CHAPTER 4

Climate change and adaptation in Central Africa: past, scenarios and options for the future

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1. Introduction

Evidence of human-induced climate change and its impacts on various sectors is steadily increasing, raising doubt whether limiting rising global average temperature to 2°C above pre-industrial levels is still a realistic goal. According to the 4th Assessment Report (IPCC AR4) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007), the African continent has an elevated susceptibility to the stress caused by climate change and relatively low capacity to adapt to the consequences. The sectors identified as the most vulnerable to climate change are: agriculture and food security, water supply, ecosystems, and health (Sonwa *et al.*, 2012). The vulnerability of these sectors requires that forest management and development strategies take climate change into account. Combating climate change requires two different approaches: reducing the rising concentrations of CO_2 and other greenhouse gasses in the atmosphere (mitigation) and preparing to live with the inevitable consequences of climate change (adaptation). Forests have played a crucial climate change mitigation role in the international negotiations on climate change since the concept of REDD (Reducing Emissions from Deforestation and Forest Degradation) arose in the middle of 2000th. Forests sequester and store atmospheric carbon; avoided deforestation and reforestation may therefore have a positive effect on atmospheric CO_2 concentration.

This chapter aims to summarize the current state of knowledge of climate change and adaptation related to forests in the COMIFAC region. This synthesis aims to assist the Congo Basin countries in developing adaptation options and policies for forests and the local communities living in forest landscapes. It builds on information from the IPCC 2007 report and other published sources as well as unpublished information from the few climate change and adaptation studies in the region.

Photo 4.1: An imminent storm. Erosion risks are high in Rwanda

Mitigation

The role of forests in climate change mitigation is receiving increasing interest in the region, as reported in previous editions of the State of the Forest of the Congo Basin (Nasi *et al.*, 2009 ; Kasulu *et al.*, 2009 ; Tadoum *et al.*, 2012). COMIFAC and its member countries have put considerable effort into the international negotiations (i.e. their common positions on REDD, see chapter 5) and into the implementation of the REDD+ concept (e.g. the regional World Bank REDD+ project and the FAO project on MRV). Responses to climate change in Central Africa generally emphasize mitigation without prioritizing adaptation (Bele *et al.*, 2011 ; Somorin *et al.*, 2012).

Adaptation

The few initiatives on climate change adaptation in the COMIFAC region has focused mainly on the agricultural sector. Nevertheless, non-timber forest products (NTFP) play a crucial food security role, and timber is a major economic sector for regional national economies. Adaptation in the forest sector in order to maintain these and other crucial forest functions for the Congo Basin countries thus becomes increasingly important. Options to optimize tropical forest management with regard to climate change adaptation need to be further explored. Several studies have started to look into climate change scenarios and impacts (e.g. the study "Climate Change Scenarios for the Congo Basin", implemented by the German International Cooperation (GIZ)) and into forest adaptation options in the Congo Basin region (e.g. the projects "COBAM" and "CoFCCA", implemented by the Center for International Forestry Research (CIFOR) etc.). The "CoForchange" project developed by the Center for International Research on Agricultural Development (CIRAD) also sought to understand the linkage between forests, climate change, and climate variability.

Vulnerability framework

Vulnerability can be defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC TAR WG II, 2003). The vulnerability framework [V= f (E, S, A)] considers vulnerability (V) as a function (f) of exposure (E), sensitivity (S), and adaptation (A). The function can also be applied to the forest sector (Locatelli *et al.*, 2008, see figure 4.1), and its principles underlie this chapter.

The **sensitivity** component in this chapter is broadly captured by the review on why forests and adaptation to climate change is needed in Central Africa. **Exposure** to climate change will be presented in the form of available information concerning observed climate change and projections of future climate change, based on the variables of precipitation and near surface air temperature. The effect of these changes in the past and the projections for future changes on different sectors, and thus on local communities, will be presented in the impact section. **Adaptation** will be covered by the section on possible responses to these impacts. As adaptation actions do not occur in a vacuum, and because joining efforts with previous initiatives can help, we will also explore the synergies with others activities.

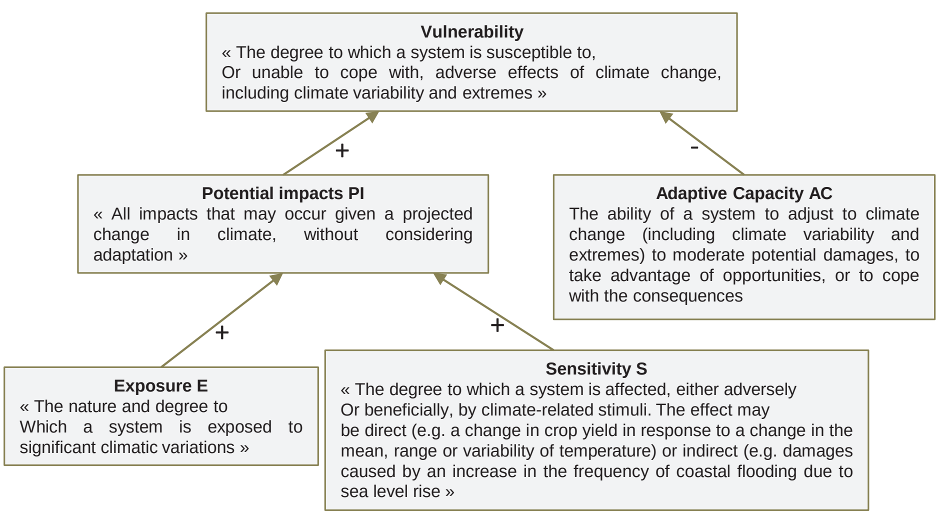

Figure 4.1 : The components of vulnerability (definitions are from IPCC : McCarthy et al., 2001). The signs under the arrows mean that high exposure, high sensitivity and low adaptive capacity induce high vulnerability.

Adapted from Locatelli et al., 2008.

Photo 4.2: Lekoni Circle – Bateke Plateaux, Gabon

2. Why "forests and adaptation" in Central Africa?

While the importance of the forestry sector, with its environmental, economic, and social benefits for the COMIFAC countries is widely recognized, the question of how to adapt to climate change remains largely unanswered. Currently, the focus is on REDD+, and few efforts have been made to mobilize adaptation funds (Ecosecurities, 2009). While Central Africa is not a highly polluted region, it nonetheless is vulnerable to the effects of climate change. The role of nature is increasingly acknowledged as playing an important role in the face of climate change. Adaptation to the impacts of climate change on the forestry sector will have repercussions on other development sectors, notably water, health, food security and energy (Sonwa *et al.*, 2012). All of these sectors are indeed interdependent and contribute to the development of Central African countries.

Biological diversity, which is the focus of much attention in Central Africa, is not immune from climate change. It is therefore necessary to examine how the climate affects biodiversity and what could be its responses (in other words, adaptation) to climate disturbances.

"Ecosystem-Based Adaptation" (EBA) is receiving increasing attention. Plans for the rational use of forest resources (from planting to sustainable harvesting to full preservation) will facilitate adaptation to the effects of climate change. "EBA" may, for example, be understood as the protection or restoration of mangroves to protect coastal areas from marine aggression, or as agroforestry practices to diversify crops and reduce vulnerability to climate variations. It also may be understood as using diversified genetic resources in forest plantations to facilitate adaptation to climate stress, or the effective management of watersheds to assure permanent supplies of water and hydro-electric energy. According to Collset *et al.* (2009), the success of EBA depends on reducing non-climatic stresses, the involvement of local communities and other actors and stakeholders, the use of sound natural resource management practices, an adaptive approach, and its integration in a comprehensive adaptation strategy. The successes of EBA should be the focus of intense communication to reach the maximum number of actors and decision-makers so that they may be widely reproduced.

While such actions can help the forest sector to adapt to climate change, the sectors putting direct or indirect pressure on the forests, such as agriculture, mining and urban settlements will play an important role in adapting to climate change in the greater Congo Basin region. Thus, forest adaptation goes far beyond the forest sector itself and incorporates all forms of competing land-use.

3. Climate parameters in the past and projection in the future

3.1 The climate and its observation in Central Africa

General characteristics

The climate of Central Africa is regulated by the annual migration cycle of the Intertropical Convergence Zone and the influence of the Atlantic and Indian Oceans. In January, the area of precipitation is located in the extreme south of the Congo Basin, while it is the dry season in the north (north Cameroon and the RCA). The area of precipitation then gradually migrates north, passing over the center of the basin in April. Rainfall occurs further north in July while it is minimal in the south (Hirst and Hasternrath, 1983). The area of precipitation starts to move south in September, re-crossing the center of the region in November. The annual rainfall cycle in the center of the region (between 5°S and 5°N) is consequently bimodal. Meanwhile, in the north and south of Central Africa, the annual rainfall cycle is monomodal, with maximum precipitation respectively in July-August and January-February. In addition to this north-south variability, climate characteristics vary from east to west. In the eastern part of the Congo Basin, maximum rainfall is recorded between March and May. In the western coastal area, rainfall is more abundant between September and November (Nicholson and Dezfuly, 2013). In addition to this spatial variation, climatic heterogeneity is observed with variations in the start and end of rainy seasons, the length of the seasons, and rainfall amounts (Guenang and Mkankam, 2012).

This strong spatial-temporal heterogeneity reflects the complexity of the Congo Basin's climate and the multitude of factors influencing it (Nicholson and Dezfuly, 2013). These factors include the flow of vapor in the lower troposphere coming from the Atlantic Ocean (McCollum, 2000). This flow of water vapor influences the annual cycle as much as the interannual variability of the water cycle in the sub-region (Pokam *et al.*, 2012). Medium and high altitude atmospheric jet streams moving across the African continent influence the sub-region's climate (Nicholson and Grist, 2003). They facilitate the supply of water vapor to the sub-region, as well as the upward movement of air masses. The topography of the Congo Basin moreover contributes to these upward movements (Vondou *et al.*, 2009) and to the heavy precipitation in western Cameroon and the eastern DRC (Nicholson and Dezfuli, 2013). Near-surface temperatures of the Atlantic, Pacific and Indian Oceans influence the interannual (Balas *et al.*, 2006) and seasonal variability (Nicholson and Dezfuli, 2013) of rainfall in the Congo Basin.

Photo 4.3: Sunset on the Congo River – Mbandaka, DRC

Observation network

There are 419 meteorological stations and 230 hydrological stations in the ten COMIFAC countries (CSC, 2013). Certain stations have produced data for well over a century. Regular climate measurements began in 1885 and 1889 at the Douala and Yaoundé stations in Cameroon (Nicholson *et al.*, 2012). The majority of the stations, however, only began their observations in the 1950s and 1960s (CSC, 2013). Since the 1980s, several stations have unfortunately stopped functioning regularly (figure 4.2), and time series are often interrupted, limiting the number of stations with reliable and complete time series data (Aguilar *et al.*, 2009).

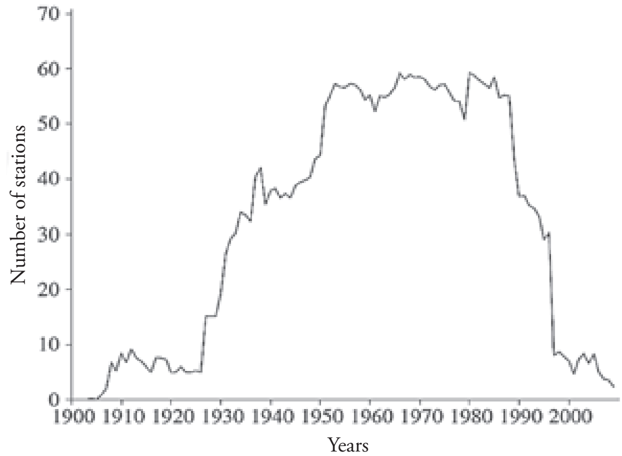

Figure 4.2: Number of rain gauges across the region 5°S-5°N, 12.5°E-30°E used per year in data of the "Climate Research Unit" at the University of East Anglia. According to Washington et al., (2013).

3.2. Past climate

Precipitation trends

A downward trend in total precipitation averages across Central Africa of 31 mm/decade was observed between 1955 and 2006 (Aguilar *et al.*, 2009). This drop in precipitation is associated with a drop in the number of extreme events by 0.67 days per decade. These reductions in precipitation vary in intensity across the region. In southern Cameroon and the Congo, the drop in rainfall persisted up to 1990 (figure 4.3). In Gabon and Central Africa, an increase was observed after 1980 and 1985 respectively (Olivry *et al.*, 1993).

Disparities exist at the local level: in the north of the Republic of Congo, the trend is marked by a drop in rainfall, while in the south of the country, rainfall levels are stable (figure 4.4) (Samba and Nganga, 2012). In the sub-region, drops in the number of consecutive days with at least 1 mm of precipitation, as well as in the number of days with precipitation above 10 mm, have been recorded (Aguilar *et al.*, 2009).

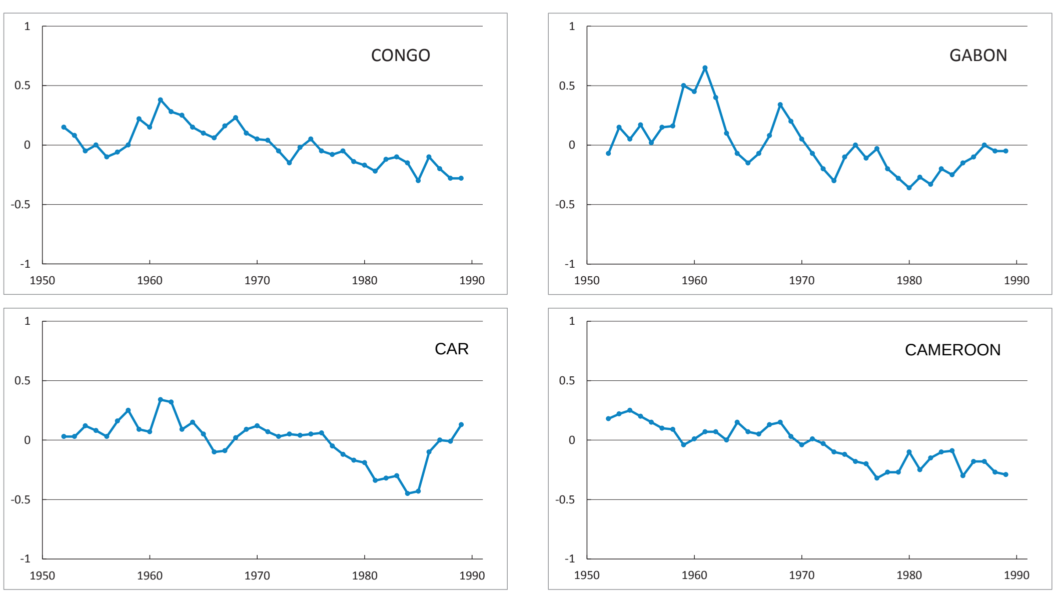

Figure 4.3: Change in annual precipitation indices since 1950 in different regions of Central Africa (according to Olivry et al., 1993). These indices are calculated using standardized annual precipitation anomalies .

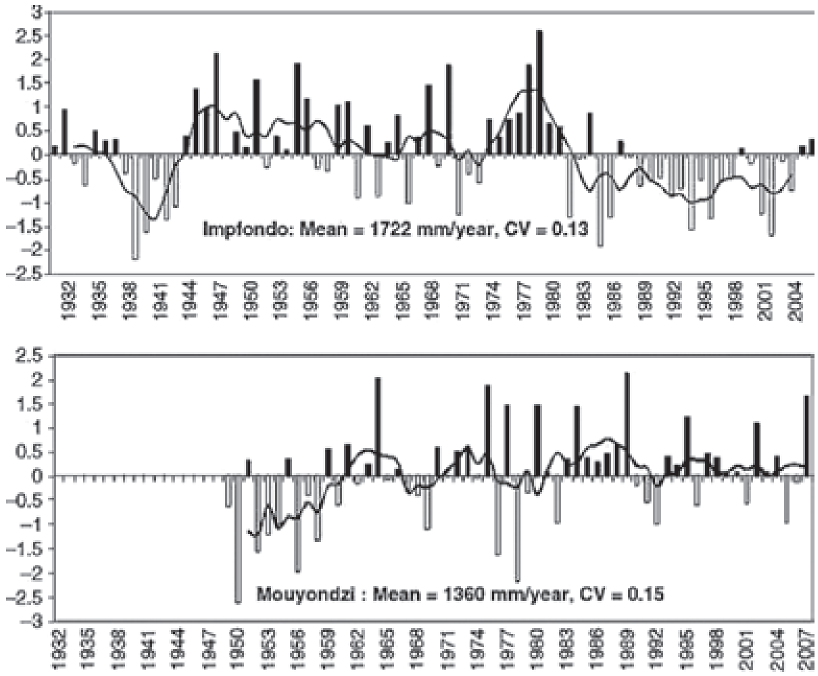

Figure 4.4 : Change in the annual precipitation indices since 1932 in two meteorological stations situated in the north (Imfondo) and south (Mouyondzi) of the Republic of Congo (according to Samba and Nganga, 2012). These indices are calculated using standardized annual precipitation anomalies.

Temperature trends

Temperatures indicate a warming trend. Between 1955 and 2006, warming has been observed across the region (table 4.1). It is important to note that the increase of heat-related parameters is about twice of the average statistics for the entire planet over the same period (Aguilar *et al.*, 2009). As for precipitation, the trend differs in amplitude across the region. In the Republic of Congo, temperatures increased by 0.5 to 1^0C during the decades of 1980s and 1990s (Samba *et al.*, 2007). At the local level, temperature increased by 0.3 to 0.5^0C in the north of the country while they remained stable in the south. Sanga-Ngoie and Fukuyama (1996) demonstrated a rise in temperatures of about 1^0C in Kinshasa, DRC over the 1960-1990 period, with values ranging from 0.6 to 1.6^0C across the rest of the country.

Table 4.1 : *Regional trends in temperature indices in Central Africa*

Index	Trend	Unit
Very hot days	+0.25	degrees Celsius per decade
Very hot nights	+0.21	degrees Celsius per decade
Frequency of hot days	+2.87	% of days in a year per decade
Frequency of hot nights	+3.24	% of days in a year per decade
Frequency of cold nights	-1.17	% of days in a year per decade
Frequency of cold days	-1.22	% of days in a year per decade

Hot day : day when the maximum temperature is above the 90^{th} percentile
Cold day : day where the maximum temperature is below the 10^{th} percentile
Cold night : night when the maximum temperature is below the 10^{th} percentile
Hot night : night when the maximum temperature is above the 90^{th} percentile
According to Aguilar et al., 2009

Global level assessments

Several COMIFAC countries in the framework of their national communications with the UNFCCC have assessed how precipitation and near surface air temperature, the most important climate parameters, might change over the course of the 21st century. These assessments, based on projections from Global Climate Models (GCM), have large confidence intervals due to their coarse spatial resolution (up to 500 km). As Table 4.2 shows, the projections differ substantially between the countries.

Table 4.2: *Overview of GCM projections used in the national communications to the UNFCCC for seven COMIFAC countries (adapted from GIZ/BMU 2011)*

Country	Number of communications to the UNFCCC	Simulated parameters	Reference period	Simulation time horizons	Trends
Burundi	2	Precipitation, temperature	1975-1990	2010, 2020, 2030, 2040, 2050	- precipitation: increase 2010-2030; decrease 2030-2040, then a new increase starting in 2050 - temperatures: 1° to 3°C increase 2010-2050
Cameroon	1 (the 2nd is being finalized)	Precipitation, temperature, marine level	1961-1990	2025, 2050, 2075, 2100	- precipitation: overall increase with strong variability in the Sudano-Sahelian region up to 2100 - temperatures: 3°C increase - rise in marine level
Congo	1	Precipitation, temperature	1961-1990	2050, 2100	-precipitation: +4 to 24 % in 2050; +6 to 27 % in 2100 - temperatures: +0.6 to 1.1°C in 2050; +2 to 3°C in 2100
Gabon	1	Precipitation, temperature	1961-1990	2050, 2100	-precipitation: +5 to 6 % in 2050; +3 to 18.5 % in 2100 - temperatures: +0.9°C in 2050; +2°C in 2100
DRC	2	Precipitation, temperature, and atmospheric pressure	1961-1990	2010, 2025, 2050, 2100	-precipitation: from +0.3 % in 2010 to +11.4 % in 2100 - temperatures: from +0.46°C in 2010 to +3.22°C in 2100 - atmospheric pressure: from 0.52 hPa in 2010 to -0.47 hPa in 2100
São Tomé and Príncipe	1	Precipitation, temperature, marine level	1961-1990	2100	- precipitation reducing - temperatures rising - rise in sea level
Chad	1	Precipitation, temperature	1961-1990	2023	-precipitation: +50 to 60 % in 2023 - temperatures: +0.6 to 1.7 °C

Sources: Initial communications on the UNFCCC, Burundi 2010, Cameroon 2004, Congo 2001, Gabon 2005, DRC 2009, São Tomé and Príncipe 2005, Chad 2001

Regional level

At the regional level, climate projection studies that cover at least a large portion of the Congo Basin are available, even though the region was not always the focus of these studies. An example are downscaling activities for the whole African continent (Mariotti, 2011) or a large portion of Africa (e.g. Paeth *et al.*, 2009 for northern Africa and the tropics; e.g. Hudson and Jones, 2002; Engelbrecht *et al.*, 2009 for subequatorial Africa). Most of these studies only date to the middle of the 21st century and use the input data of only one GCM-run model for one specific scenario. With a single GCM-run model for one specific scenario the sample size is extremely low, thus resulting in a very low confidence interval. Therefore, these studies can be classified as case studies rather than as comprehensive climate change projections. While these studies do agree on a basin-wide increase in temperature, the results differ for precipitation. Some studies project a decrease in rainfall over large parts of the basin by the middle (following the A1B scenario; Paeth *et al.*, 2009) and the end of the century (fol-

Photo 4.4: Typical village house in the forest, CAR

Photo 4.5: Central Africa is a region of intense, strong and sudden rains

lowing the A2 scenario, Engelbrecht *et al.*, 2009); other studies project constant rainfall amounts until the end of this century (following the A1B scenario; Mariotti, 2011).

Regional level assessments: CoFCCA-study

The Congo Basin Forests and Climate Change Adaptation (CoFCCA) project recently conducted a first attempt at modeling the climate in the region using the regional climate model PRECIS (Providing Regional Climates for Impacts Studies) to make the projections (Pokam *et al.*, 2011). The study projected changes in near-surface air temperature and precipitation for the period from 2071–2100 under the high emission scenario with a reference period spanning from 1961–1990. Broadly considered, PRECIS predicts an increase in precipitation in Central Africa, with the highest increase (around 14%) increase from September to October. However, this increase in precipitation will not occur over the whole region. The eastern part of the COMIFAC region will experience a decrease in precipitation. An overall increase of near-surface air temperature for the whole region compared to the reference period is predicted, with the largest value (around 4.3°C) during the season June-July-August.

Regional level assessments: Climate Change Scenarios Study

The German Federal Ministry for the Environment (BMU) funded a recent study from 2010-2012, "Climate change scenarios in the Congo Basin," a comprehensive regional climate change assessment for the greater Congo Basin region (CSC, 2013). Besides Chad, where only the southernmost third of its surface was covered because of technical reasons, the study covered the entire land-surface of all COMIFAC member countries (from 15°N to 15°S and from 7°E to 35°E). This assessment used 77 existing and additionally compiled global and regional climate change projections from 18 independent models (global and regional), the largest data set used so far, to analyze the impacts of high and low-emission scenarios (see: Annex 2 for methodological details). This analysis not only estimated the potential magnitudes of projected climate change signals, but also judged the reliability of the projected changes. Furthermore, within this project, a representative subset of the climate change projections have been used as input for subsequent impact assessments and the formulation of adaptation options (CSC, 2013).

We would like to caution the reader that the scope of this study was regional (the entire Congo Basin) and that it made projections for the middle and end of the 21st century. This makes it difficult to compare with presently observed changes, which are often at a local scale. It is also possible that these projections actually contradict the observed climate changes in the recent past, simply because of the much longer time horizon of the projections and because the climate in the region shows a distinct variability on the decadal time scale.

Near-surface air temperature

The Climate Change Scenarios study (CSC, 2013) revealed that all models, independent of season and emission scenario, show a warming of near-surface air temperature by at least 1°C towards the end of the 21st century. Temperature extremes, like the frequency of cold and hot days and nights, also decrease and increase respectively, independent from season and emission scenario (table 4.3). For these purposes, the frequency of cold days for example is defined as number of days with a daily maximum near-surface air temperature below the 10th percentile of the daily maximum near-surface air temperatures of the period 1961–1990. Since all models are projecting changes in the same direction, the likelihood of these changes occurring is very high. However, the range of possible changes is large, mainly because of a few outlier model projections. Therefore, a sub-range (the central 66% of projections) was defined as "likely changes." A projected climate change signal is considered to be robust if at least 66% of the model predictions agree in the direction of change (IPCC, 2007). For near-surface annual mean temperature, the sub-range ("likely changes") predicts between 3.5°C and 6°C increase in temperature for a high emission scenario and between 1.5°C and 3°C increase in temperature for a low emission scenario towards the end of the century. In general, the projected temperature increase is slightly higher (above average of the predicted changes for the entire study area) in the northern parts of the region and slightly lower (below average of the predicted changes for the entire study area) in the central parts.

Total Precipitation

The results of the different projections are not as robust for total precipitation as for near surface air temperature. Some models project an increase in the annual total precipitation in most parts of the greater Congo Basin region, whereas other models project a decrease over the same areas. However, towards the end of the 21st century a general tendency for a slight increase in annual total precipitation is projected for most parts of the Basin. The largest increase in annual total precipitation is projected for the generally dryer northern part of the region, which is related to the northward expansion of the tropical convection zone and to the relatively low total precipitation over this area. The "likely range" for changes in total annual precipitation is between -10 and +10 % (-10 and +30 % in the north) and between -5 and +10 % (-10 and +15 % in the north) for the high and low emission scenarios respectively. These results suggest that it is unlikely that drastic future changes in annual total rainfall will occur.

In contrast, substantial changes in the characteristics of rainfall are projected. The intensity of heavy rainfall events (95th percentile of daily precipitation amounts, but only wet days (days with daily rain amounts of at least 1 mm/day) are considered) is likely to increase in the future (the "likely range" is predominantly positive, up to +30 %). Also the frequency of dry spells (periods in the rainy season with at least six consecutive days with daily rain amounts of less than 1 mm/day) during the rainy season is projected to increase substantially for most parts of the region, indicating a more sporadic future rainfall distribution.

Table 4.3: *"Likely range" (centered on the median) of projected changes (in %) for the frequency of cold/hot days/nights averaged over the entire Congo Basin region.*

Projected Changes	Low emission scenario		High emission scenario	
	2036 - 2065	2071 - 2100	2036 - 2065	2071 - 2100
Cold Nights (in %)	- 9 to - 7	-10 to -7	-9 to -8	-10
Cold Days (in %)	-8 to -5	-9 to -6	-9 to -6	-10 to -9
Hot Nights (in %)	+27 to +43	+29 to + 56	+38 to +53	+64 to +75
Hot Days (in %)	+12 to +21	+13 to +29	+16 to +28	+31 to + 54

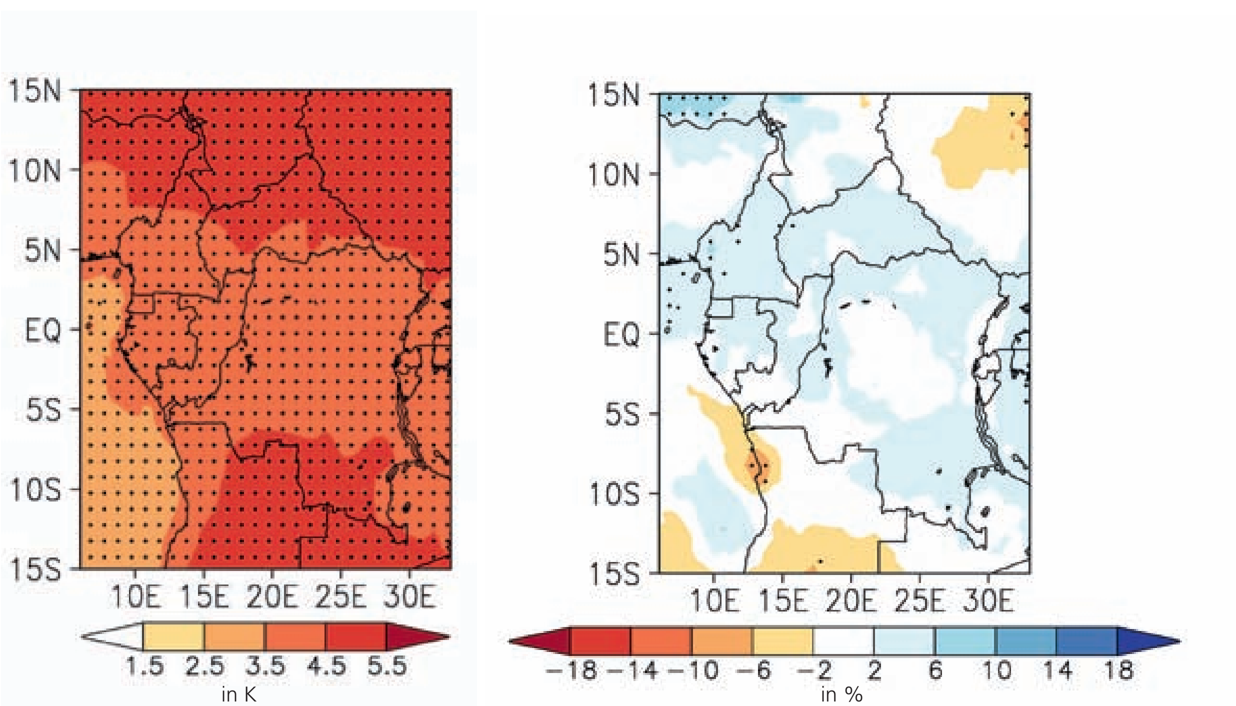

Figure 4.5: Projected change in annual mean temperature (left) and annual total precipitation (right) until the end of the 21st century (2071 to 2100) compared to the period 1961 to 1990 for a high emission scenario. The depicted change is the median change from a set of 31 different climate change projections from global and regional climate models. The black stipples highlight regions where the majority of the models agree in the direction of change. Projected changes in these regions are therefore more robust than over regions without stipples.

Source: CSC 2013

Photo 4.6: Abandoned laterite quarry, Gabon

In general, the study shows that projected rainfall changes will not lead to a general water shortage in the region. Some prolonged and more frequent dry periods might nevertheless become more likely in the future. While this finding is rather independent of the underlying emission scenario, near-surface air temperature is projected to increase substantially more under the high emission scenario. This conclusion is based on the results of the Climate Change Scenario study (CSC, 2013) which used a large ensemble of climate change projections from regional and global climate models. The models used do not take into account regional specific demographics, land use change, water extraction and other factors potentially having an impact on water availability, for example.

4. Climate change impacts

4.1 Past Impacts

Without entering into a discussion of whether changes in the recent past can be attributed to climate change or should be attributed to the impact of often overwhelming changes in land use, we present a number of observations focusing on the impact of climate variability or change on hydrology, vegetation and on society and economy.

Impacts of climate variation on watercourses

Land use and the climate can have both immediate and sustained effects on hydrology (Li *et al.*, 2007). We mainly present here climate-related impacts. The repercussions of past climate variations on watercourses are reflected in changes in their regimes. For example, Sircoulon (1990) showed that the average flow of all of the principle Sahelian rivers (Senegal, Niger and Chari), which was 136 km^3 per year prior to 1969, fell to 79 km^3 during the 1970-1988 period (a 43 % drop), and was just 36 km^3 in 1984 (a 74 % deficit). In humid tropical Africa, during the 1981-1990 period, there was a fall in river flow regimes marked by deficits assessed at 365 km^3 (or 32 % of the total flow of these rivers into the Atlantic Ocean). These deficits have led to numerous failures in the functioning of hydroelectric installations, notably in Cameroon. Table 4.4 presents the values of annual mean flow deficits calculated for several watersheds in Central Africa.

The decline in flows has repercussions on the quantity of water filling lakes, which are natural reservoirs. The example of Lake Chad well illustrates this point. During the 1955-1975 period, its surface area dropped from about 24 000 km^2 to about from 2 000 to 6 000 km^2 (Lemoalle *et al.*, 2012). In certain regions of the Congo Basin, an increase in precipitation was recorded beginning in the 1990s. This increase led to an increase in the flow of certain watercourses. This occurred in the Congo River where the flow started increasing in the early 1990s (Conway *et al.*, 2009).

Impact of climate variation on vegetation

The impact of climate change on water regimes has affected vegetation. Prior to the considerable drop in water levels of Lake Chad, vegetation in the north of the Congo Basin was mainly composed of *Phragmites*, *Cyperus papyrus*, *Vossia, Typha, Potamogeton* and *Ceratophyllum.* The drop in the lake's water level led to important vegetation changes and by 1976, the bulk of the vegetation no longer constituted *Vossia* and *Aeschynomene sp.* (Olivry, 1986). Changes in aquatic vegetation were observed in the Logone flood plain in northern Cameroon where flooding had declined in the 1970s following the upstream construction of a dam. Certain plant species characteristic of flood areas, such as *Vetiveria nigritana* and *Echinochloa pyramidalis,* were replaced by other species, notably *Sorghum arundinaceum* (Scholte *et al.,* 2000 ; Scholte, 2007).

Climate change also affects the reproduction and growth of trees, and it can cause their decline. However, the effects of climate change are often indirect, for example by affecting the frequency of fires or modifying the behavior of pests and diseases. During the "El Niño" years of 1983, 1987, and 1997, fires were particularly destructive in southeastern Cameroon. The effects of climate change can accelerate biodiversity loss through the disappearance of species or by reducing the resilience of severely disrupted ecosystems.

Socio-economic impacts

Climate change can have impacts on human populations : their energy and water supply, food security, health, etc. Certain changes can lead to significant social upheaval, ranging from a change in livelihood activities to the displacement of populations to more hospitable regions. For example, fishermen and livestock farmers have become crop farmers, leading to an escalating number of disputes over land and competition for the use of natural resources. High migration towards towns and areas with more favorable living conditions also has been observed (Sighomnou *et al.,* 2000). In addition, farmers in numerous places have adapted to drought by developing off-season crops on low-lying land and flood-recession cropping at the expense of natural biological diversity. In the Adamaoua region, for example, there has been a land rush on flood-recession plains, and competition over land has provoked numerous clashes between crop and livestock farmers (Boutrais, 1989). In northern Cameroon, the influx of agricultural laborers from Chad and Central Africa has led to the systematic cutting of woody plants to grow sorghum ; and in the western highlands, tapping springs for irrigating crops in higher altitude areas is causing shortages of potable water in the dry season on the plateaux.

Table 4.4 : *Deficits of mean values calculated in certain hydrometric stations before and after the abrupt change over the 1950-1989 period.*

Country	Station	Watershed	River	Change Date	Deficit
Cameroon	Eséka	Nyong	Nyong	1971	-18 %
Cameroon	Mbalmayo	Nyong	Nyong	none	Low deficit
Cameroon	Doume	Congo	Doume	none	Low deficit
CAR	Bangui	Congo	Oubangui	1970	-30 %
Congo		Congo	Sangha	1975	-22 %

Source : Servat et al., 1998

Photo 4.7: Forest fire in the dry forests on the plain, Gabon

4.2 Future Climate Change Impacts

As discussed above, we recommend the reader interpret the results presented with particular attention to their regional (entire Congo Basin) and temporal (towards the middle–end of the century) dimensions. Many changes in our environment, often at a local scale, are difficult to link with these projected changes, which will only be tangible for future generations, yet influenced by our present-day responses.

Impact on hydrology and energy

Some studies dealing with the future impacts of potential climate change on the water resources in the region have been compiled. An older study (Kamga *et al.*, 2001) showed a future change in annual river flow from -3 to +18 % for the upper Benoué River located in the sub-humid savannas of northern Cameroon. A regional-level study assessed the impact of climate change on the hydrology of the Oubangui and Sangha sub-basins of the Congo Basin (Tshimanga & Hughes, 2012). A decrease in total runoff of about 10 % is projected for the future, mainly caused by an increase in evapotranspiration, whereas no change is projected for rainfall.

The Climate Change Scenario Study (CSC, 2013) mentioned above showed that the projected changes in rainfall and temperature will result in substantial changes in the hydrology of the Congo Basin. Rising temperatures potentially lead to increased evaporation rates. For the hydrologic assessment within the Climate Change Scenario Study (CSC, 2013), a subset of 6 climate projections was used to analyze the potential impacts of the climate change described in paragraph 3.2. Such a subset of projections automatically has a smaller confidence interval and might sometimes lead to contradicting results compared to the more global results of the actual climate change scenarios. With that in mind, the impact studies showed that the increase in rainfall might exceed the increase in evaporation, and as a result, the run-off is projected to increase up to 50 % in some parts of the Basin. Run-off and stream flow will increase in the wet season especially, suggesting a significant increase in flood risks in the future, especially in the central and western parts of the Congo Basin. The scenarios predict conflicting results for the dry season : some scenarios indicate a drier dry season, while others show higher flows of water during the dry season. However, all of the models indicate that the difference between the wet and dry seasons will become larger compared to present day conditions ; the wet extremes, especially, will become more frequent and more intense, which is also related to the predicted higher frequency of heavy rainfall events.

In general, the analyses show that more water will be available in the future. In this regard, climate change may have a positive impact on potential electricity production. However, the variability of rainfall is also projected to increase, which means that in some years power production will be much lower compared to other years. Countries should therefore ensure they have other sources of electricity to cover the reduced hydropower production during dry periods.

Photo 4.8: Wagenia fishery in the Congo River rapids – Kisangani, DRC

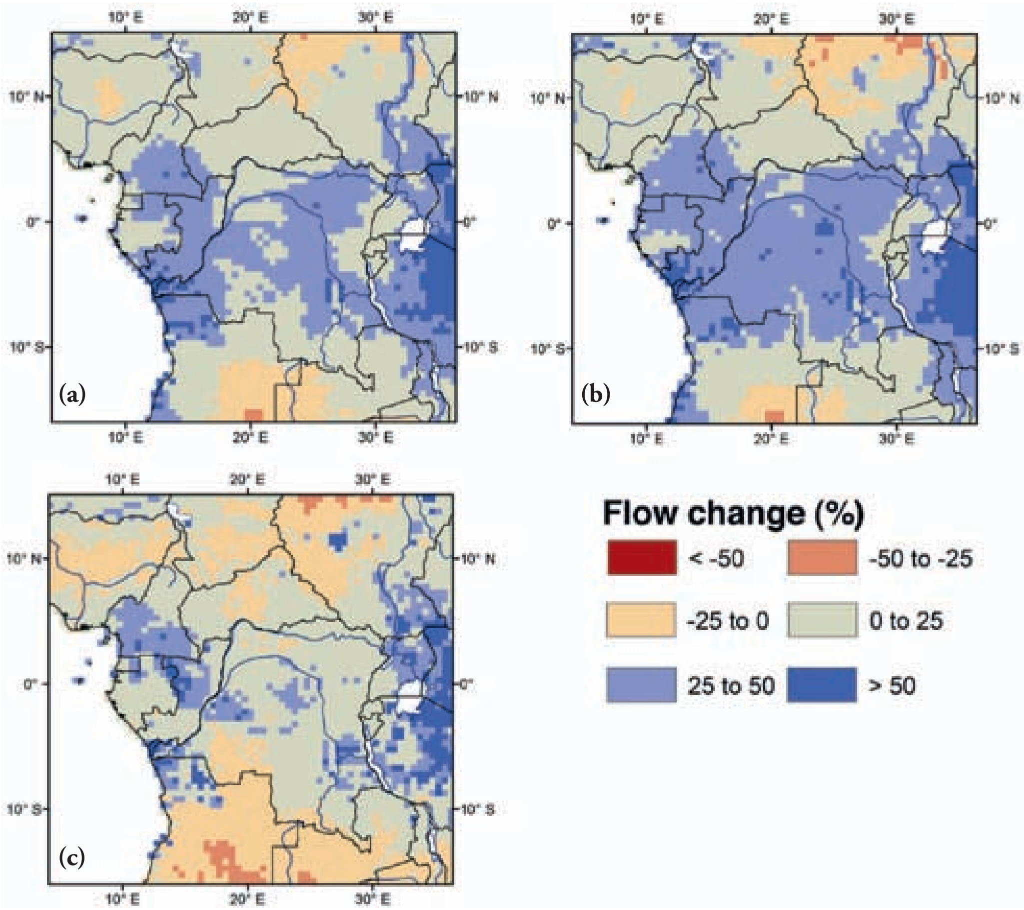

Figure 4.6. Maps show the projected mean of changes in mean flow (a), high flow (Q95) (b) and low flow (Q10) (c) for 2071-2100 relative to 1971-2000 for a high emission scenario. Flows are calculated using the Variable Infiltration Capacity (VIC) model in combination with three different climate models.
Source: CSC, 2013

Impacts on Forests

Climate change is expected to have a range of impacts on forest ecosystems. However, the effects of CO_2 and temperature on tropical forest growth are not yet fully understood. Generally it appears that higher atmospheric CO_2 concentrations might increase forest growth and carbon capture. Higher temperatures, however, might have negative impacts on forest growth and reduce the amount of carbon in the forests (Jupp *et al.*, 2010). The impact analyses show that the Congo Basin is unlikely to see a decline in forest growth as is sometimes predicted for the Amazon Basin as a result of climate change. Instead, there could be a moderate increase in ecosystem carbon, including vegetation and soil carbon (figure 4.7). Depending on how the climate will change, there could also be a shift in the ecosystems' land cover between forest and savanna. Based on the analysis, the most likely future scenario involves a moderate expansion of evergreen forests into savannas and grasslands to the North and the South of the current forest-savanna-transition zone. There is a large uncertainty range in the model assessments, highlighting the importance of collecting new data to further narrow the prediction ranges (e.g., biomass in the central Congo Basin and responses of forests to changing climate and CO_2 concentrations).

Impacts on Agriculture

Currently, it seems that other factors such as field management and nutrient availability are limiting agricultural production much more than climatic conditions. Only on the (drier) edges of the region is water availability limiting agricultural potential. In humid tropical climates, too much rainfall and high humidity limits agricultural production through nutrient leaching, fungal growth, and other factors potentially influenced by increased humidity such as insect pests, bacteria, weeds etc. In most of the Basin, water stress will increase slightly in the future (CSC, 2013). On the other hand, evapotranspiration (the process whereby liquid water is converted to water vapor) is projected to decrease between 2.5 and 7.5 % under the high emission scenario. The low emission scenario shows a general decrease in

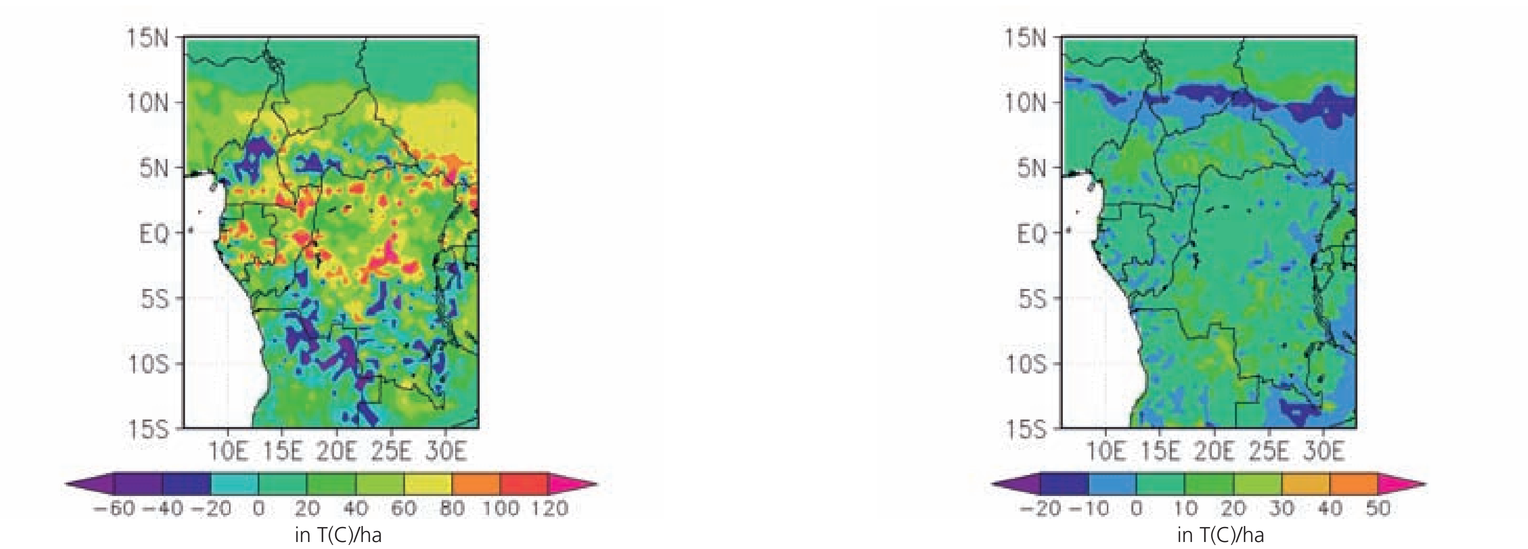

Figure 4.7: The projection of change towards the end of this century (mean of the period 2071-2100 compared to the mean of the period 1961-1990) under a high emission scenario. In the left panel, changes in potential vegetation carbon are shown, and in the right panel, changes in potential soil carbon are shown. The sum of these two panels indicates the changes in total ecosystem carbon. Changes in potential vegetation and soil carbon are calculated using the Lund-Potsdam-Jena-managed lands (LPJ-ml) model in combination with a single climate model (ECHAM5).

Source: CSC, 2013

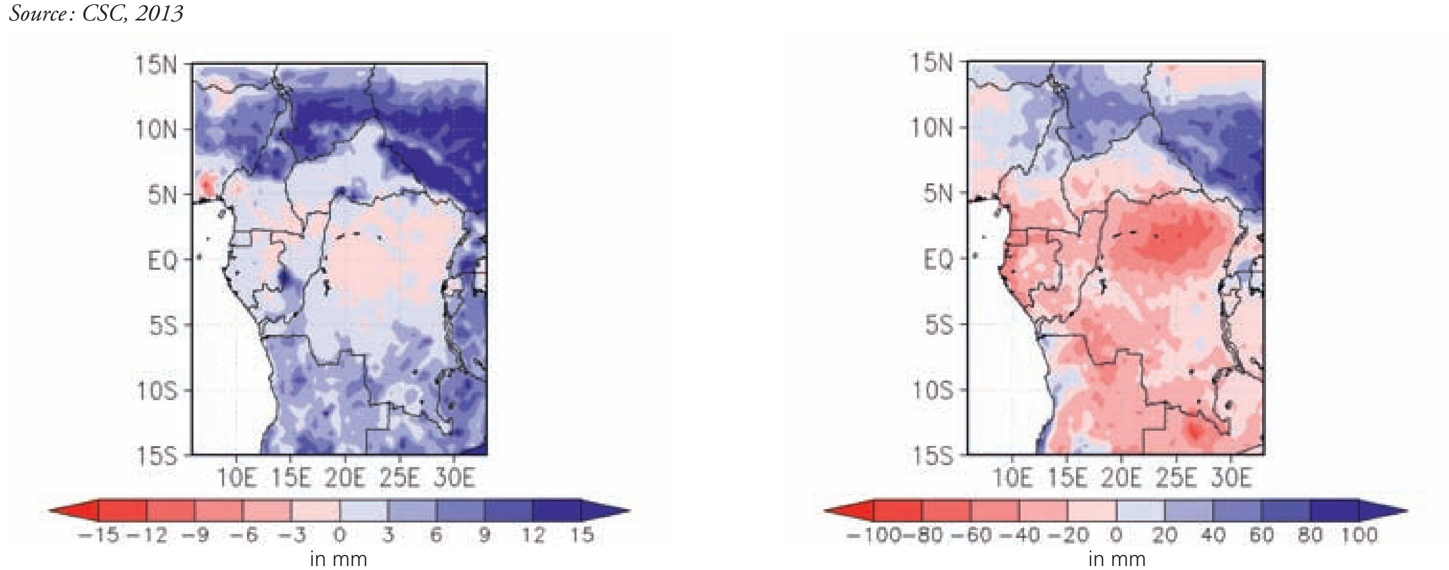

Figure 4.8: The projection of change towards the end of this century (mean of the period 2071-2100 compared to the mean of the period 1961-1990) under a high emission scenario. The left panel shows changes in greenwater consumption (the total water amount evapotranspired by crops) and the right panel shows changes in evapotranspiration. Greenwater consumption and evapotranspiration are calculated using the LPJ-ml model in combination with a single climate model (ECHAM5).

Source: CSC, 2013

evapotranspiration as well, but toward the end of the century the trend becomes slightly positive. Only in the northern zone of the greater Congo Basin, belonging partly to the Sahel zone, is evapotranspiration projected to increase slightly. Therefore, the impact of future climate change on agricultural production will most likely be limited in the region, and agriculture will probably not suffer from structural water shortages. Only agriculture in the savanna regions surrounding the Congo Basin might potentially face water shortages in the future. In the southern savanna region, analyses indicate that more frequent droughts will affect agriculture production through water stress.

Impacts on Economic Growth

In several of the COMIFAC countries there is a clear correlation between annual rainfall and gross domestic product (GDP) growth. GDP and agricultural GDP growth rates tend to be higher in years with above-average rainfall than in the dry years (CSC, 2013). The impact of climate variability on GDP growth is most pronounced during dry years ; during below-average-rainfall years growth is sometimes severely reduced. All above-average-rainfall years tend to exhibit relatively similar economic growth rates. The correlation between rainfall and GDP growth rates is stronger in countries with lower and more variable rainfall. In most countries, agricultural GDP growth rates are more affected by climate variability than the total GDP growth rates. For example, in the Democratic Republic of Congo during dry years, agricultural GDP growth was negative, while during average and above-average-rainfall years the economic output of the agricultural sector increased. In Chad, the situation is even more dramatic with large reductions in agricultural productivity during dry years and rapid growth during the years with near-average rainfall.

Photo 4.9 : Central African urban populations are constantly growing – Bukavu, DRC

In terms of future climate change impacts on economic development, our analysis shows that COMIFAC countries are especially vulnerable to a reduction in rainfall and a significant increase in inter-annual rainfall variability. Some climate change scenarios show large increases in climate variability, which could have a negative impact on development.

In conclusion, Central Africa will face a more variable climate and a more variable hydrological regime. Also, the differences between seasons and between different years are likely to become greater. The region will experience more intense rainfall and probably more floods during the wet season. The dry season could become either wetter or drier. It is also clear that near-surface temperatures will increase in the future. Climate change adaptation should therefore focus on reducing the impacts of increased rainfall variability and higher temperatures.

5. Possible Adaptation Responses

According to the UNFCCC, adaptation responses are necessary and should be part of national transformation processes aimed at the vulnerabilities facing local stakeholders. To be effective, climate change adaptation should include a well-balanced mixture of approaches at local, national, and regional levels.

5.1 Local Level

Locally, forest communities suffer the effects of climate change (Bele *et al.*, 2010). In the absence of well-planned policy and institutional frameworks, communities appear unprepared to cope with climate change as shown by the vulnerability studies undertaken under CoFCCA (Congo Basin Forests and Climate Change Adaptation) (Bele *et al.*, 2011). By using Participatory Action Research (PAR), the CoFCCA project initiated pilot adaptation responses in the DRC, the CAR, and Cameroon. These initiatives involved the introduction or use of climate stress-resistant varieties (manioc, plantain), planting trees, adding value to non-timber forest products (NTFPs), and the development of apiculture to diversify peoples' income sources (see Bele *et al.*, 2013 for the pilot projects in Cameroon). Under the COBAM project, pilot projects also will be set up that take into account the synergy between adaptation and mitigation actions.

Photo 4.10: Oubangui, major tributary of the Congo River, at the beginning of the dry season, CAR

Since adaptation to climate change is highly local, institutions, particularly in rural areas, have an important role to play in fostering adaptation and resilience to climate change. Local institutions also play a role in mediating external interventions in a community (Agrawal, 2008, 2010). Research conducted as part of the CoFCCA project explored the types of institutions present within forest-dependent communities in three provinces of Cameroon (Brown, 2011). Results showed that diverse institutions, both formal and informal, exist within villages, including informal savings and loan groups, forest or agriculture groups, and forest or agriculture product marketing groups. While groups sometimes were gender specific, most often, this was not the case. Villagers are often members of several groups, and this may present opportunities for social learning. Social learning occurs when people engage with one another, sharing perspectives and experiences in order to address changing circumstances (Brown, 2011). This can be an opportunity for building resilience to climate change.

5.2 National level

The work of CoFCCA also illustrates national institutional responses to climate change (Brown *et al.*, 2010). The adaptive capacity or capability to adjust to and limit risk in the face of climate change is low for Cameroon, the CAR, and the DRC. This is because they lack key determinants of adaptive capacity such as economic wealth, technology, information, skills, and infrastructure. Vulnerability is exacerbated, particularly in the CAR and the DRC as a result of recent civil conflict and on-going insecurity in some parts of both countries (Brown, 2010 ; Brown *et al.*, 2010 ; Brown *et al.*, 2013). An analysis of policies and institutions in the CAR, Congo, and Equatorial Guinea indicates an absence of coordination between national agencies (Nguema & Pavageau, 2012 ; Gapia & Bele, 2012 ; Pongui & Kenfack, 2012), and weak intra-sectoral and multi-level coherence and complementarity in the planning and implementation of adaptation responses. Effective coordination is nonetheless crucial. An awareness of the threats posed by climate change exists in the respective countries, but this is not necessarily translated into the creation of institutions capable of coping with them. Several countries, such as the CAR and the DRC have developed national adaptation programs of action (NAPAs). The DRC received NAPA funding related to food security. Cameroon is developing a national adaptation plan (NAP). An analysis of these NAPAs and of other documents indicates that forest resources have not, or have only scarcely been considered in climate change adaptation planning (Bele *et al.*, 2011). While NAPA documents state the need for a gender-sensitive approach to climate change adaptation, there has not been broad participation in the development of the documents, with only vague strategies to address gender concerns (Brown, 2011).

Most of the COMIFAC member countries, which are characterized by generally low incomes and high poverty rates, face large development challenges. These immediate development needs may currently be more important priorities than climate change adaptation. However, planning for future development also creates opportunities for adaptation. To avoid making poor investment decisions and to reduce the future cost of adaptation, climate change adaptation strategies should be integrated into current development plans.

5.3 Regional level

In time COMIFAC, which is a federating platform for climate change response, should integrate scientific and operational initiatives for adapting to the effects of climate change. However, the region is not sufficiently mobilized to obtain funds for adaptation. Discussions and actions to reduce vulnerability in Central Africa have mainly focused on the issue of the fall in the water levels of Lake Chad and the rivers supplying it.

"Climate change" initiatives have come mainly from the research sector working with a few policy makers (Sonwa *et al.*, 2012). The positions taken by COMIFAC ministers regarding adaptation are much more mixed than those taken on REDD+. The same is true for CBFP international partners, conservation, and civil society stakeholders, which have not yet supported a regional level response to the problem of populations/communities and forest resources vulnerability to climate change. The Economic Community of Central African States (ECCAS) and COMIFAC have established a group of climate experts, a counterpart to IPCC at the Central African level, which has undertaken and is publishing a review of knowledge on the Central African climate.

At the conclusion of the climate change scenarios study, proposals were made for COMIFAC to deepen discussions and actions. There is a need to improve preparedness for extreme weather events, such as droughts and floods, because such events are likely to occur more often in future. In addition, the agricultural and energy

Photo 4.11 : Anything goes when setting yourself up in the forest – Bas-Congo, DRC

sector should spread risk through the diversification of activities. Farmers should grow different crops and also different varieties of the same crops to reduce the impact of climate variability. Countries should be careful not to become fully dependent on hydropower, because it makes them especially vulnerable to increased climate variability including droughts. Other sustainable energy sources, such as solar and biofuels could also be promoted. To prevent forest degeneration and erosion, there should be more attention on reforestation and agroforestry. Food and water security programs should develop strategies to manage climate variability so they are prepared for both dry and wet periods. The knowledge of climate change impacts and adaptation is still very limited in the region, and there is a need to build more capacity and raise awareness of the issues.

Besides COMIFAC, there are other regional organizations, widening the possibilities of regional adaptation options significantly. The economic drawbacks of not considering adaptation in national development strategies are obvious and clearly involve the ECCAS. In the hydrology sector, there are specialized regional organizations, like CICOS (International Commission for the Congo-Oubangui-Sangha Basin) and LCBC (Lake Chad Basin Commission), which work on watershed management and thus can take action related to the anticipated impacts on hydropower and flooding.

Neighboring countries to the north and south, which are expected to be severely affected by climate change, may also produce important indirect impacts on the Congo Basin countries. The increase in variability in agricultural production might lead to an increase in migration from these countries into the Congo Basin. Adaptation options that address such impacts should be considered.

Photo 4.12: Sea erosion along the Gabon coastline

6. **Synergies with other Initiatives**

The forest resources and rural communities targeted by climate change adaptation initiatives are already the focus of several biodiversity conservation and climate change mitigation projects and programs. The climate influences several sectors of national and rural economies and responses must be integrated and multi-institutional. The response to vulnerabilities cannot be made without considering existing initiatives. Synergy, particularly when it is well planned in advance, can help save time and resources.

6.1. Link between adaptation and REDD+ initiatives

Synergies with REDD+ and adaptation efforts in the forest sector could support an integrated response to climate change. Complementarities between REDD+ and adaptation are possible (Guariguata *et al.*, 2008 ; Locatelli *et al.*, 2010) because REDD+ activities can readily integrate adaptation actions into mitigation strategies making REDD+ activities more sustainable. Certain REDD+ activities could help rural communities cope with climate change, acting to serve both mitigation and adaption objectives simultaneously. For example, the restoration of mangroves captures CO_2 as the trees mature. Mature mangrove trees, in turn, will reduce the intensity of waves, which increases with climate change. On land, tree planting stores carbon but can also serve adaptation goals if these trees are resistant to climate change, act as windbreaks, and allow households to diversify their sources of income. Funding from REDD+ could also support poverty reduction which in turn would help people become more resilient to climate change (Somorin *et al.*, 2012**).** However, for an activity to further both mitigation and adaptation goals, these synergies must be integrated from the outset in both planning and execution. The opportunities and potentials offered by this synergy is what the COBAM project seeks by exploring regional, national, and local policies and strategies needed to cope with the effect of climate change in the Congo Basin. The project is initiating pilot adaptation and mitigation- synergy activities in 5 of 12 biodiversity conservation landscapes of Central Africa. Preliminary national level studies in Equatorial Guinea, the CAR, and the Congo (Nguema & Pavageau, 2012 ; Gapia & Bele, 2012 ; Pongui & Kenfack, 2012) indicate that current policies do not encourage this synergy.

6.2. A need for coordination between regional structures

COMIFAC and the International Commission of the Congo-Oubangui-Sangha Basin (CICOS) group the regional states around forests and hydrology. However, these two initiatives have not yet focused on joint actions needed to respond to climate change. The link between forestry and hydrology at the watershed level is well established. A reduction in rainfall could lead to a reduction in hydroelectric energy supply. The cutting of wood could fill these energy deficits but soil erosion and silted reservoirs from forest clearing will act to reduce energy supply. The solution is to be found in institutional coordination at the watershed level. This must also be considered at the sub-regional level with effective coordination between COMIFAC and CICOS. The latter, which addresses one of the most sensitive sectors to the effects of climate change has not yet received the same degree of attention as COMIFAC. Also, the necessary partnerships between local communities and forest management is lacking in Central Africa (Sonwa *et al.*, 2012).

Synergy with the hydraulic sector would allow CICOS and COMIFAC to coordinate initiatives and eventually develop payments for environmental services (PES) mechanisms for electricity and water in adapting to climate change that henceforth could involve the private sector. Integrating climate change adaptation measures

Photo 4.13 : Typical straw hut – Monassao, CAR

into other initiatives (like the example of the water and electricity sector given here) will make the region's natural resources more resilient to climate change.

Integrating climate change adaptation into biodiversity conservation, REDD+ and water management would also make these initiatives more resilient. Ecosystem-based adaptation (EBA) would further enable forest resources management techniques to support climate change adaptation in development sectors. However, this requires well-planned sub-regional structural coordination. Sustainable development that takes climate into account depends greatly on this coordination.

7. Conclusions

Climate change mitigation measures have received considerable attention, especially with the development of REDD+, the subject of chapter 5 in this volume. Adaptation responses to future climate change at local, national, and regional levels are, with only few exceptions, still in their infancy. However, they are receiving increased attention and the results of the scenarios presented in this chapter provide important background information for initiatives presently under way.

The network of climate observation in Central Africa has been decreasing.

An increase in temperature (up to 1°C) and a reduction in average annual rainfall (e.g. 31 mm/decade) have been observed in the Congo Basin since the 1950s, albeit with considerable regional variation. Based on an extensive regional study, projections suggest the development of a more variable climate with substantial changes in the hydrology of the Congo Basin towards the middle to the end of the 21st century. Temperatures will increase by at least 2°C, and the difference between the wet and dry seasons will become larger compared to the current climate. The wet extremes, especially, will become more frequent and more intense. Run-off and stream flow will likely increase in the wet season, suggesting a significant future increase in flood risks, especially in the central and western parts of the Congo Basin. This will have major consequences for the use of hydropower, where infrastructure will have to take these changes into account.

Without taking into account changes in land use, a moderate expansion of evergreen forests into savannas to the North and South can be expected due to climate change, although considerable uncertainty with these predictions exists due to limited references to field conditions. The impact of climate change on agricultural production, as studied on a regional scale, will likely be limited to the northern and southern fringes of the Congo Basin. The semi-arid northern and southern flanks of the Basin are predicted to become much drier, with dramatic consequences for their human populations. Furthermore, the Congo Basin is not isolated, and people from neighboring areas will increasingly be induced to migrate into the Basin's relatively high-potential agricultural areas. Adaption for this, and other unexpected consequences of climate change, will require considerable attention.

Particular attention should be devoted to avoiding the fragmentation of institutions, as adaptation responses overarch the classical sectors of forest, agriculture, hydrology, infrastructure, etc. and require far more integration.

Photo 4.14: Fishing camp on the Lukenie River – Bandundu Province, DRC