the carbon stocks and potential sinks from shaded coffee production. A synthesis of the information available should be conducted to try to resolve the relationship between these two processes and evaluate the potential for on-farm sinks to compensate emissions and contribute to a climate friendly carbon neutral coffee industry.
10. The programme has the opportunity to facilitate value chain adaptation strategies to manage variations in the supply of coffee due to climate change so as to not affect the long-term relationships between actors.

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Annex I

List of stakeholders

Stakeholders in Guatemala around coffee and climate change

Institution	Role	Actions
ANACAFE	Technical support, promotion and regulation of coffee sector	Development tool to evaluate environmental services Collaborator on development of climate module
Universidad del Valle, Environment Centre	Research climate mitigation and adaptation	Project Livelihoods Analysis of coffee farmers response to climate change Validation of SAN climate module
Efico		Development of SAN climate module
Rainforest Alliance	Environmental certification of commodities	Development of SAN climate module
La Cieba Insurance company/Berkley University/ FEDECOCAGUA	Agricultural insurance Research university Coffee Coop Federation	Development of climate insurance for coffee

Stakeholders in Central America

Institution	Role	Actions
CATIE	Research, education and training	Projects: Sensibility and Adaptation of coffee to climate change (with CIAT and CIRAD) Validation of coffee climate insurance (with FIDES, CIRAD) Adaptation to climate and market risks – implementation project
CIAT	International Research	Application of climate models to coffee distribution Development of strategies for adaptation to climate change – Coffee Under Pressure
CIRAD	International Research	Development of coffee model and collaboration research climate response of coffee
PROMECAFE	Coordinate coffee research in Central America	Identified topic as of interest, no current projects
CAFENICA/PRODECOOP	Association of coffee Coops in Nicaragua	Collaborator on AdapCC, interested in C mitigation
COOCAFE	Association of coffee Coops, Costa Rica	Projects on climate friendly coffee
FIDES	Inter-American Federation of Insurance companies	Agricultural Climate insurance – IADB funded pilot

Stakeholders in México

Institution	Role	Actions
ECOSUR	Research and Training	Carbon sequestration from agroforestry/forestry
UAM	Research	Climate modelling
MasCafe/AdapCC	Association coffee Coops	Implementing adaptation strategy
Scolel Te	Producer organisation	Programme payment of environmental services
CI/Starbucks	Conservation and sustainable development	Development strategy adaptation to conserve biodiversity in Sierra Madre, Chiapas

Stakeholders in Brazil

Institution	Role	Actions
CPTEC Center for Weather Forecasts and Climate Studies of the National Institute for Space Research (INPE)	Research	Develops, produces and disseminates weather forecasts as well as seasonal climate forecasts since early 1995
INPE – Instituto Nacional de Pesquisas Espaciris	Research on behalf of Ministerio de Ciencia e Tecnologia	Assessment of impacts and vulnerability to climate change in Brazil and strategies for adaptation options
Instituto Agronomico de Campinas IAC	Research	Genetic breeding initiative: The Instituto Agronomico de Campinas in Brazil – IAC and others are working on the possibility of transferring some of the characteristics of robusta to Arabica, such as resistance to pests, vigour and above all, better resistance to higher temperatures
Embrapa and Embrapa Cafe In cooperation with Unicamp	Research	Study on Global Warming and the new geography of agricultural production in Brazil, 2008 Study Climatic risk zoning for coffee trees in the state of São Paulo, Brazil, 2001 Impact assessment study of climate change on agriculture zoning (including coffee), 2006 Pesquisa Agropecuária Brasileira – Risk analysis of climate change on coffee nematodes and leaf miner in Brazil, 2008
4C regional office Brazil 4c-coffeeassociation.org	Standard	
P&A International Marketing / P&A Marketing Internacional peamarketing.com.br		
South, South, North Network www.southsouthnorth.org		

Stakeholders in Vietnam

Institution	Role	Actions
VICOFA www.vicofa.org.vn	Vietnam Coffee and Cocoa Association	
Vinacafe – Vietnam Coffee Corporation	State Corporation with 100% of the capital of the State and is the largest member of the Association of Vietnam Coffee and Cocoa. This is a large enterprise, there are 70 companies, factories and farms. VINACAFE annual export large amounts to 20–25% of the country's coffee.	
World Bank Agriculture and Rural Development Department	Research	The socialist republic of Vietnam – coffee sector report, June 2004, Giovannucci et al.
E.D.E Consulting	Consulting	Study on irrigation and coffee in Vietnam (Dave D'Haeze).
International Conservation	NGO	Projects to define strategies to adapt to climate change in Mexico and Indonesia, As an initial overview.
Tchibo	Roaster	
4C coffeeassociation.org	Sustainability Standard	
GIZ	Development Agency	Environmental protection and management of natural resources (EPMNR) in Dak Nong province, including development of coffee value chain.
Rainforest Alliance	Sustainability Standard	
Ministry of Natural Resources and Environment	Government	National target programme to respond to climate change, 2008.
Ministry of Agriculture and Rural Development	Government	Action plan framework for adaptation to climate change in agriculture 2008–20.
Arizona State University, University of East Anglia, International Institute for Applied Systems Analysis IIASA	Research	Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems Hallie Eakin, Alexandra Winkels, Jan Sendzimir. Alexandra Winkels rural in-migration and global trade managing the risks of coffee farming in the central highlands of Vietnam.

Stakeholders in Vietnam (continued)

Institution	Role	Actions
WASI – Western Highlands Agro-Forestry Scientific and Technical Institute	Public Research and Development Institute	Farming systems, agro-industries and post-harvest, animal production and health, biotechnology, forestry and agroforestry, plant production and protection and socioeconomic.
Buon Ma Thuot Coffee Association	Coffee Association, set up in October 2010 by Members involving production and trading green coffee	
Dak Lak Dept. of Science and Technology (DOST)	Research and development	Local state agency funding for research and development projects involving various aspects of socio-economic development, and focusing on agriculture including coffee production, providing fund for Western Highland Agro-forestry Science and Technology Institute (WASI-based in BMT City) to develop low water volume irrigation system as a solution for increasing water scarcity as a result of water over-exploiting and chronic drought possibly from climate change in the region.
VUFO-NGO Resource Centre	The climate change working group facilitates information sharing, capacity building and co-ordination among non-governmental organisations in Vietnam and between non-governmental organisations and government in relation to climate change responses.	Publications on how to assess adaptation needs and integrate solutions into political programmes, climate change adaptation toolkit Capacity building, knowledge sharing, co-ordination of climate change activities in Vietnam.
CARE International		Leading the working group climate change adaptation aiming to raise awareness and help vulnerable communities achieve the capacity to adapt to climate change.

Stakeholders in Tanzania

Institution	Role	Actions
Tanzanian Coffee Research Institute (TaCRI)	Research and training	Preliminary assessments of relationship coffee and climate.
HRNS Tanzania		
Tanzania Coffee Board	Representation of sector	
Institute of Resource Assessment, University Dar Es Salaam	Research and training	National co-ordinator agriculture adaptation project.
Natural Resources Institute	Research and capacity building	Regional co-ordinator agricultural adaptation project.
Office of the Vice-President	National climate change plans	National communication and NAPA.

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