University of Zurich[UZH]

Analysis of climate change adaptation in the department of Cundinamarca (Colombia) based on projected climate change impacts on the department's hydrological resources and agroclimatic potential

GEO 511 Master's Thesis

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Abstract

Climate change is felt all over the globe and like many other developing countries, Colombia is highly vulnerable to its impacts. A big part of Colombia´s economic activity and of its population is concentrated in the Andes mountain range, an area that has been identified as especially vulnerable to the effects of climate change. This makes climate change adaptation (CCA) essential in central, mountainous areas like the department of Cundinamarca and the capital district of Bogotá. Temperature and precipitation changes based on two climate models were used to assess the expected impacts of climate change on Cundinamarca´s hydrological resources and agroclimatic potential. And through an analysis of CCA literature the suitability of national and regional CCA strategies to those impacts was assessed. The results show that despite the strong water storage and regulation system in the Bogotá river catchment, water can be expected to get locally and temporally scarce. The direct impacts of increasing temperatures are found to be advantageous for the cultivation of the main crops in Cundinamarca. However, the direct impacts of precipitation changes as well as indirect impacts of temperature changes, like increases in pest and disease infestation, may be expected to become challenging for agricultural cultivation. The literature analysis indicates that national and regional CCA measures are generally robust and suitable for the projected climate change impacts. The CCA measures led by the regional environmental authority are consistent with the national and regional strategies. Results show that adaptation measures are pushed by climatic stressors as well as by non-climatic stressors like environmental degradation and the loss of ecosystem services. While CCA measures for climatic stressors are mainly anticipatory, they are strongly reactionary for non-climatic stressors. It is to be emphasized that anticipatory adaptation based on climate change research should not get neglected. The analysis of the practical implementation and follow-up of CCA measures revealed shortcomings in the consideration of the social context, in CCA continuity and in CCA evaluation and research. Firstly, it was found that in order to enable effective and efficient CCA adaptation it is essential to take into account the social, cultural, economic, financial and political context in which a project is embedded. Secondly, results indicate that missing continuity due to administrational and financial instabilities takes up more financial and human resources and slows down the expected effect of a certain CCA measure. Setting up systematic and periodic monitoring and maintenance systems and routines is thus crucial to ensure their sustainability. And thirdly, it was found that the importance of CCA evaluation is not sufficiently recognized and strategies for CCA evaluation are sparse. It is, therefore, suggested that future CCA in Cundinamarca and Colombia should engage more strongly in specific CCA research and systematic CCA evaluation, in the continuity of CCA projects, and in the consideration and incorporation of the social, cultural, financial, economic and political context of CCA.

Content

Figures

Tables

Abbreviations

AbE	Ecosystem-based Climate Change Adaptation Guide (Esp.: Guía de Adaptación al Cambio Climático basada en Ecosistemas)
ANLA	National Agency of Environmental Licences (Esp.: Agencia Nacional de Licencias Ambientales)
CAR	Autonomous Regional Corporation of Cundinamarca (Esp.: Corporación Autónoma Regional)
CC	Climate Change
CCA	Climate Change Adaptation
CCSM4	Community Climate System Model 4
CI	Conservation International
CIC	Conservation International (Esp.: Conservación Internacional Colombia)
CMIP	Coupled Models Intercomparison Project Phase
CONPES	National Council of Economic and Social Politics (Esp.: Consejo Nacional de Política Económica y Social)
DNP	National Department for Planning (Esp.: Departamento Nacional de Planeación)
ECDBC	Colombian Strategy of Low Carbon Development (Esp.: Estrategia Colombiana de Desarrollo Bajo en Carbono)
ENREDD+	National Strategy for Reducing Emissions from Deforestation and Forest Degradation, and the role of Conservation of Forest Carbon Stocks, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks (Pt.: Estrategia Nacional para Redução das Emissões Provenientes do Desmatamento e da Degradação Florestal, Manejo Sustentável de Florestas e Aumento de Estoques de Carbono Florestal)
ERA	Regional Water Evaluation (Esp.: Evaluación Nacional del Agua)
FONAM	National Environmental Fund (FONAM) (Esp.: Fondo Nacional Ambiental)
GEF	Global Environment Facility
IDEAM	Institute for Hydrology, Meteorology and Environmental Studies (Esp.: Instituto de Hidrología, Meteorología y Estudios Ambientales
IIAP	Environmental Research Institute of the Pacific (Esp.: Instituto de Investigaciones Ambientales del Pacífico)
INVEMAR	Institute of Marine and Coastal Research (Esp.: Instituto de Investigaciones Marinas y Costeras)
IPCC	Intergovernmental Panel on Climate Change
IVAH	Research Institute on Biological Resources Alexander Von Humboldt (Esp.: Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt)
MADS	Ministry of Environment and Sustainable Development, formerly called MinAmbiente

	(Esp.: Ministerio de Ambiente y Desarrollo Sostenible)
MPI-ESM	Max Planck Institute Earth System Model
NDC	Nationally Determined Contribution
PAA	Environmental Action Plan (Esp.: Plan de Acción Ambiental)
PAC	4-year Action Plan (Esp.: Plan de Acción Cuatrienal)
PES	Sectorial Strategy Plan (Esp.: Plan Estratégico Sectorial)
PGAR	Regional Environmental Management Plan (Esp.: Plan de Gestión Ambiental Regional)
PIGCCS	Integral Sectorial Climate Change Management Plans (Esp.: Planes Integrales de Gestión del Cambio Climático Sectoriales)
PIGCCT	Integral Territorial Climate Change Management Plan (Esp.: Planes Integrales de Gestión del Cambio Climático Territoriales)
PMGRD	Municipal Disaster Risk Management Plan (Esp.: Plan Municipal de Gestión de Riesgo de Desastres)
PNACC	National Plan of Adaptation to Climate Change (Esp.: Plan Nacional de Adaptación al Cambio Climático)
PNCC	National Climate Change Policy (Esp.: Política Nacional de Cambio Climático)
PND	National Development Plan (Esp.: Plan Nacional de Desarrollo)
PNN	National Nature Parks (Esp.: Parques Nacionales Naturales)
POMCA	Watershed Regulation and Management Plan (Esp.: Plan de Ordenación y Manejo de Cuencas Hidrográficas)
PRICC	Integral Regional Plan for Climate Change (Esp.: Plan Regional Integral de Cambio Climático)
RCP	Representative Concentration Pathway
REDD+	Reducing Emissions from Deforestation and Forest Degradation, and the role of Conservation of Forest Carbon Stocks, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks
SETIS	Corporation for protection of natural resources and ecosystem preservation (Esp.: Semillas de la tierra del sol)
SINA	National Environmental System (Esp.: Sistema Nacional Ambiental)
SINAP	National System for Protected Areas (Esp.: Sistema Nacional de Áreas Protegidas)
SINCHI	Amazonian Institute of Scientific Research (Esp.: Instituto Amazónico de Investigaciones Científicas)
SINGRD	National Information System for Disaster Risk Management (Esp.: Sistema Nacional de Información para la Gestión del Riesgo de Desastres)

SISCLIMA National System for Climate Change
(Esp.: Sistema Nacional de Cambio Climático)

SNGRD National System for Disaster Risk Management
(Esp.: Sistema Nacional de Gestión del Riesgo de Desastres)

SPNN National Natural Park System
(Esp.: Sistema de Parques Nacionales Naturales)

SRES Special Report on Emissions Scenarios

TACC Territorial Approach to Climate Change

UNDP United Nations Development Programme

UNFCCC United Nations Framework Convention on Climate Change

UNGRD National Unit for Disaster Risk Management
(Esp.: Unidad Nacional para la Gestión del Riesgo de Desastres)

USAID United States Agency for International Development

1 Introduction

1.1 Relevance

While the impacts of climate change are felt all over the globe, they affect in particular the poorest and most vulnerable countries, that have fewer social, technological and financial resources for adaptation. As many other developing countries, Colombia is highly vulnerable to the effects of climate change. (IDEAM, 2001; UNDP and IDEAM, 2010a; The World Bank, 2012) Due to its territory's geographical complexity, Colombia is exposed to many geological and hydro-meteorological hazards. Climatic variability, associated with the phenomena of El Niño-Southern Oscillation (ENSO) leads to acute extreme events in Colombia. (CAR, 2016) Its diversity of extremely fragile and unique ecosystems, make it exceptionally sensitive to climate change (The World Bank, 2006) and its inequality gap between regions and within the population exacerbate the state´s vulnerability to climate change impacts (IDEAM, UNDP, MADS, DNP and Cancillería, 2017).

Climate change in Colombia has a direct impact on the country´s population as well as their economic activities. Continuous climatic changes as well as climatic extreme events like droughts, floods, cyclones, forest fires, flash floods, landslides and many more can lead to water and food scarcity, infrastructure and settlement damages, displacement, decrease of livelihoods and mortality beside others. (MADS, 2017) Colombia presents the highest rate of hazardous events caused by natural phenomena in Latin America (MADS, 2017) and is the country with the tenth highest economic risk deriving from natural hazards globally. (Banco Mundial, 2014) 84.7 % of Colombia´s population and 86.6 % of its assets are located in areas exposed to two or more natural hazards. (Banco Mundial, 2014) Importantly, 90 % of the reported natural disasters in Colombia during 1998-2011 are related to hydroclimatic phenomena. (DNP, MADS and UNGRD, 2012) The strong impacts of climate change on the hydrological balance are especially enhanced in mountainous catchments which are prone to extremely variable flow volumes, flash floods and droughts. This is particularly relevant considering that a big part of Colombia's population lives in the mountains of the Andean region. (UNDP and IDEAM, 2010b) The importance of Colombia´s mountain region is made evident by the fact that the Centre-East region consisting of the departments of Cundinamarca, Boyacá, Norte de Santander, Santander and Bogotá Capital District make up for roughly 50 % of the nation´s industrial GDP. (DNP, 2016)

Colombia´s National Plan of Adaptation to Climate Change (PNACC) states that climate, ecosystems and economic development are strongly connected, as there is an evident relation between climatic behaviour, ecosystem capacity to provide goods and services, and the transformation of those into welfare and economic growth. Thus, importantly the climate and its changes can enhance or limit economic and social development in Colombia. (DNP, MADS and UNGRD, 2012) While Colombia´s National Development Plan 2014-2018 recognizes the tension between economic growth, environmental degradation and climate change impacts (DNP, 2016), anthropologic pressure on ecosystems keeps increasing. This will inevitably lead to a decline in the ecosystems´ adaptive capacity to climate change and variability and thus cause increased vulnerability of the population in the affected areas.

Some of Colombia´s major economic pillars are highly sensitive to climate change on one hand and strongly affect the country´s capacity to adapt to climate change on the other hand. With two thirds of the country´s energy being hydro-generated, Colombia's power sector is particularly vulnerable. (The World Bank, 2006) A reduction in precipitation would strongly affect the country's energy production and might potentially lead to an increase in the portion of thermal energy, which in turn would lead to increases in greenhouse gas emissions. (IDEAM, 2009) More than 50 % of the country´s water resources are used for agriculture and livestock farming. (República de Colombia and MADS, 2015) The growing demand for pasture areas leads to land use conflicts, illicit land use, and in the following to soil deterioration, as well as ecosystem and biodiversity loss. With deforestation as one of the country´s main environmental challenges caused by livestock farming and agricultural expansion, urbanization, wood extraction and wildfires, soils are prone to further deteriorate. (Suárez *et al.*, 2016) In consequence soil erosion, compaction, waterlogging and fertility loss will lead to low productivity and economic losses. (Suárez *et al.*, 2016) Extractive mining activities all over Colombia pollute and harm water, air, soil and biodiversity and hence affect the country´s ecosystems and their ability to adapt to climate change. (CAR, 2016)

Due to climate change impacts as well as inappropriate and uncontrolled land use Colombia will in the near future face the loss of much of the environmental goods and services provided by some of its unique ecosystems. The loss of these services can be expected to considerably affect the national economy, if no adaptations to climate change impacts are made. (República de Colombia and MADS, 2015) Climate change adaptation (CCA) in all sectors and regions is thus fundamental for the country´s persistence, development and growth.

However, as a great deal of Colombia´s economic activity and of its population is located in the Andes mountain range it is key to highlight this area´s importance. The tropical Andes have been identified as especially vulnerable to effects of climate change, as well as land use and land cover change (Laurance *et al.*, 2011) and the Andes of central Colombia hold some of the country´s most important high-mountain ecosystems, namely the Andean and the high Andean forests and the high Andean wetlands "Páramos". (The World Bank, 2006)

1.2 Goal

Considering the importance of climate change adaptation (CCA) in Colombia, and specifically in Central Colombia´s high-mountain environment, this work aims at the analysis and evaluation of the different organizational levels of climate change adaptation in Colombia, and more specifically in the central department of Cundinamarca. In order to gain an insight into the scope of climate change adaptation in Colombia and especially in Cundinamarca, it addresses the coherence and gaps between the

- national and regional strategies and guidelines to climate change on a general level,
- the registry of adaptation measures in the department of Cundinamarca,
- and the practical implementation, monitoring and follow-up of CCA measures based on ground experience in the field.

Colombia´s history of climate change adaptation, dates back to the early 90ies and formally began 25 years ago in 1994 with the approbation of the United Nations Framework Convention on Climate Change (UNFCCC) (UNDP and IDEAM, 2010a). While it includes a lot of reports documenting frameworks, orientations, norms, and plans for climate change and climate change adaptation, it is relatively poor in documents analysing and evaluating climate change adaptation.

Most of the adaptation evaluations are limited to impacts, vulnerability and adaptation planning, but only very few evaluations consider the realization and implementing, or the effects of adaptation measures (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017). A contrary example sets the evaluation of the Integral Regional Plan for Climate Change (PRICC) (Otter and Escovar, 2014), however, it only regards the directly visible outcomes of the PRICC 1-2 years after its implementation, and it does not analyse the links and gaps between the different organizational levels of climate change adaptation.

In the interest of filling this gap, the present work tries to answer the following questions:

1. Is there a coherent link between the expected climate change impacts in the department of Cundinamarca based on scientific data, and the strategies and guidelines to CCA proposed by the national and regional government?

2. Is there a coherent link between the strategies and guidelines to CCA proposed by the national and regional government, and the registered CCA measures in the department of Cundinamarca?

3. Is there a coherent link between the registered CCA measures in the department of Cundinamarca and the practical implementation of CCA based on local case studies?

4. What are the strengths and weaknesses, achievements and difficulties of the CCA strategies implemented in the department of Cundinamarca?

1.3 Structure

In order to respond to the posed research questions, the following work will address the climate, climate changes, expected climate change impacts, and the different levels of climate change adaptation in the department of Cundinamarca.

The **second chapter** of this work will talk about the climate in Colombia and the climate change in the country, based on the results taken from different scientific publications.
The **third chapter** will talk about projected climate change in the department of Cundinamarca, and about their impacts on the department´s hydrological resources and on its climate corridors for agricultural cultivation. The projections in this chapter are based the analysis of climate data from the two models CCSM4 and MPI-ESM-MR.
The **fourth chapter** is divided in three levels, structured as subchapters. The first of which describes the national and regional strategies and guidelines to CCA, including CCA´s historical development, relevant institutions, frameworks, documents, plans and projects for Colombia and Cundinamarca. The second contains a registry of regional CCA measures, including the categorization and simple statistical analysis of the measures. The third subchapter describes and analyses the practical implementation, monitoring and follow-up of specific CCA measures in the field with help of ground experience depicted in several case studies.
The **fifth chapter** discusses the link and coherence between the expected climate change impacts and the CCA strategies suggested by the national and regional governments, and between the different levels of CCA planning, implementation and follow-up. It tries to analyse and connect the findings and sketch out the achievements and difficulties of the CCA strategies in Cundinamarca.

1.4 Definitions

For general understanding, this section contains the definitions of the most important terms recurrently used in this work.

The Intergovernmental Panel on Climate Change (IPCC) defines ***climate change*** as a "change in the state of the climate […] that persists for an extended period, typically decades or longer [whether due to natural variability or as a result of human activity]". The United Nations Framework Convention on Climate Change (UNFCCC) on the other hand, limits it to the changes in climate attributed to human activity altering the composition of the global

atmosphere. (IPCC, 2018) In the scope of this work we will stick to the broader definition by the IPCC and we will not concentrate on the specific causes of the changes occurring in climate.
Climate variability is defined as the "variations in the mean state and other statistics (such as the standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events". Climate variability may be due to natural internal processes of the climate system, or to variations in natural or anthropogenic factors. (IPCC, 2018)
While the ***mitigation*** of climate change refers to the action of reducing the sources or enhancing the sinks of greenhouse gases and thus impede the cause of climate change, in order to counteract it, ***adaptation*** to climate change refers to the action of reducing the impacts of climate change, rather than reducing climate change itself (Locatelli *et al.*, 2011). The Intergovernmental Panel on Climate Change (IPCC) defines climate change adaptation as adjustment which is made by natural human systems in response to real or expected climatic stimuli or effects, which attenuates the damage caused, or exploits beneficial opportunities (IPCC, 2007).
As stated by McDowell et al. (2018) it is important to take into account that the impacts of climate-related changes aren't just a direct product of climatic changes, but that socio-economic and political factors play an important role in the effect climate change can have for different people in different situations. To evaluate the effects that changes in climate variables can have, it is thus essential to consider factors like exposure-sensitivity, adaptive capacity and vulnerability. (McDowell *et al.*, 2018)
Exposure-sensitivity links "climatic changes to existing social conditions, highlighting both the nature of biophysical changes as well as the differing susceptibility of social actors to be harmed by such changes." (Ford, Smit and Wandel, 2006) For example, land in areas exposed to natural hazards is often of lower cost and may act as a pull factor for low-income residents, which leads to the residents of the area likely being both exposed and sensitive to hazardous events. (McDowell *et al.*, 2018) ***Adaptive capacity*** is the "ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences." (IPCC, 2007) According to Engle (2011) this is an "ability known to vary greatly among and within populations due to factors such as access to information and financial resources." (Engle, 2011) Following the definition of the IPCC ***vulnerability*** is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system. (IPCC, 2007)

2 Colombia and the department of Cundinamarca

This chapter will give an overview over the geographical and climatic context Colombia, and more specifically the department of Cundinamarca is located in. It will then in further detail address the national and regional climate as well as recent observed and projected future climate changes.

2.1 Study area

Colombia is a tropical, equatorial country located between latitudes 13°N and 4°S in the north of South America, bordered by Venezuela, Brazil, Peru, Ecuador and Panama from east to northwest, and with access to both the Pacific and the Caribbean Sea. It has a variety of different climate zones and reaches from sea level up to more than 5700 m a.s.l. It comprises extremely diverse natural regions reaching from the Andes mountain range, the Pacific and the Caribbean coastal regions, the highlands, the Orinoquía grasslands (los Llanos), the Amazon rainforest to insular areas in the Atlantic and the Pacific oceans, which makes it one of the countries with the highest biodiversity in the world (see **Figure 1**). While the Llanos and the Amazon rainforest make up more than half of Colombia´s territory, urban centres are concentrated mainly in the Occidental, Central and Oriental mountain ranges of the Andean highlands and to a lesser degree at the Caribbean coast – both, regions highly sensitive to climate change. The country comprises 32 departments and the capital district of Bogotá.

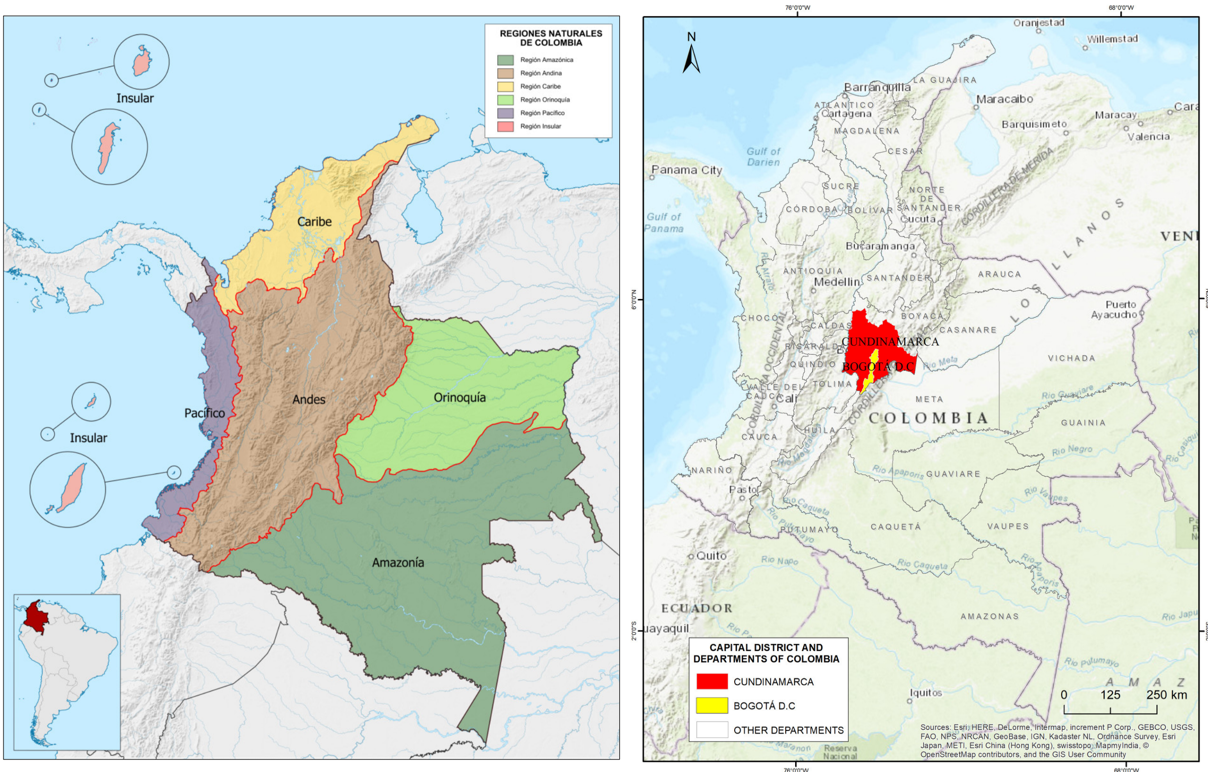

Figure 1: Map of the natural regions of Colombia (left) and of the departments of Colombia with the department of Cundinamarca and the capital district of Bogotá highlighted in red and yellow respectively (right). Sources: Wikipedia.org, based on geoportal.igac.gov.co (left), ArcGis (right)

Being mainly located in the Oriental Andean mountain range and acting as Colombia´s industrial heart, the central department of Cundinamarca is of special importance. While not politically including it, Cundinamarca almost completely surrounds the Bogotá capital district. The department has roughly 2.5 million inhabitants, that sum up to 10 million when counting the capital district, making the department of Cundinamarca the home to and the direct surroundings of one fifth of Colombia´s total population. The greatest part of the department of Cundinamarca is under the jurisdiction of the Autonomous Regional Corporation of Cundinamarca (CAR), that additionally administrates the Bogotá capital district. We thus differentiate the department of Cundinamarca and the slightly smaller CAR territory (see **Figure 2**). The CAR territory has a very large altitudinal gradient with the lowest areas around the Magdalena river at roughly 300 m a.s.l. and the highest areas at more than 4000 m a.s.l. in the Sumapaz páramo, and thus presents many different life zones and biomes. (CAR, 2016) Including some of the biggest páramos in the country, an extremely fragile but fundamentally important high mountain wetland ecosystem that acts as water regulator and filter (Van der Hammen *et al.*, 2002), the department plays a fundamental role in the supply of hydrological resources for the whole central region. 46 % of the CAR's territory is topographically located above 2500 m a.s.l., including beside others the capital district, the Bogotá Savannah and the Ubaté valley. 64 % of Cundinamarca's area is used for agricultural production, cattle industry and the exploitation of natural resources like carbon, construction materials, limestone, emeralds and salt. (CAR, 2016; Gobernación de Cundinamarca, 2016) While in theory only about 30 % of the CAR´s territory has an aptitude for agricultural use and livestock farming, in practice roughly 60 % of the territory is used for pasturing and crop cultivation. (CAR, 2016) Agricultural and livestock production as well as extractive activities exert significant pressure on the territory´s soils and hydrological resources and natural resources are often overexploited. (Gobernación de Cundinamarca, 2016)

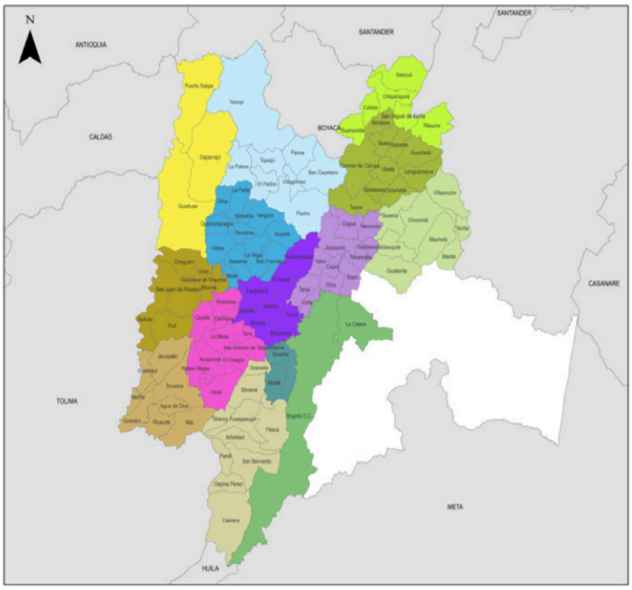

***Figure 2**: Administrative division of the jurisdiction of the Autonomous Regional Corporation of Cundinamarca (CAR). The area in white is part of the department of Cundinamarca but not of the CAR territory. Source: (CAR and CI, 2007)*

The high mountain area has been categorized as the zone presenting the highest vulnerability to climate change in central Colombia. (CAR, 2016) Potential precipitation reductions and temperature increases, and the associated climate variability are expected to lead to drier summers and more intense rainy seasons in these areas. Some of the observed consequences linked to these climatic changes are the disappearance of lagoons in high mountain areas, the ascent of páramo vegetation to higher altitudes without fulfilling the water regulating function associated with the páramo ecosystem, the ascent of fauna and flora of to higher altitudinal levels, the loss of biodiversity and the dispersion of vector diseases. (CAR, 2012)

2.2 Climate

Colombia´s climate is heavily diverse and characterized by its altitudinal levels and its natural regions. Due to its proximity to the equator Colombia is within the area of influence of the Inter-Tropical Convergence Zone (ITCZ), which strongly determines the country´s climate. The macroscale climate in Colombia is influenced by the Tropical Atlantic and Pacific Oceans and the Caribbean Sea, as well as by the Amazon basin, mainly contributing to the air humidity, and by the complex Andes mountain range, presenting an obstacle for the flow of moist air masses and influencing the precipitation as well as the temperature pattern. (IDEAM-UNAL, 2018)

The mean air temperature in Colombia is strongly influenced by the country´s altitudinal differences and is represented by seven thermal floors or altitudinal zonations: warm (> 24°C), temperate (18-24°C), cold (12-18°C), very cold (6-12°C), subpáramo (3-6°C), páramo (1.5-3°C) and nival (< 1.5°C). (IDEAM, UNDP, MADS, DNP and Cancillería, 2017) The monthly mean temperature shows a seasonal behaviour. Due to Colombia´s equatorial situation the annual cycle shows really small differences in monthly mean temperatures in all regions with roughly 2°C of difference between the hottest and the coldest month. However, the daily temperature amplitudes can be relatively large especially in mountainous regions with up to 20°C difference between the hottest and the coldest moment of the day. The temperatures are highest in northern Colombia and at the Caribbean coast and lowest in the high altitudes of the Andes region (see **Figure 3**, left). (IDEAM-UNAL, 2018)
The annual precipitation pattern in Colombia is monomodal in the oriental part of the country, almost monomodal in the Caribbean region, and bimodal in the Andes region and some parts of the Caribbean region. The two wet periods and the two dry periods per year are connected to the shifts in Inter-Tropical Convergence Zone (ITCZ). (IDEAM-UNAL, 2018) For most of the areas with bimodal precipitation behaviour, the precipitation maxima are in May and October and the minima in January and July. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017) The annual mean precipitation is highest at the Pacific coast and lowest in the northern regions of the Caribbean coast as well as in some valleys in the Andes mountain range (see **Figure 3**, right). (IDEAM-UNAL, 2018)
The inter-annual precipitation variability in Colombia is associated with the ITCZ fluctuations, the dynamics of the Pacific and the Atlantic Oceans and the dynamics of the Amazonas and Orinoco watersheds. The El Niño-Southern Oscillation (ENSO) system with the phenomena of El Niño and La Niña is the best-known cause for inter-annual variability in Colombia. Of main importance for the Bogotá Savannah for example are the North Pacific Pattern, the surface temperature of the Central Pacific (ENSO), the Madden Julian East oscillation, the quasi-biennial oscillation and the Sahel precipitation, which makes the forecasting and modelling especially of precipitation patterns relatively complicated. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017)

The interaction of the ITCZ, the equatorial trade winds and the complex orography in the Colombian Andes region favours the formation of regional and local circulations and generates diverse climatic conditions in the department of Cundinamarca. (Pabón, 2011)
The mean annual air temperature fluctuates between 26°C and 28°C in the western sector of Cundinamarca around the Magdalena river valley, and around 10°C in the páramo areas of the sector. In the sector of the high plateau annual mean temperatures lie between 12°C and 14°C (see **Figure 4***,* left). While the annual amplitude of monthly mean temperatures is relatively low, the daily cycle can present maximum and minimum temperatures up to 10°C higher and lower than the daily mean temperature. (Pabón, 2011)
The mean annual precipitation generally lies between 900 mm and 3000 mm with a few sectors that present only around 500-600 mm. The sectors richest in precipitation are to be found in the Gualivá and Bajo Magdalena provinces in the north-west of the CAR territory, and in a sector between the Sumapaz, Tequendama and Alto Magdalena provinces in the south of the CAR territory. An extensive area that covers big part of the high plateau to the north of the Bogotá-La Calera province and almost all of the provinces of Soacha, the occidental and central Savannah, Ubaté and Almeidas-Guatavita presents annual precipitation volumes of less than 900 mm (see **Figure 4***,* right). While the annual precipitation cycle is monomodal for

the eastern sector of the CAR territory with a rainy season by the middle of the year, it is bimodal with rainy seasons in March-May and in September-November for the high plateau and the western sector with gradients towards the Magdalena river. (Pabón, 2011)

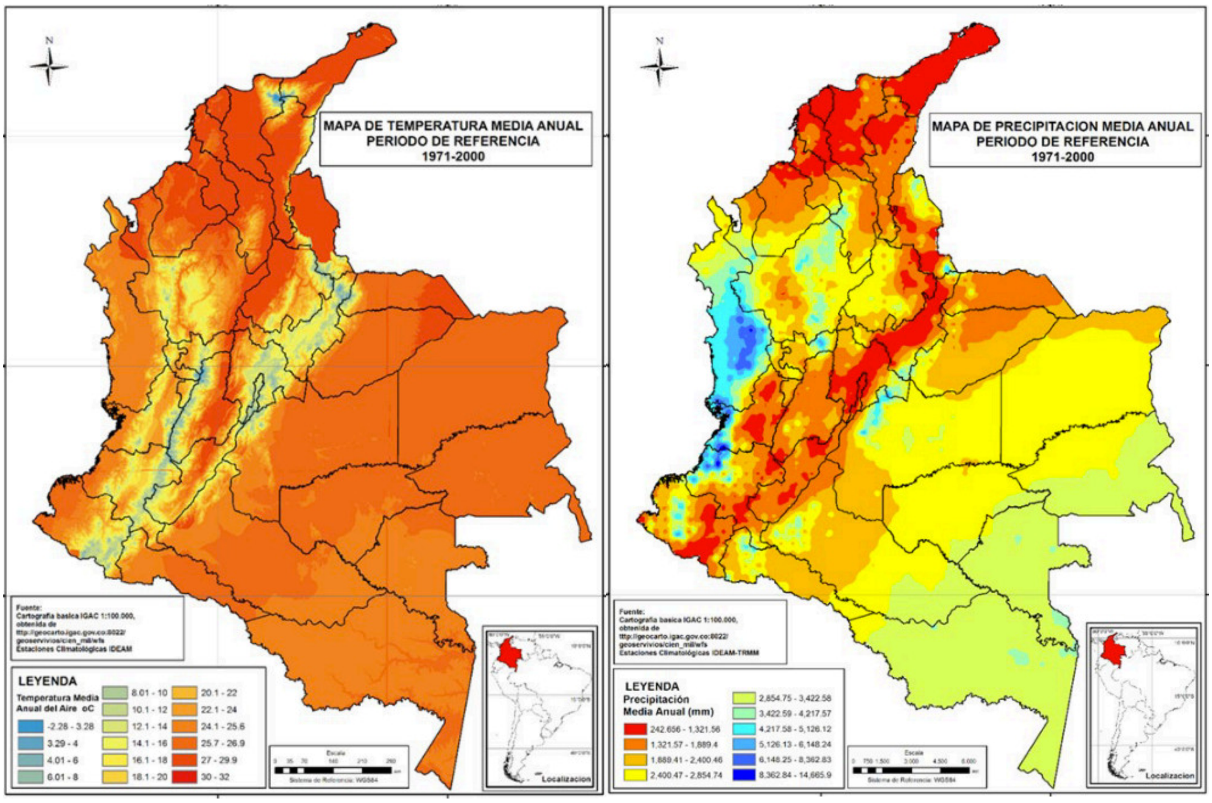

***Figure 3**: Mean annual air temperature in °C (left) and precipitation in mm (right) for 1971-2000 in Colombia. Source: Alarcón Hincapié, 2017*

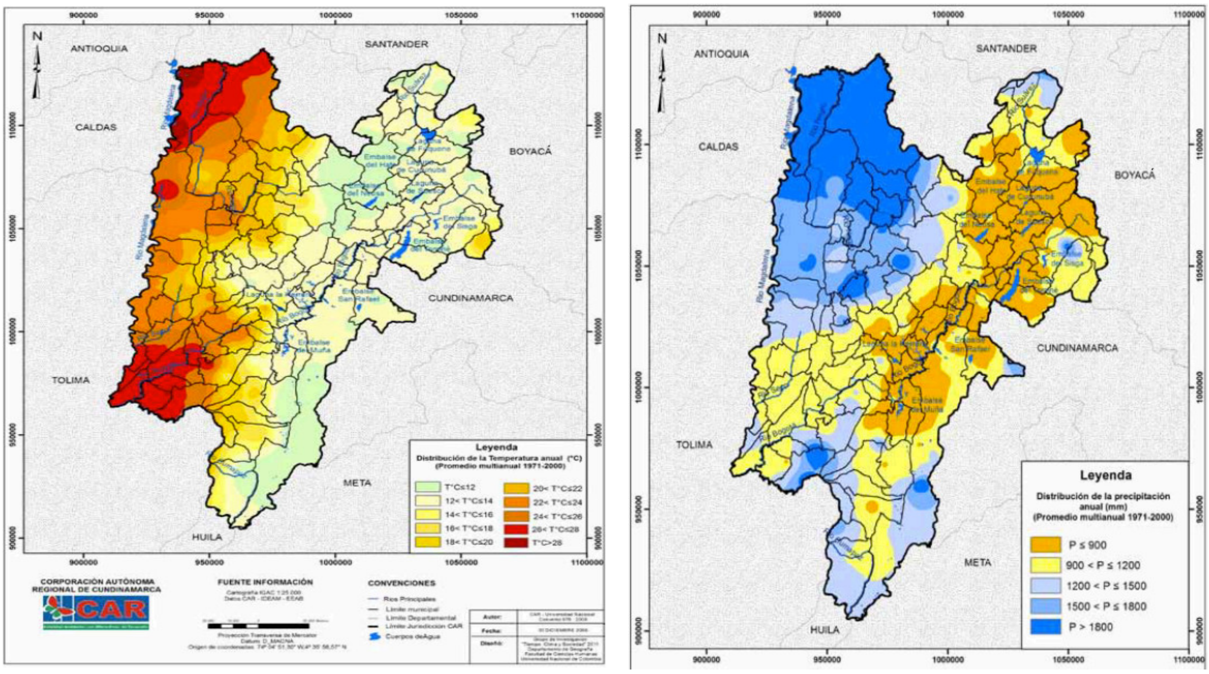

***Figure 4**: Mean annual air temperature in °C (left) and precipitation in mm (right) for 1971-2000 in the CAR territory. Source: Pabón, 2011*

2.3 Climate change

Climate change in the scope of this work can be divided in observed and projected climate change. The first part of this chapter elaborates the observed recent climatic changes in Colombia and specifically the department of Cundinamarca.

In order to give an overview of the projected climatic changes in Colombia and in the department of Cundinamarca, five publications on climate change on the globe, in Colombia or in Cundinamarca are presented in the second part of this chapter:

1. *The 5th assessment report of the Intergovernmental Panel on Climate Change* (2014) gives an overview over the projected climate changes in northern South America.
2. *New climate change scenarios for Colombia from 2011-2100* by the IDEAM et al. (2015) addresses the projected climate changes in Colombia.
3. Colombia´s *2nd and 3rd national communication on climate change* (2010 and 2017) concentrate on climate changes in Colombia and some of the greater regions.
4. And *Climate change in the territory of the Autonomous Regional Corporation of Cundinamarca* by J. D. Pabón (2011) addresses the projected climate changes in the territory of the CAR.

Their most important results are summarized in a comparative **Table 1** at the end of this chapter.

Due to the greater complexity of the analysis of changes in extreme events, only changes in temperature and precipitation will be considered in detail. However, it can be mentioned that the IPCC AR5 states that it is "virtually certain that, in most places, there will be more hot and fewer cold temperature extremes [on daily and seasonal time scales] as global mean temperatures increase." (IPCC, 2013)

2.3.1 Observed recent climate change

Summarizing the results from different studies about recent climate changes in Colombia, IDEAM-UNAL (2018) find that during the second half of the 20th century the mean annual air temperature in Colombia increased by 0.1-0.2°C per decade and the mean daily maximum temperature increased by around 0.6°C per decade. They find that the precipitation pattern presented changes within -4 % and +6 % per decade, with precipitation decreases in the inter-Andean valleys like the Magdalena and the Cauca valley and the Caribbean region, and precipitation increases in the eastern foothill areas of the Oriental Andes mountain range and in the central-northern Pacific region. (IDEAM-UNAL, 2018)

According to Hurtado (2012) there is a tendency towards the increase of heat waves (several consecutive days of maximal temperatures above defined critical values) all over the country and the decrease of cold waves (several consecutive days of minimal temperatures below defined critical values) in the majority of the Caribbean region as well as in the north and centre of the Andes region.

According to UNDP and IDEAM (2010b) strong increases in maximum daily temperatures have been experienced in the high mountainous páramo regions with roughly +1°C/decade, and in the high Andean forest and subpáramo regions with +0.3-0.6°C/decade. The increases in daily minimum temperatures for the páramo region have been relatively small. The strongest increases in daily mean temperature were observed in the high Andean region of superpáramo. (UNDP and IDEAM, 2010b)

A trend towards a decrease of extreme precipitation events was observed in the páramos at altitudes between 3000-4200 m a.s.l., whereas an increase of extreme precipitation events was registered in most other thermal floors between 0-2000 m a.s.l. (UNDP and IDEAM, 2010b)

In Cundinamarca the mean annual air temperature increased by 0.11-0.25°C per decade for the Bogotá Savannah, the Sogamoso river and the Magdalena valley, and the mean annual precipitation increased by 1.5-3 % compared to the multiannual mean of 1961-1990. (Pabón, 2003) According to Pabón (2011) between 1960 and 2000 the mean annual air temperature in the CAR territory increased by 0.1-0.2°C per decade with some sectors of slightly larger increases.

Precipitation shows varying tendencies for the region of Cundinamarca. Some sectors (e.g. Laguna de Fúquene) present an increase in annual mean precipitation but a slight decrease of days with precipitation which suggests an increase in intense precipitation events, while others show the contrary phenomenon (e.g. Sisga sector). For the Bogotá Savannah as well as for the sector towards the Magdalena river in the south-west of the CAR territory a decrease in the mean annual precipitation volume and in the number of days with precipitation was observed. (Pabón, 2011)

2.3.2 Projected future climate change

5th Assessment Report of the Intergovernmental Panel on Climate Change

The 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC), published in 2014 includes climate change projections based on 42 climate models from the CMIP5 model generation for the scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. All models were considered equally likely projections and thus given the same weight. It plots surface air temperature change and relative precipitation change for the periods of 2016-2035, 2046-2065 and 2081-2100. The projections refer to the reference period of 1986-2005 and are expressed as anomalies or differences from this reference period. (IPCC, 2013)

For the macro-area of northern South America, where the centre of Colombia and the department of Cundinamarca is located, annual temperature change is projected to be between +0.5 and +1°C for the period of 2016-2035 in all four concentration scenarios. For the period of 2046-2065 the annual temperature change is projected to lie between +0.5°C and +1.5°C for RCP 2.6, between +1°C and +2°C for RCP 4.5, between +1°C and +1.5°C in RCP 6.0, and between +1.5°C and +3°C for RCP 8.5. And for the period of 2081-2100 by the end of the century, the annual temperature change is projected to stay between +0.5°C and +1.5°C for RCP 2.6, to also stay between +1°C and +2°C for RCP 4.5, but to increase by +2°C to +3°C for RCP 6.0 and by +4°C to +5°C for RCP 8.5. (See **Figure 5**)

While the contrast between areas of increasing and areas of decreasing projected precipitation in Northern South America grows bigger along the increasing RCPs from 2.6 towards 8.5, the pattern for Colombia and especially for the central sector, where the department of Cundinamarca is located, is relatively unclear. For the area above central Colombia and Cundinamarca the annual precipitation change is projected to stay between +10 % and -10 % for all three periods and all four RCPs. (See **Figure 6**)

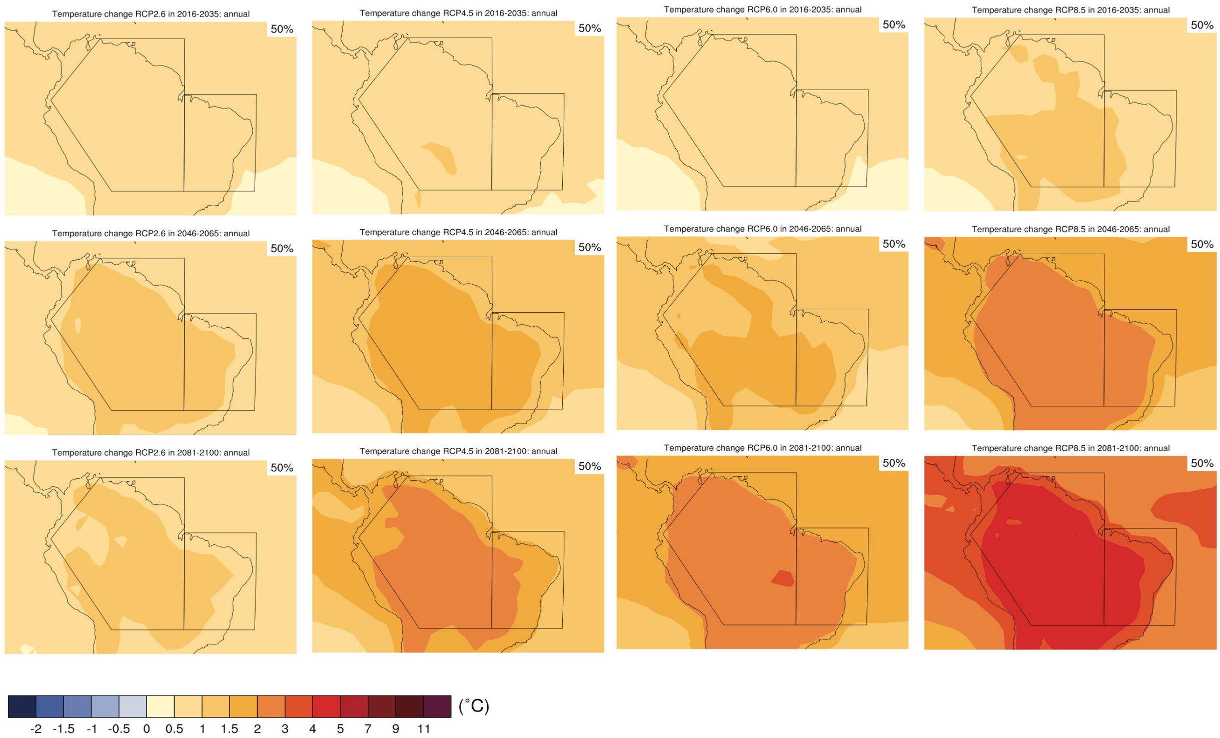

***Figure 5**: Projected annual temperature changes in °C for the RCPs 2.6, 4.5, 6.0 and 8.5 from left to right, and for the projection periods of 2016-2035, 2046-2065 and 2081-2100 from top to bottom with respect to the reference period of 1986-2005 for the 50th percentile (median) of the distribution of the CMIP5 model ensemble. Source: compiled from IPCC, 2013*

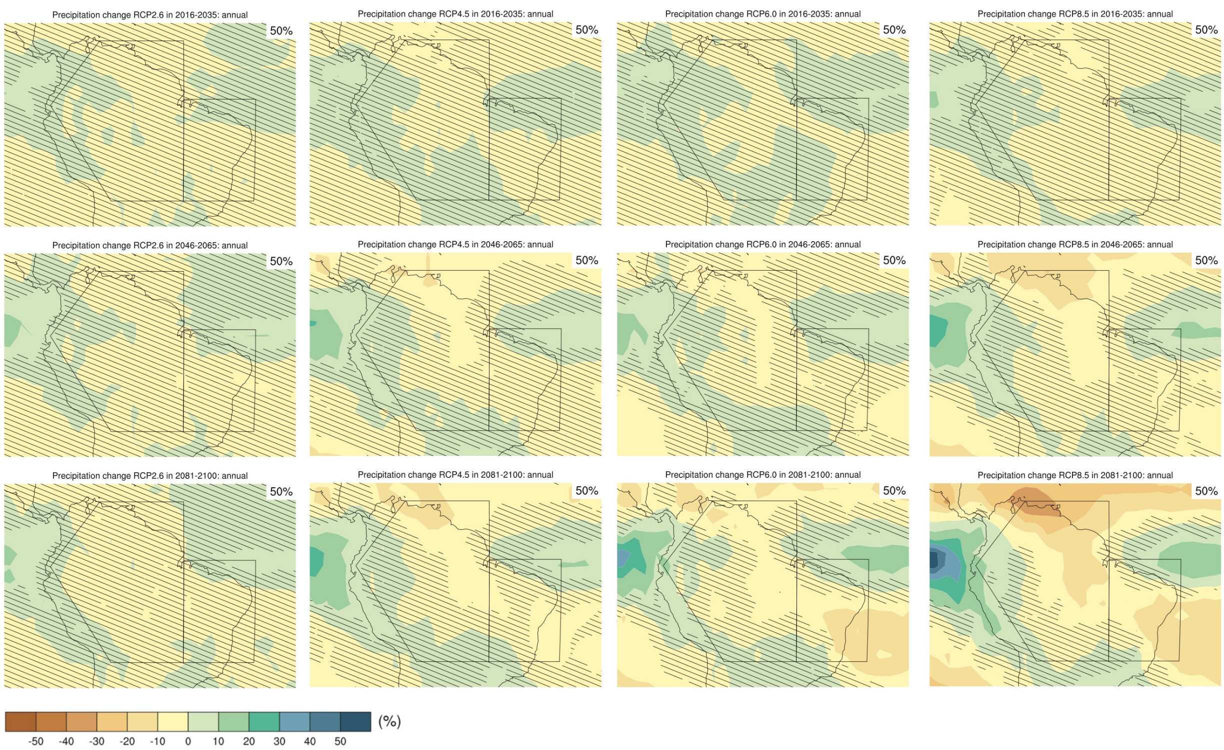

***Figure 6**: Projected annual precipitation changes in % for the RCPs 2.6, 4.5, 6.0 and 8.5 from left to right, and for the projection periods of 2016-2035, 2046-2065 and 2081-2100 from top to bottom with respect to the reference period of 1986-2005, for the 50th percentile (median) of the distribution of the CMIP5 model ensemble. Source: compiled from IPCC, 2013*

New climate change scenarios for Colombia 2011-2100

A publication about new climate change scenarios for Colombia from 2011-2100 was made by IDEAM et al. in 2015. Its results are based on a multi model mean from 16 models of the CMIP5 model generation for a multi-scenario ensemble of scenarios RCP 2.6, 4.5, 6.0 and 8.5. It projects mean annual air temperature changes and mean annual precipitation changes for the periods of 2011-2040, 2041-2070 and 2071-2100 with respect to a reference period of 1976-2005. (IDEAM *et al.*, 2015)

For Colombia the mean annual air temperature is projected to increase 2.8-3.0°C by the end of the 21st century (see **Figure 7**), while the projections in precipitation change in most of the country´s territory are extremely unclear (see **Figure 8**). By the end of the 21st century precipitations are projected to decrease by 10-30 % in 27 % of the national territory and to increase by 10-30 % in 14 % of the national territory. (IDEAM *et al.*, 2015)

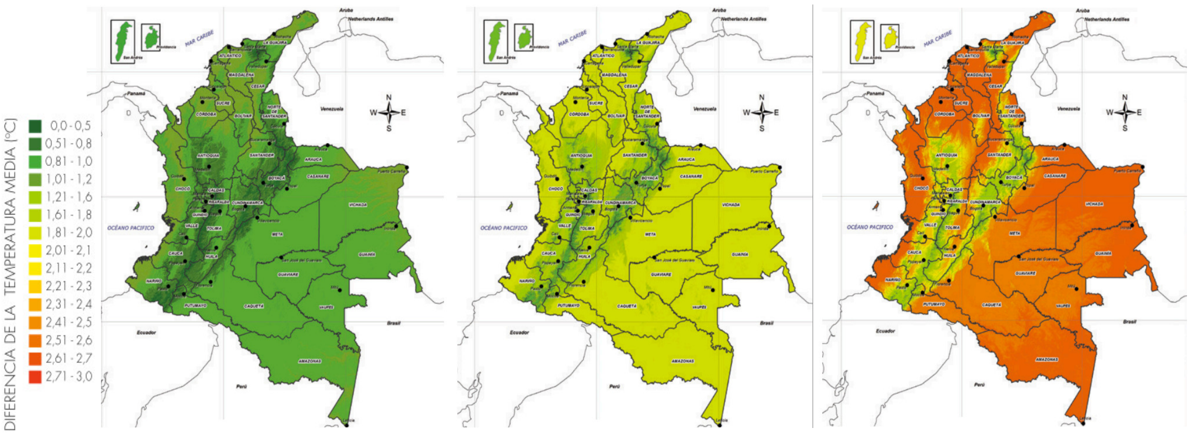

Figure 7*: Projected changes in mean annual air temperature in °C for a multi-scenario ensemble of RCP 2.6, 4.5, 6.0 and 8.5, and for the projection periods of 2011-2040, 2041-2070 and 2071-2100 from left to right with respect to the reference period of 1976-2005 in Colombia. Source: IDEAM et al., 2015*

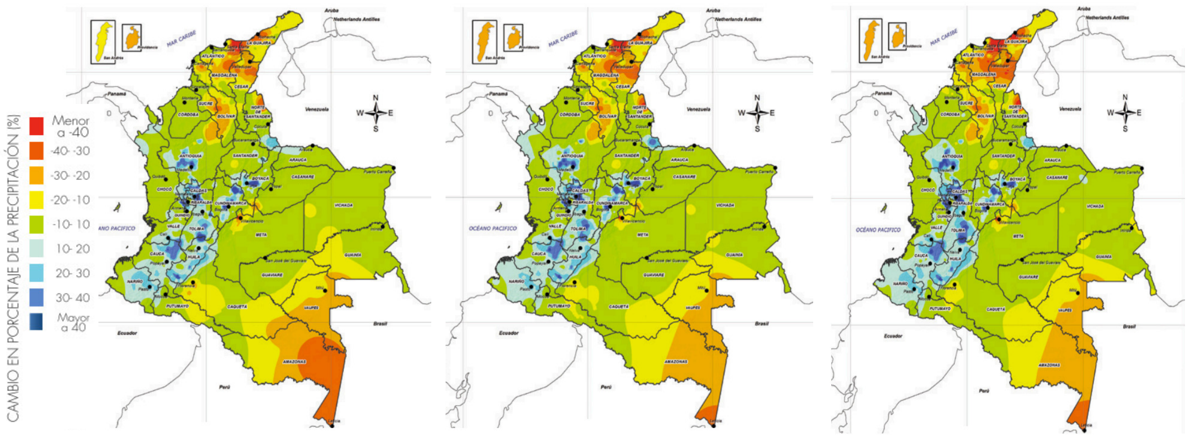

Figure 8*: Projected changes in mean annual precipitation in % for a multi-scenario ensemble of RCP 2.6, 4.5, 6.0 and 8.5, and for the projection periods of 2011-2040, 2041-2070 and 2071-2100 from left to right with respect to the reference period of 1976-2005 in Colombia. Source: IDEAM et al., 2015*

For Cundinamarca the mean annual air temperature is expected to increase by +0.5-1°C in the period of 2011-2040, by +1-1.8°C in 2041-2070 and by +1.6-2.4°C with the strongest increases in the Alto, Medio and Bajo Magdalena and in Medina in 2071-2100. The mean annual precipitation is projected to be within a +10 % and -10 % change for the majority of Cundinamarca with some smaller areas of precipitation decreases between -20 % and -10 %

and precipitation increases of more than +40 % for all three time periods. By the end of the 21st century the main precipitation increases are projected to be seen in the central and western Bogotá Savannah, in northern Bogotá, Ubaté and Almeidas with +10-30 %, and main decreases are projected to be experienced in Medina with -20 %. (See **Figure 9**) (IDEAM et al., 2015)

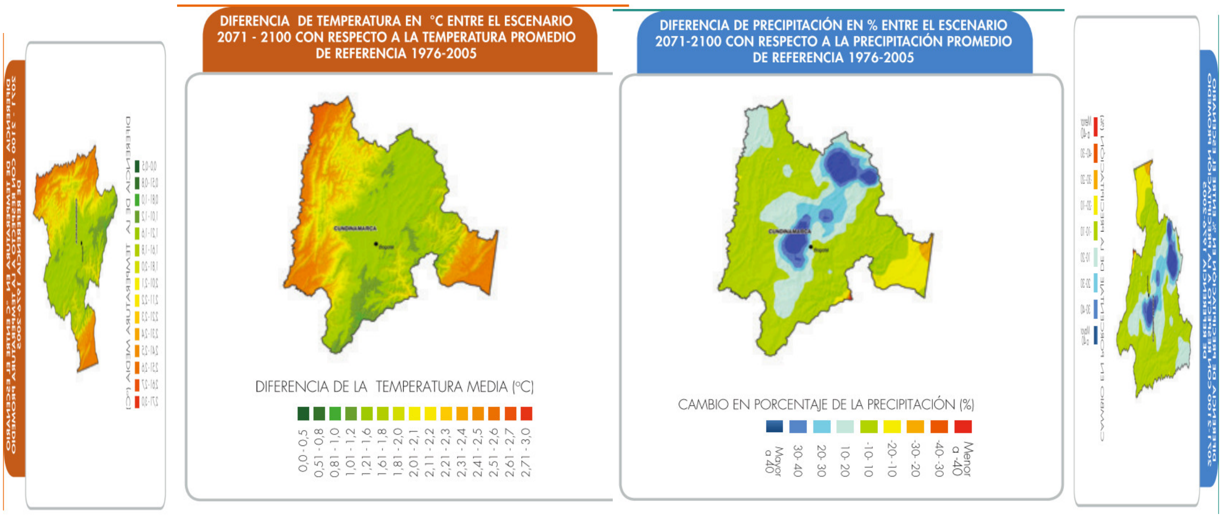

***Figure 9**: Projected changes in mean annual air temperature in °C (left) and mean annual precipitation in % (right) for a multi-scenario ensemble of RCP 2.6, 4.5, 6.0 and 8.5, and for the projection period of 2071-2100 with respect to the reference period of 1976-2005 in the department of Cundinamarca. Source: IDEAM et al., 2015*

Colombia´s Second National Communication on Climate Change

Colombia´s second national communication on climate change, published in 2010, includes the results of climate change projections based the models GSM-MRI, Precis and WRF for a multi model average of the scenarios SRES A2, A2S, B2, B2S, A1B and A1BS. The results presented by the 2nd national communication are mainly based on a technical note about climate change projections using meteorological high-resolution models, published by Ruiz and the IDEAM in 2010. They plot projected surface air temperature change and relative precipitation change for the periods of 2011-2040, 2041-2070 and 2071-2100 and use the years of 1971-2000 as reference period. (UNDP and IDEAM, 2010b)

For Colombia, the mean annual temperature change is expected to be of +1.4 for 2011-2040, +2.4°C for 2041-2070, and +3.2°C for 2071-2100. Maximum mean temperature changes per decade are projected to be of +0.11-0.16°C depending on the model, and minimum mean temperature changes are projected to be of +0.1°C per decade. Projected temperature increases for the CAR territory are between +2-3°C for 2011-2040, +3-4°C for 2041-2070, and >+4°C in the Magdalena valley, +2-3°C in the eastern sector and +2-4°C in the Bogotá Savannah for 2070-2100. (UNDP and IDEAM, 2010b)

The projected mean annual precipitation patterns for Colombia are unclear with increases in some sectors and decreases in others. Increasing precipitation is projected beside others in some areas of the Andes. However, generally a slight decrease in precipitation is expected in Cundinamarca. For the period of 2011-2040 the annual mean precipitation is expected to decrease by 30 % beside others in the Medio Magdalena and the north-eastern sector of the CAR territory. For Bogotá it is projected to increase by >30 %, and for the rest of the CAR territory changes are projected to be within -10 % and +10 %. For the period of 2041-2070 the annual mean precipitation is projected to decrease further in the Medio Magdalena and the north-eastern sector of the CAR territory. For Bogotá, Soacha, the central Bogotá Savannah and Sumapaz it is expected to increase by >40 %. For the period of 2071-2100 the mean annual precipitation is projected to go back to being within a range of -10 % and +10 % of today´s volume in the centre and the east of the CAR territory. On the contrary for the Bajo Magdalena and Guali projected mean precipitation turns into a deficit of 30 % compared to the reference period. (UNDP and IDEAM, 2010b)

Colombia´s Third National Communication on Climate Change

Colombia´s third national communication on climate change, published in 2017, presents monthly mean air temperature and precipitation projections based on a multi model mean from 20 models of the CMIP5 generation. It uses projection periods of 2011-2040, 2041-2070 and 2071-2100 with 1976-2005 as a reference period for the scenarios RCP 2.6, 4.5, 6.0 and 8.5. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017)

The expected mean air temperature change for Colombia is between +1°C and +1.5°C for the period of 2041-2070 and RCP 2.6 and around +2°C for the other RCP. For the period of 2071-2100 the expected change is around +1°C for RCP 2.6, around +2°C for RCP 4.5 and RCP 6.0 and up to +4°C for RCP 8.5. The largest temperature increases are to be expected in the Andean region, especially in high mountain areas. Some of the sectors that are expected to be most affected by the temperature increases, like the Medio Magdalena and the Bogotá Savannah, form part of the department of Cundinamarca. The temperature changes are projected to be similar all year round. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017)

The future precipitation patterns for most of Colombia are unclear with changes of ±10 % and there are no significant differences for precipitation volume between the different RCPs. However, for the centre and north of the Andean region precipitation is projected to increase by 10-30 % in the period of 2011-2100 with the largest increases besides others in the Altiplano Cundiboyacense where part of Cundinamarca is located. The largest increases in the Andean region are to be expected between the months of June and November. On the other hand, for the months December through February strong decreases in precipitation (larger than 20 %) can be expected for the north of the Andean region. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017)

Projections from Colombia´s 3rd national communications make believe that there may be a decrease in consecutive dry days and an increase in extreme precipitation events expected in Cundinamarca as well as in many other areas of the national territory. (IDEAM, UNDP, MADS, DNP and Cancillería, 2017)

Climate change in the territory of the Autonomous Regional Corporation of Cundinamarca

In a publication about climate change in the territory of the CAR, published in 2011, climatologist J. D. Pabón from the National University of Colombia (UNAL) makes projections based on the model Precis for the scenarios SRES A2 and B2. Surface air temperature and precipitation change are modelled for the periods 2011-2040, 2041-2070 and 2071-2100 with respect to a reference period of 1971-2000. (Pabón, 2011)

For the period of 2011-2040 a general change of +1°C in mean annual air temperature with some spots of > 2°C increase is expected for the territory under the CAR jurisdiction. A decadal temperature increase between +0.1°C and +0.2°C is projected. For 2041-2070 the general tendency of an increase of +1°C with respect to the reference period stays the same with some areas of +1-2°C increases. For SRES B2 changes are projected to be of roughly +2°C for most of the region and of more than +3°C for the north-east of the CAR territory. By the end of the century for period 2071-2100 temperature changes of +3-4°C are to be expected in large part of the region with increases of +4-5°C in the west of the department. The Magdalena valley is generally projected to present the strongest mean annual air temperature increases. Temperatures are expected to increase most in the dry months of July and August. (Pabón, 2011)

The mean annual precipitation change for the period of 2011-2040 is expected to be above +10 % in the east and south of the CAR territory, as well as in Bajo Magdalena in the north-west of the department. Precipitation is projected to decrease by 10-30 % in the north-east of the CAR territory, and by 30-50 % in the Alto and Medio Magdalena in the south-west of the department as well as in the western high plateau including the central and western Bogotá Savannah, and in the Rio Negro province. For the period of 2041-2070 the general tendency of an increase of more than 10 % in big part of the territory stays the same. A decrease of 10-30 % is projected for the north-east of the territory as well as for the central part of the territory including the high plateau, the western and central Bogotá Savannah, the upper part of the Rio Negro and Gualivá provinces and the Alto and Medio Magdalena. For the period of 2071-2100 precipitation decreases are projected for the whole region with extremes of >-50 % for the eastern sector of the CAR territory and >-30 % on the high plateau. Exceptions are the Bajo Magdalena in the north-west of the territory as well as the Sumapaz and Tequendama provinces with precipitation changes of +10 %. (Pabón, 2011)

The following **Table 1** gives an overview of the results from the different publications presented above.

Table 1: Organizational summary of projected future climate changes suggested by the publications UNDP and IDEAM (2010b), Pabón (2011), IPCC (2013), IDEAM et al. (2015) and IDEAM, UNDP, MADS, DNP and Cancillería (2017).

	2nd National Communication		**Pabon 2011**	**IPCC AR5**	**IDEAM et al. 2015**		**3rd National Communication**
Publication year	2010		2011	2014	2015		2017
Reference period	1971-2000		1971-2000	1986-2005	1976-2005		1976-2005
Climate Models	GSM-MRI, Precis, WRF		Precis	CMIP5: 42 models	CMIP5: 16 models		CMIP5: 20 models
Scenarios	SRES A2/A2s/B2/B2s/A1B/A1Bs		SRES A2/B2	RCP2.6/4.5/6.0/8.5	RCP2.6/4.5/6.0/8.5		RCP2.6/4.5/6.0/8.5
Period 1	2011-2040		2011-2040	2016-2035	2011-2040		2011-2040
Period 2	2041-2070		2041-2070	2046-2065	2041-2070		2041-2070
Period 3	2071-2100		2071-2100	2081-2100	2071-2100		2071-2100
Temperature							
for region	Colombia	CAR region	CAR region	Central Colombia/Cundinamarca	Colombia	Cundinamarca	Colombia
for period 1	+1.4°C	+2°C - +3°C	+1°C	+0.5°C - +1°C		+0.5°C - +1°C	
for period 2	+2.4°C	+3°C - +4°C	+1°C: big part of the region +2°C - +3°C: North-East and South-East	RCP2.6: +0.5°C - +1.5°C RCP4.5: +1°C - +2°C RCP6.0: +1°C - +1.5°C RCP8.5: +1.5°C - +3°C		+1°C - +1.8°C	RCP2.6: +1°C - +1.5°C RCP4.5: +2°C RCP6.0: +2°C RCP8.5: +2°C
for period 3	+3.2°C	+2°C - +3°C (East) > +4°C (Magdalena valley)	+3°C - +4°C: big part of the region +4°C - +5°C: West	RCP2.6: +0.5°C - +1.5°C RCP4.5: +1°C - +2°C RCP6.0: +2°C - +3°C RCP8.5: +4°C - +5°C	+2.6°C	+1.6°C-+2.3°C +2.4°C: upper, mid and lower Magdalena, and Medina	RCP2.6: +1°C RCP4.5: +2°C RCP6.0: +2°C RCP8.5: +4°C
Annual cycle			strongest warming in July/August				temperature changes are similar all year round
Regional	Cundinamarca not mentioned as one of the departments with largest expected temp. increases				largest temperature increases expected in Arauca, Vichada, Vaupes and North Santander		largest temp. increases expected in the Andean region, besides others some parts of Cundinamarca
Precipitation							
Annual precipitation	nationally unclear pattern			nationally unclear pattern			nationally unclear pattern of ±10%
for region	Colombia	CAR region	CAR region		Colombia	Cundinamarca	
for period 1		-30% (Medio Magdalena & North East) > +30% (Bogota & Soacha) ±10% (rest of the CAR)	for A2 and B2: > +10%: East, South and North-West (lower Magdalena) -10%-30%: North-East -30%-50%: South West (upper and mid Magdalena), Western altiplano (central and Western Bogota Savannah), and Rio Negro province			±10%: main part -20%-10%: far East (Medina) +10-40%: centre	

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Continuation of **Table 1**

for period 2		> -30% (Medio Magdalena and NE) > +40%: Bogotá, Soacha, centre of Bogotá Savannah & Sumapaz	for A2 and B2: > +10%: major parts -10%-30%: central part (Altiplano, Centre and Western Savannah), North-East, upper part of Rionegro and Gualivá, upper and mid Magdalena			±10%: main part -20%-10%: far East (Medina) +10-40%: centre	
for period 3		±10% centre and East of the CAR -30% (Bajo Magdalena, Guali)	for A2 and B2: decrease for almost the whole region > -30%: Altiplano > -50%: East +10%: North-West (lower Magdalena), Sumapaz & Tequendama		-10%-30% in 27% of the territory +10%-30% in 14% of the territory	±10%: main part -20%-10%: far East (Medina) +10-40%: centre	
Regional	decrease for Cundinamarca			very unclear pattern of ±10% for Cundinamarca	mostly unclear pattern of ±10% for Cundinamarca		increase of 10-30% beside others in the altiplano Cundiboyacense
Annual cycle			period 2: increases Jan-May and decrease in August almost everywhere period 3: slight increase in October-February and strongest decrease in May-September				largest increases Jun-Nov in the Andes and largest decreases in Dec-Feb in the Northern Andes

3 Projected climate change impacts in Cundinamarca

Changes in climate can have manifold impacts in all kinds of scopes and sectors of the human life. To analyse some of those possible impacts this chapter concentrates on the role temperature and precipitation plays in the provision of hydrological resources and on the agroclimatic potential of some areas in the department of Cundinamarca. It the first of its three subchapters, projected climate changes for the department of Cundinamarca based on two global climate models are analysed and plotted in detail. In the second and third subchapter the impacts of the elaborated climatic changes on the hydrological resources and on the agroclimatic potential of are worked out.

3.1 CCSM4 and MPI-ESM-MR climate change projections for Cundinamarca

3.1.1 Method

In order to assess the expected impacts of climate change on Cundinamarca´s hydrological resources and the department´s agroclimatic potential, climate data based on two global climate models - CCSM4 and MPI-ESM-MR - was analysed. The data was elaborated at the National University of Colombia (UNAL) by Professor José Daniel Pabón for the Representative Concentration Pathways RCP 4.5 and RCP 8.5.

The use of CCSM4 and MPI-ESM-MR is motivated by a study by Rodríguez Roa and IDEAM (2012) that compares 20 climate models used for CMIP5 on their performance in representing climate in Colombia and suggests the North American CCSM4 and the German MPI-ESM-LR together with two other models for the representation of precipitation and temperature in Colombia. While according to Rodríguez Roa and IDEAM (2012) MPI-ESM-LR shows a particularly strong performance in precipitation prediction, CCSM4 and MPI-ESM-LR both show strong performances in temperature prediction. However, the validation study of CMIP5 climate models by Bonilla-Ovallos and Mesa Sánchez (2017) states that none of 16 examined models rigorously represents the precipitation distribution over all months of the year over the territory of Colombia. It mentions that most of them have trouble representing the months of June-August and that the MPI-ESM-MR only represents them moderately well. CCSM4 was not evaluated in Bonilla-Ovallos and Mesa Sánchez (2017). According to the study all models overestimate precipitation for the Andean region and there exist difficulties to predict the precipitation over tropical mountainous regions like Colombia.

The main reason the climate projections were elaborated for RCP 4.5 and RCP 8.5 instead of including RCP 2.6, as it is up to the moment generally done, was the opinion of Colombian climatologist J. D. Pabón, director of the department of geography of the UNAL, that RCP 2.6 it is a highly optimistic and very improbable scenario.
Two future periods of a 20 year's duration in the 21st century will be worked with in this study. The first period dates from 2040-2059 to represent the mid 21st century while the second period dates from 2080-2099 to represent the end of the 21st century.

The North American Community Climate System Model 4 (CCSM4) by the University Corporation for Atmospheric Research (UCAR) is based on separate components for the atmosphere (Community Atmosphere Model CAN), the ocean (Parallel Ocean Program POP), the land (Community Land Model CLM), the land-ice and the sea-ice (Community Sea Ice Model CICE), and has been used in the CMIP5 (Coupled Models Intercomparison Project Phase) process. (Gent *et al.*, 2011)

The German Max Planck Institute Earth System Model (MPI-ESM) is based on components for the atmosphere (ECHAM6), the ocean (MPIOM), the terrestrial biosphere (JSBACH) and the ocean biogeochemistry (HAMOCC) and has been used in the CMIP5 and CMIP6 process. In contrast to earlier Earth System Models (e.g. ECHAM5/MPIOM) the carbon cycle has been added to the model system. For this project the MPI-ESM was used with a MR resolution (Highly Resolved Middle Atmosphere). (Max-Planck-Institut für Meteorologie, no date)

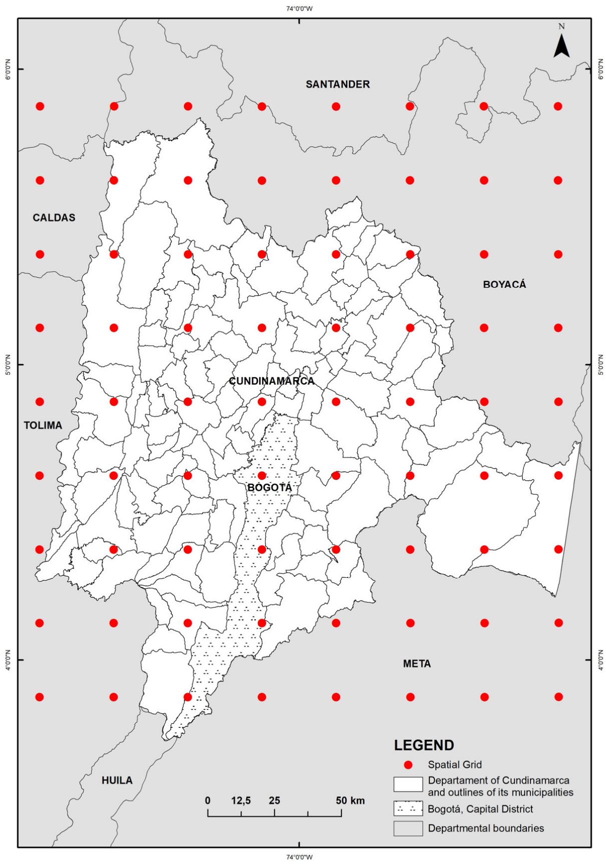


***Figure 10**: Illustration of the department of Cundinamarca and the outlines of its municipalities overlaid with the spatial grid used for the interpolation of projected climate data. Source: Compiled on ArcGis*

Both model outputs provide monthly mean temperature and precipitation data from January 1981 through December 2099 for 9x8 grid points with 27.68 km distance over the area of the department of Cundinamarca. (see **Figure 10**)

The temperature and precipitation patterns in the department of Cundinamarca were analysed calculating multiannual monthly mean temperatures and precipitation for different time periods. While the years 1981-2005 were used as a reference period representing the historical climate in Cundinamarca, the future periods 1 dating from 2040 to 2059 and 2 dating from 2080 to 2099 represent two projected climate situations in the department. The corresponding tables can be found in **Annex 1**

3.1.2 Results

When comparing the two models' mean temperature data for the department of Cundinamarca, the average difference between them is of 0.01°C in the historical multiannual monthly mean with no clear tendency of one model showing higher temperatures than the other (see **Figure 11**, left). When comparing the two models' precipitation data for the department of Cundinamarca, the average difference between them is of 3 mm in the historical multiannual monthly mean with no clear tendency of one model showing higher precipitation than the other (see **Figure 11**, right).

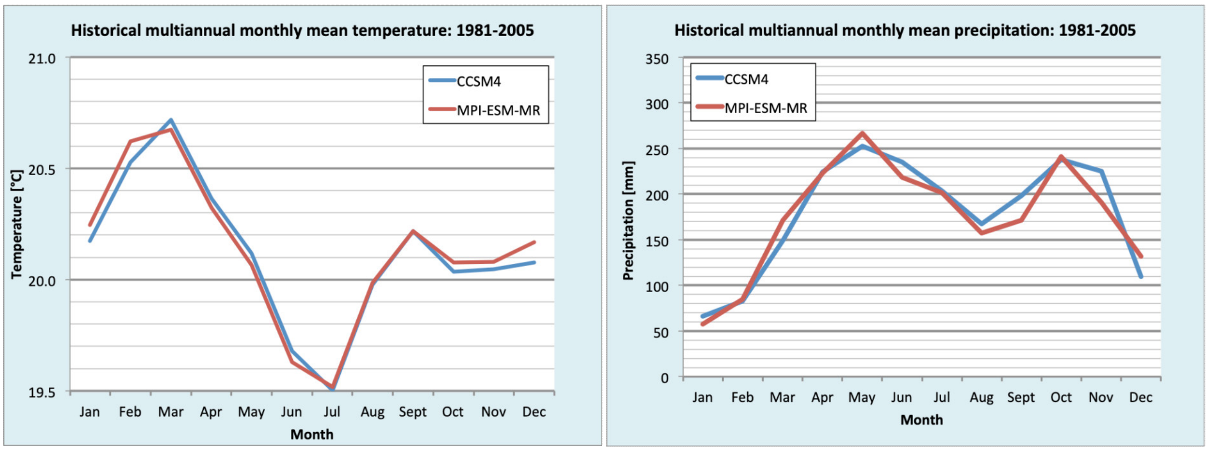


Figure 11*: Historical multiannual monthly mean temperature in °C (left) and precipitation in mm (right) for the department of Cundinamarca modelled by CCSM4 and MPI-ESM-MR for the period of 1981-2005.*

However with increasing RCP and time the MPI-ESM-MR shows clearly higher temperatures with average differences of 0.48°C for RCP 4.5 and 0.65°C for RCP 8.5 in the first period (2040-2059), and of 0.54°C for RCP 4.5 and 1.14°C for RCP 8.5 in the second period (2080-2099) (see **Figure 12**). The temperature difference between the two models is highest around the maximum temperature peaks and lowest around the minimum temperature peaks.

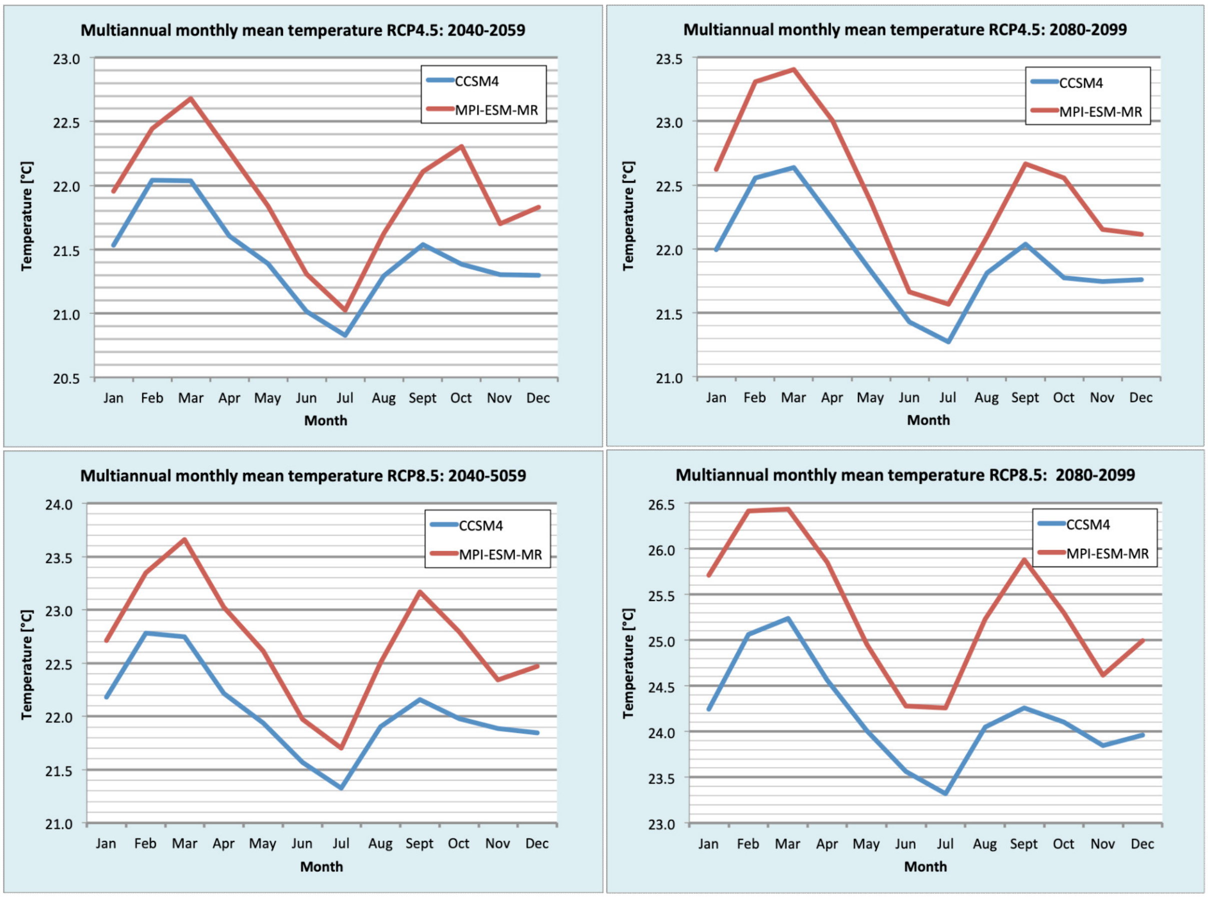


Figure 12*: Modelled multiannual monthly mean temperatures (°C) in the department of Cundinamarca for the periods of 2040-2059 and 2080-2099 from left to right, and for the RCPs 4.5 and 8.5 from top to bottom.*

While for the RCP 4.5 and the first period the CCSM4 shows a higher monthly average precipitation of 11 mm, the difference decreases to 4 mm for RCP 8.5 in the first period and to 2 mm for RCP 4.5 in the second period, and in the second period of RCP 8.5 it reverses to the MPI-ESM-MR showing a higher monthly average precipitation of 19 mm (see **Figure 13**). The CCSM4 shows more flattened maximum precipitation peaks, especially for the first wet season of the year from April through July.

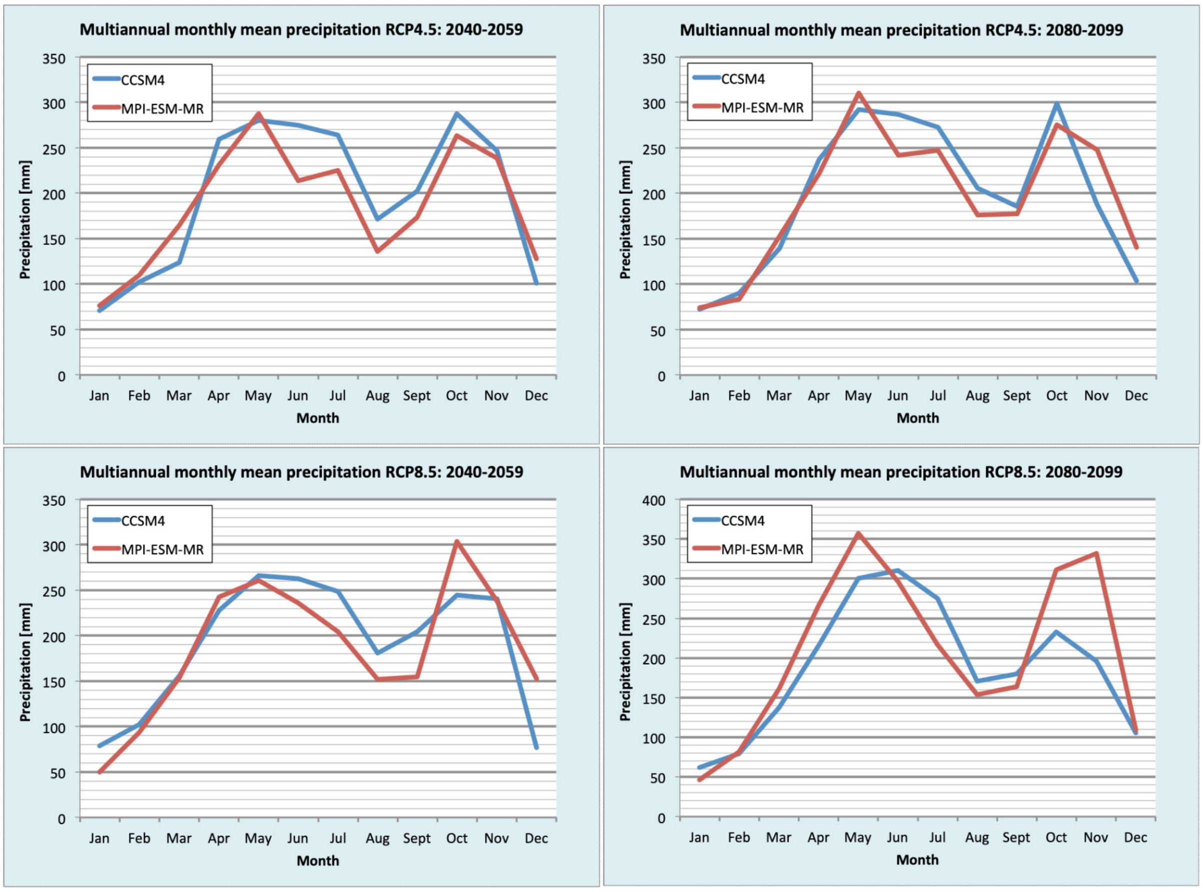


Figure 13: Modelled multiannual monthly mean precipitation (mm) in the department of Cundinamarca for the periods of 2040-2059 and 2080-2099 from left to right, and for the RCPs 4.5 and 8.5 from top to bottom.

Due to significant differences in temperature and precipitation patterns, in the further course of this work data of both models were used separately rather than using a mean of both outputs.

Temperature

The recent historical temperature over the whole area of the department of Cundinamarca lies in a range of 19.5°C and 20.7°C according to data based on both models, the CCSM4 and the MPI-ESM-MR (see **Figure 14**, top). For the sub-region of the Bogotá Savannah the monthly mean temperatures are roughly 6°C lower and range from 13.3°C to 14.5°C for both models (see **Figure 14**, bottom). The historical temperature pattern shows one season of rather high temperatures from February to April with another small peak in September for the whole department of Cundinamarca, and one season of rather low temperatures in June and July. The amplitude of monthly mean temperatures for both regions is very low (1.1-1.2°C) with the hottest months being February and March for the department of Cundinamarca and March and April for the region of the Bogotá Savannah, and the coldest months being June and July for both regions.

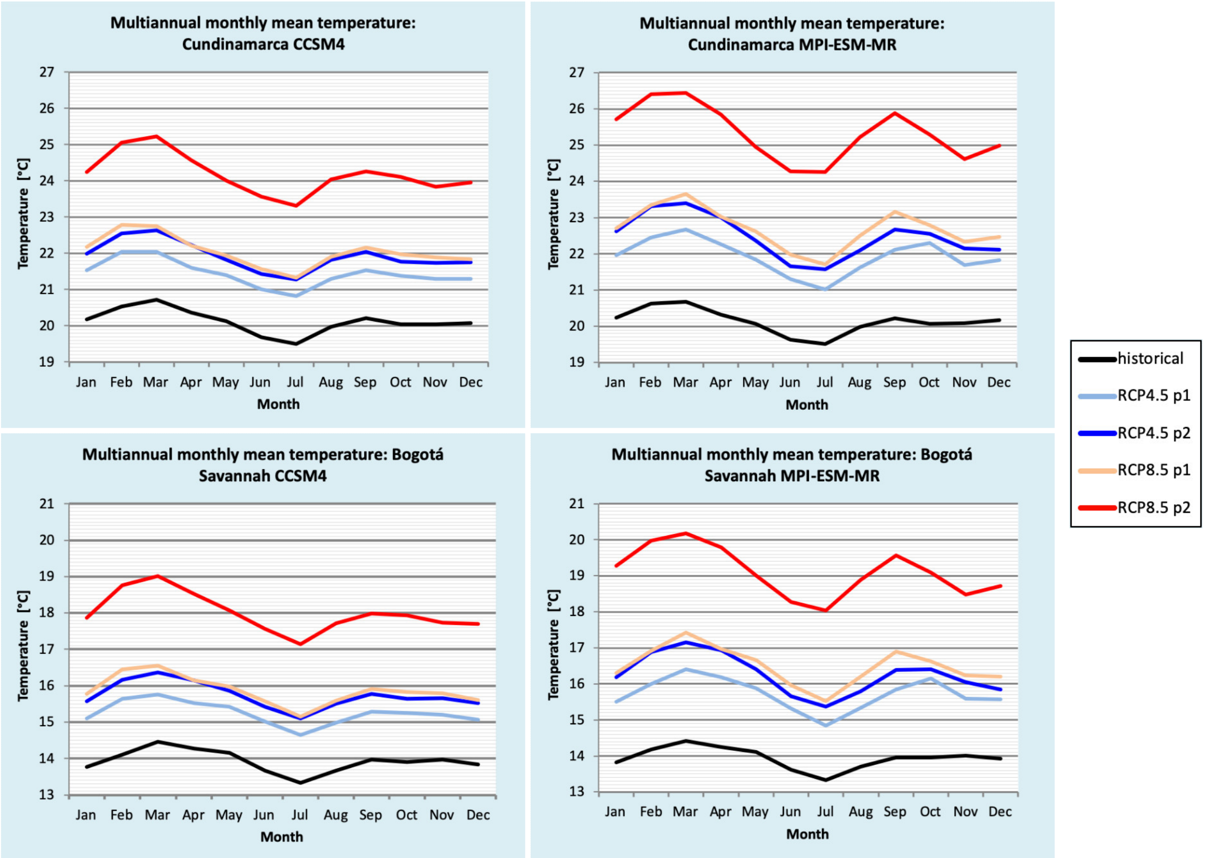


***Figure 14**: Modelled multiannual monthly mean temperature (C°) for the historical reference period of 1981-2005 and the RCPs 4.5 and 8.5 over the periods of 2040-2059 (p1) and 2080-2099 (p2) based on CCSM4 (left) and MPI-ESM-MR (right) for the whole department of Cundinamarca (top) and the Bogotá Savannah (bottom).*

The temperatures based on data from both models CCSM4 and MPI-ESM-MR are substantially higher for both RCPs 4.5 and 8.5 and both periods 2040-59 and 2080-99. The average temperature increase from the historical situation to the first period of RCP 4.5 is of 1.3°C in both regions for CCSM4 and 1.8°C in both regions for MPI-ESM-MR. The average temperature increase from the historical situation to the second period of RCP 4.5 is 1.8°C for CCSM4 and 2.3°C for MPI-ESM-MR in both regions. The increase from the first to the second period in RCP 4.5 is thus relatively low being around 0.5°C.
The average temperature increase from the historical situation to the first period of RCP 8.5 is 1.95°C for CCSM4 and 2.55°C for MPI-ESM-MR in both regions. The average temperature increase from the historical situation to the second period of RCP 8.5 is 4.1°C for CCSM4 and 5.2°C for MPI-ESM-MR in both regions. The increase from the first to the second period in RCP 8.5 is roughly the same as the increase from the historical period to the first period in RCP 8.5 being around 2.15°C for CCSM and 2.65°C for MPI-ESM-MR.
While the coarse temperature pattern over the course of the year remains the same, the peaks are projected to intensify and while the temperature amplitude does not change for the first period of RCP 4.5 for CCSM, it increases from 1.1°C in the historical reference period to 1.6°C roughly for MPI-ESM-MR. For the second period of RCP 4.5 the temperature amplitude increases to 1.36°C in all of Cundinamarca and to 1.27°C in the region of the Bogotá Savannah for CCSM4, and even higher to 1.84°C in all of the department and to 1.78°C in the Bogotá Savannah for MPI-ESM-MR. For the first period of RCP 8.5 the amplitude is roughly 1.4°C for CCSM4 and 1.96°C in all of Cundinamarca as well as 1.89°C in the Bogotá Savannah for MPI-

ESM-MR. For the second period of RCP 8.5 the amplitude is 1.92°C and 1.88°C in all of Cundinamarca and in the Bogotá Savannah respectively for CCSM4, and 2.18°C in all of Cundinamarca and 2.14°C in the Bogotá Savannah for MPI-ESM-MR.
While the hottest time of the year in all of Cundinamarca remains to be during the months of February and March, for the region of the Bogotá Savannah where the hottest months used to be March and April in a the historical reference period, the strongest temperature increases occur in February which moves the hottest months to earlier in the year in February and March for CCSM4. For MPI-ESM-MR this only happens in the second period of RCP 8.5.
June and July keep being the coldest months of the year for all scenarios and time periods. However, the lowest temperature increases are noted in November and December for CCSM4 and while for MPI-ESM-MR July has still the least increasing temperature in the first periods of the respective RCPs, in the second period the lowest temperature increases are also noted in November and December.

In conclusion some general tendencies can be noted:

- With increasing temperature, the temperature amplitudes between the coldest and the warmest months increase, meaning that the low and high temperature peaks are more noticeable with increasing RCP and time period.
- The sub-region of the Bogotá Savannah has lower monthly mean temperatures than the total area of Cundinamarca, nevertheless it does not have lower temperature increases than the average department.
- CCSM4 data shows a shift of the main maximum temperature peak towards a little earlier in the year, a tendency that can also be seen for the second period in RCP 8.5 in the MPI-ESM-MR data.

Precipitation

The recent historical monthly precipitation over the whole area of the department of Cundinamarca lies in a range of 66 mm and 253 mm with an average sum of 2154 mm distributed over the whole year according to data based on the CCSM4, and in a range of 58 mm and 267 mm with an average annual sum of 2116 mm according to data based on MPI-ESM-MR (see **Figure 15**, top). For the sub-region of the Bogotá Savannah the monthly mean precipitation ranges from 55 mm to 163 mm for CCSM4 and from 50 mm to 170 mm for MPI-ESM-MR, and the annual sum is significantly lower with 1426 mm and 1406 mm for CCSM4 and MPI-ESM-MR respectively (see **Figure 15**, bottom).
The historical precipitation pattern shows two wet and two dry seasons, of which the wet seasons on average last from April to June and from October to November in Cundinamarca, and from April to May as well as from October to November in the region of the Bogotá Savannah. For both regions, the main dry season lasts from December to February and has its peak in January. A second rather dry season takes place in the middle of the year between the two wet seasons with a smaller precipitation low in August. The average precipitation difference between the wettest and the driest month over the whole area of Cundinamarca is 187 mm and 209 mm for CCSM4 and MPI-ESM-MR respectively. For the region of the Bogotá Savannah this amplitude is considerably lower with 106 mm and 120 mm for CCSM4 and MPI-ESM-MR respectively.

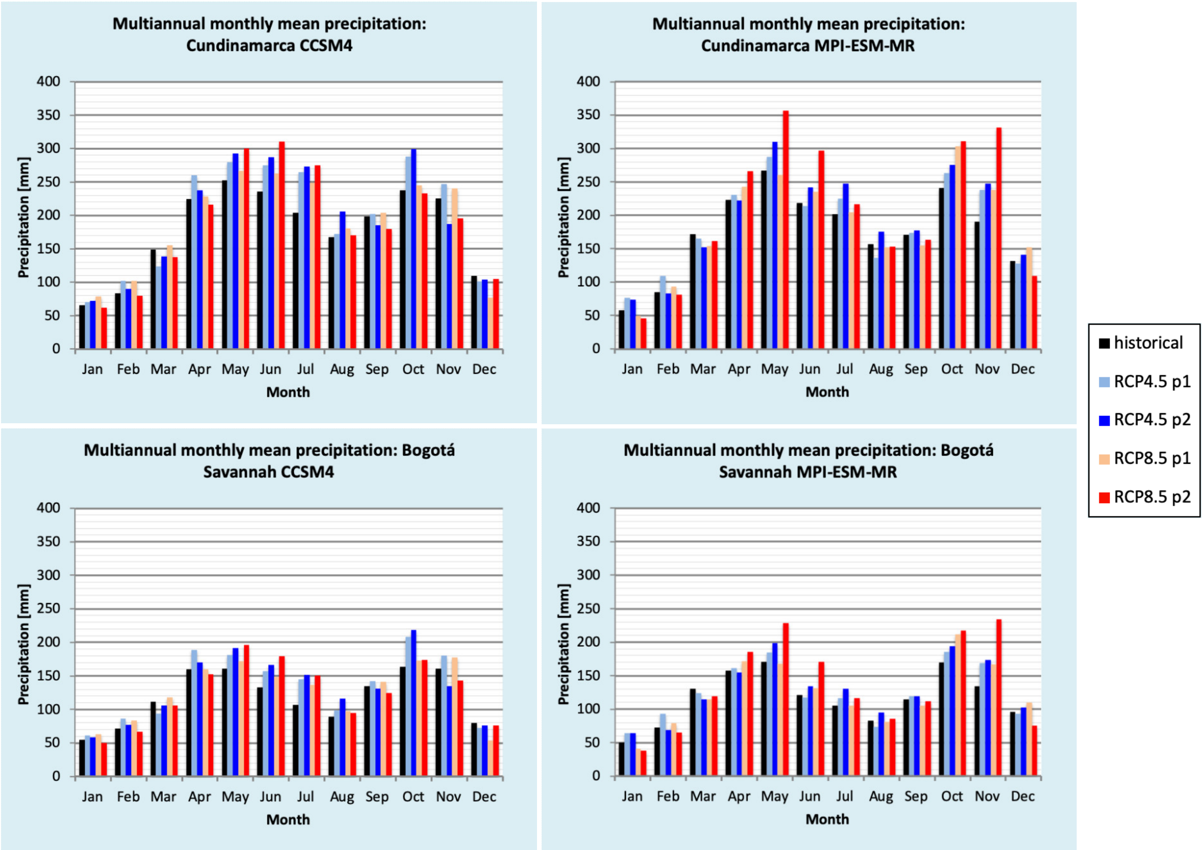


Figure 15*: Modelled multiannual monthly mean precipitation (mm) for the historical reference period of 1981-2005 and the RCPs 4.5 and 8.5 over the periods of 2040-2059 (p1) and 2080-2099 (p2) based on CCSM4 (left) and MPI-ESM-MR (right) for the total department of Cundinamarca (top) and the Bogotá Savannah (bottom).*

In contrast to the temperature pattern, the differences between the future projections and their precipitation patterns are less clear. While the monthly patterns vary, the projected annual precipitation is higher than the historic for both RCPs and time periods in both data sets and both regions. However, there is a difference in the increase of the precipitation between the two data sets. In the CCSM4 data annual precipitation increases most in the first period for the RCP 4.5 and is as high as 111 % compared to the historical precipitation for Cundinamarca and 113 % for the Bogotá Savannah. It then slightly decreases again to 110 % and 112 % for the two regions in the second period of RCP 4.5, and is even lower for the first and second periods of RCP 8.5 with 106 % and 105 % for all of Cundinamarca and 107 % and 106 % for the region of the Bogotá Savannah. In the MPI-ESM-MR data precipitation keeps increasing from the first to the second period in both RCPs for both regions. It is 106 % for all of Cundinamarca and 107 % for the Bogotá Savannah in the first period of RCP 4.5, and 111 % and 110 % respectively for the second period of RCP 4.5. For the first period of RCP 8.5 it is 106 % for both regions and for the second period it is 118 % for an average of all of Cundinamarca and 117 % for the sub-region of the Bogotá Savannah. So, while based on the CCSM4 data, precipitation increases most in the first period of RCP 4.5 and then decreases again, it keeps increasing over both time periods and shows the highest precipitation values in the second period of RCP 8.5 for the MPI-ESM-MR data.

The annual pattern remains the same but shows stronger peaks of wet and dry seasons. Some months have strong precipitation increases, but at the same time other months have precipitation losses. The strongest precipitation increases can mainly be seen in the months of the wet season for both periods and RCPs of the CCSM4 data set over the whole area of

Cundinamarca. For the region of the Bogotá Savannah they occur after the main wet season in July. According to the MPI-ESM-MR data set the strongest precipitation increases occur in the months of the second wet season, mainly in November for both regions in both scenarios and RCPs expect for the first period of RCP 4.5 where they occur in the dry period of January and February.
For CCSM4 maximum monthly precipitation losses show in March with -17 % in Cundinamarca and -16 % for the Bogotá Savannah over the first period in RCP 4.5 and in November with -17 % in Cundinamarca and -16 % for the Bogotá Savannah over the second period in RCP 4.5. Over the first period of RCP 8.5 they are maximal in the month of December at -30 % for Cundinamarca and at -33 % for the Bogotá Savannah. Over the second period maximum losses occur in November at -13 % and -11 % for Cundinamarca and the Bogotá Savannah respectively.
For MPI-ESM-MR maximum monthly precipitation losses are visible in August with -13 % in Cundinamarca and -11 % in the region of the Bogotá Savannah over the first period in RCP 4.5 and in March with -11 % and -12 % respectively for the second period in RCP 4.5. Over the first period of RCP 8.5 precipitation losses are maximal in January with -14 % on average for the whole region of Cundinamarca and -20 % for the Bogotá Savannah. Over the second period maximum losses occur in January and December with -20 % and -17 % for Cundinamarca and -24 % and -21 % for the Bogotá Savannah.

The average precipitation difference between the wettest and the driest month over both, the whole area of Cundinamarca and the sub-area of the Bogotá Savannah increases for all periods and RCPs respective to the historical reference period. Based on CCSM4 in the department of Cundinamarca the amplitude increases by 16 % and 21 % for the first and second period in RCP 4.5 and by 2 % and 33 % for the first and second period in RCP 8.5. In the region of the Bogotá Savannah it increases by 40 % and 52 % for the first and second period in RCP 4.5 and by 12 % and 23 % for the first and second period in RCP 8.5. Based on MPI-ESM-MR data the amplitude increases by 1 % and 13 % for the first and second period in RCP 4.5 and by 21 % and 49 % for the first and second period in RCP 8.5 on average over the whole department of Cundinamarca. For the sub-area of the Bogotá Savannah it increases by 0 % and 11 % for the first and second period in RCP 4.5 and by 43 % and 59 % for the first and second period in RCP 8.5.
For CCSM4 the first rainy season of the year seems to become longer and expand from April-June to April-July for both RCPs and time periods, while the second rainy season of the year seems to become shorter and more pronounced in October than in November in the second period of both RCPs. The absolute change in the dry periods is of less extent and the pattern does not change.
For MPI-ESM-MR the pattern of the rainy seasons does not significantly change for both RCPs and periods in the region of the Bogotá Savannah. In the whole department of Cundinamarca on average, it remains the same in both first periods but slightly shifts the first yearly rainy season from April and May to May and June in the second periods of both RCPs. Again, the absolute change in the dry periods is of rather smaller extent than the one in the wet periods. However, for the region of the Bogotá Savannah the dry period of January and February already starts in December in the first period of RCP 4.5 and the second period of RCP 8.5.

In conclusion some general tendencies can be noted:

- The sub-region of the Bogotá Savanna presents lower monthly precipitation volumes than the total department of Cundinamarca, except for the dry period in January and February where precipitation in the Savannah almost reaches the volumes of the

average area of Cundinamarca.
- However, the annual precipitation increases are similar for the Bogotá Savannah and for the average area of Cundinamarca.
- The amplitudes between the wettest and the driest months increase, meaning that the wet and dry seasons are projected to become more pronounced. This tendency is particularly strong for the end of the century in RCP 8.5.
- CCSM4 data shows an extension of the first rainy season from April-June to April-July, and a slight shortening of the second rainy season with its maximum peak being stronger in October than in November, while for MPI-ESM-MR it is stronger in November than in October.

3.2 Climate change impacts on hydrological resources

In order to assess the impacts of climate change on the hydrological resources of the department of Cundinamarca, the projected climate changes were used to estimate the changes in the hydrological balance of the Bogotá river catchment located in the centre of the CAR territory. In the first part of this chapter the methodological approach to the assessment is explained. The second part contains a description of the Bogotá river catchment and its hydrological resources based on available literature. The results are then presented in the third and discussed in the fourth part.

3.2.1 Method

In an attempt to quickly assess the availability of hydrological resources in the area the catchment's hydrological balance was analysed. To adjust the hydrological balance to potential climate and demographic changes in the future, the runoff equation provided by the regional water evaluation of the CAR (2019f) was applied to track and understand the role of the variables for the Bogotá river catchment. The Regional Water Evaluations (ERAs) of the Bogotá river catchment calculate the hydrological balance for regulated catchments with the influence of big water reservoirs and hydraulic interventions as follows:

$$Rn = P - ETR - D + Rt \pm Tr \pm \Delta S - \Delta disc.$$

(Equation 1)

with	Rn	= measured runoff	Rt	= water returned to the catchment
	P	= precipitation	Tr	= water transferred to the catchment
	ETR	= evapotranspiration	ΔS	= change in storage (e.g. reservoirs)
	D	= demand	Δdisc.	= discrepancy term

However, in the ERAs published, the calculations made to obtain the water supply are not provided. Hence, in order to better understand the supply part of the hydrological balance, the values given for the hydrological balance were calculated adjusting the equation as follows:

$$P - ETR - Evap. - D + Rt + Tr + GW - Inf. = Hydr.\ Balance$$

(Equation 2)

with	P	= precipitation	Rt	= water returned to the catchment
	ETR	= evapotranspiration	Tr	= water transferred to the catchment
	Evap.	= evaporation	GW	= groundwater

D = demand Inf. = infiltration

Using data from CAR (2019f, 2019g, 2019h), Acueducto de Bogotá (2013), CAR (2019k) and IDEAM (2019) for the different variables the monthly and annual hydrological balance was calculated for the total Bogotá river catchment and compared to the values presented by the ERAs. The monthly values for precipitation and evapotranspiration were taken directly from the ERAs of the upper, the mid and the lower Bogotá river catchment CAR (2019f, 2019g, 2019h). The data for the reservoir evaporation is based on the Watershed Regulation and Management Plan (POMCA) (CAR, 2019j). The demand is divided in agriculture, livestock, domestic and industrial demand from CAR (2019f, 2019g, 2019h). The water returned to the catchment (Rt) was calculated as 63 % of the agricultural demand based on the index of water that is not returned to the catchment (0.37) by the national water study (ENA) (IDEAM, 2019). The volume of water transferred to the catchment (Tr) was calculated according to numbers presented by the Acueducto de Bogotá (2013). And the values for the monthly infiltration and groundwater extraction are based on the annual sum presented by CAR (2019f, 2019g, 2019h) assuming they are linearly distributed over time.

In order to make future projections for the hydrological balance the climatic variables were adjusted according to the changes in precipitation and temperature projected by the climate models CCSM4 and MPI-ESM-MR, and to the changes in the demand according to expected changes in the agricultural and domestic sectors.
For the climatic variables the changes will probably most affect the precipitation and the evapotranspiration. As evaporation is of minor importance to the total hydrological balance due to the small open water surface area of the catchment, and the variables for infiltration and groundwater extraction are simplified, they both were not considered in this exercise.
The projection of the precipitation is based on the relative precipitation changes calculated for the CCSM4 and the MPI-ESM-MR model data.
The projection of the evapotranspiration (ETR) is relatively complicated as CAR (2019f, 2019g and 2019h) do not present the calculations they made in detail to find their ETR values. In thiw work the ETR was calculated based on the potential evapotranspiration (ETo) multiplied by a factor KC that represents the vegetation cover of the catchment area. The calculated ETR (ETR_{calc}) was then compared to the ETR values given by the ERA (ETR_{real}) and a monthly correction factor was calculated that was applied to all projected values for ETR_{calc} in order to get closer to the reality. For the values of the potential evapotranspiration the ETo Calculator provided by the Food and Agriculture Organization of the United Nations (FAO) was used (FAO, no date e). The calculations of the program are based on the monthly maximum, minimum and mean temperature, the mean relative humidity and the daily duration of sunshine. As projected climate data are only available for the monthly mean temperature, the approximate maximum and minimum temperature were deducted from observed temperature changes published by IDEAM-UNAL (2018). They state that while during the second half of the last century the monthly mean temperature increased by around 0.2°C per decade, the maximum temperature increased by about 0.6°C and the minimum temperature increased only very little. (IDEAM-UNAL, 2018) Looking at the relative temperature changes this means that the maximum temperature increases by a factor of 3 with respect to the mean temperature. For the minimum temperature change a factor of 0.5 was assumed as the minimum temperature change is said to be smaller than mean temperature change. A table presenting the values for the minimum, maximum and mean temperatures for all RCPs and periods for the two models CCSM4 and MPI-ESM-MR and the other variables used for the calculation of the ETo can be found in **Annex 2**. For the calculation of the future ETo the

number of sun hours and the relative humidity were not adjusted, but only the maximum and minimum temperatures.

To project potential changes for the demand the agricultural demand and the domestic demand were considered. The agriculture sector makes up the biggest part of the water demand in the Bogotá river catchment with about 86 %, while the domestic demand is about 7 % and livestock farming and the industry sector only demand 3 % and 1.5 % of the total (see **Table 2**). The last two were not considered for projected changes.
There are no recent numbers found for the projected increase in agricultural activity in Cundinamarca. However, the combined sector of agriculture, livestock farming, hunting, forest cultivation and fishing grew by 2.7 % from 2017 to 2018 in Cundinamarca. (Cámara de Comercio de Bogotá, 2019) For Colombia the agriculture and livestock sector grew by 2.1 % in 2018 and was projected to grow by 2 % in 2019 and by 2.3 % in 2020. (FEDESARROLLO, 2019) For this work the assumption was made that the agriculture sector alone grows by an annual 1.5 % for the next two decades and then remains stable.

3.2.2 Hydrological system of the Bogotá river catchment

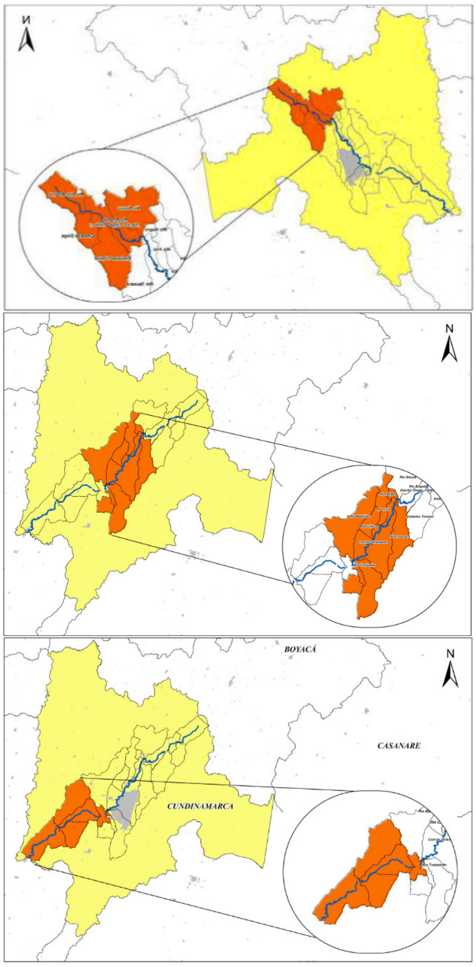
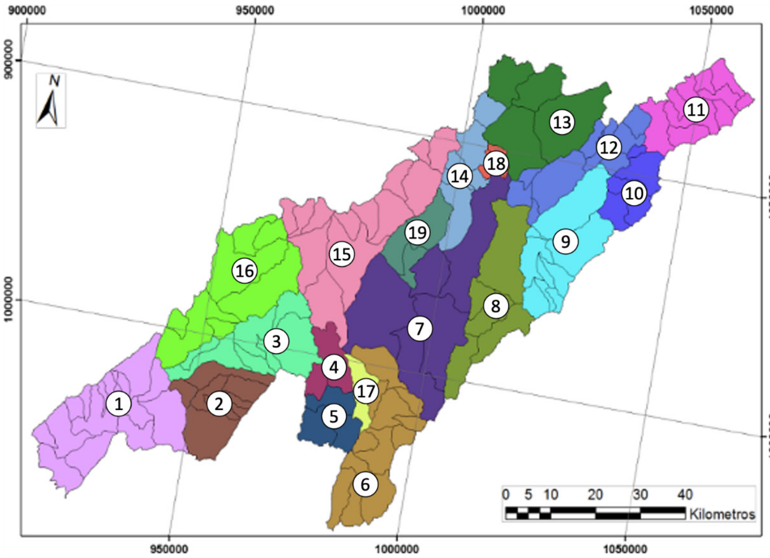


Figure 16: Location of the upper (top), mid (middle) and lower (bottom) Bogotá river catchment in the department of Cundinamarca. Source: CAR, 2019f,g,h

The catchment of the Bogotá river is described in detail in the most recent ordinance and management plan of the hydrographic catchment (POMCA) of the Bogotá river. (CAR, 2019i) It is located in the centre of Cundinamarca and with its 5895 km^2 it covers about ¼ of the department's area as it reaches diagonally from Villapinzón in the North-East of the department to Girardót in the very South-West of the department. (see **Figure 16**) The Bogotá river catchment is part of 47 municipalities and has 19 sub-catchments, as can be seen in **Figure 17**. It is home to roughly 20 % of Colombia´s inhabitants and to the production of around 1/3 of the country´s GDP. (CAR, 2017f) The Bogotá river discharges into the Magdalena river in the municipality of Girardót. (CAR, 2019i)
The area's recent climate is cold and semi-humid in the upper catchment, with páramo zones in the high mountains to the extreme East and the extreme West of the sub-catchment. In the mid catchment climate is cold and semi-humid to semi-arid. The lower catchment has a temperate and semi-humid to semi-arid climate, with warm and semi-arid conditions in the very South of the catchment. The Bogotá river catchment shows high annual temperature differences because of the large altitude differences within its area. While the annual temperature is around 20-24°C in the very South West of the catchment, it is only around 10-14°C in the centre and North of the catchment. The region has a bimodal hydrological regime with rainy seasons in spring and autumn. Similar to the temperature pattern, the catchment divides into a Southern part where annual precipitation is clearly higher with around 1100-1200 mm and a central and northern part with lower annual precipitation values

of around 800 mm. An exception to this are the oriental hills in the very East of the catchment that also accumulate precipitation of values similar to the ones in the South of the catchment. (CAR, 2019i)

According to the most recent POMCA by the CAR (2019i) the total catchment's demand is 24.7 m^3/s or 778.4 million m^3 per year, which is significantly lower than the what the ERAs from



Código	Subcuencas	Área (Km²)
212001	Río Bajo Bogotá (Apulo-Girardot)	540,32
212002	Río Apulo	485,66
212003	Río Calandaima	268,46
212004	Río Medio Bogotá (El salto de Apulo	318,19
212005	Río Bogotá (Sector Salto-Soacha)	127,67
212006	Embalse del Muña	133,95
212007	Río Soacha	39,42
212008	Río Balsillas	633,34
212009	Río Tunjuelo	392,11
212010	Cerros Orientales	700,83
212011	Río Chicú	146,02
212012	Río Frío	202,47
212013	Río Teusacá	356,18
212014	Río Negro	32,33
212015	Río Neusa	433,6
212016	Río Bogotá (Sector Sisga-Tibitoc)	277,44
212017	Embalse de Tominé	366,39
212018	Embalse Sisga	152,67
212019	Río Alto Bogotá	278,73

Figure 17*: The Bogotá river catchment with its 19 sub-catchments numbered according to the ending of their 6-digit code. Adjusted from CAR, 2019i*

the same year state, namely 1123.9 million m^3 (CAR, 2019f, 2019g, 2019h)
However, based on the POMCA's annex with data about the water demand in the Bogotá river catchment (CAR, 2019k) the annual demand is 1083.8 million m^3, which is a lot closer to what the ERAs suggest. The water supply of the Bogotá river catchment is of 2468.3 million m^3 for a medium year and of 1982.2 million m^3 for a dry year according to the most recent POMCA (CAR, 2019i)

While the annual water volume added to the catchment by precipitation is above 4000 million m^3, the largest part of this water is evapotranspirated (~62 %) and evaporated (~1 %) or unavailable for extraction as makes up the superficial streams´ environmental base flow volume (~25 %). This leaves an available annual water supply of around 480 million m^3 for domestic consumption, agriculture, livestock farming and industry. As this does not cover the total annual demand in the Bogotá river catchment (1123.9 million m^3), three extensive water reservoir and transportation systems are used to supply part of the demand (see **Figure 18**): The Tibitoc system, the Chingaza system and the La Regadera system with a total volume of 1196.45 million m^3 of usable storing capacity and a long-term maximum flow capacity of around 21 m^3/s and a current used capacity of 15 m^3/s. (Acueducto de Bogotá, 2013) These 15 m^3/s make up the average drinking water supply of the city of Bogotá with 9 m^3/s and of its neighbouring municipalities with 6 m^3/s. (Peña-Guzmán, Melgarejo and Prats, 2016) While the Regadera system and the Tibitoc system are located in the Bogotá river catchment of the Magdalena-Cauca basin, the Chingaza system is fed with water from the Orinoco basin, using water from a catchment area of 279 km^2. The Chingaza system is a páramo ecosystem and contains the reservoir Chuza with 223 Mm3 usable capacity that regulates the flow of Guatiquía river which is part of the Orinoco catchment. The water is transferred from the Orinoco catchment to the Bogotá river catchment through the San Rafael reservoir of a usable capacity of 70 million m^3 and the water treatment facility Francisco Wiesner. The Wiesner

treatment plant has a filtration capacity of 14 m^3/s of which 10 m^3/s are normally in operation. The Regadera system contains the reservoirs Chisacá and La Regadera of 6.75 million m^3 and 3.7 million m^3 capacity respectively. The associated treatment plants La Laguna and El Dorado have capacities of 0.45 m^3/s and 1.6 m^3/s, with La Laguna only operating in exceptional cases and El Dorado releasing 0.4 m^3/s under normal conditions. The Tibitoc system consists of the Tominé, Neusa and Sisga reservoirs of 691 million m^3, 101 million m^3 and 101 million m^3 usable capacity respectively, and the Tibitoc treatment plant has a maximal capacity of 12 m^3/s of which 4.6 m^3/s are released in normal operation. (Acueducto de Bogotá, 2013)
Of the three systems, the Chingaza system is the main supplier meeting around 70 % of the water demand of the city of Bogotá (Red Bogotá, no date). With a capacity of 293 million m^3 and continuously used treatment capacity of 10 m^3/s it accounts for about 315 million m^3 or 14 % of the Bogotá river catchment´s available supply.

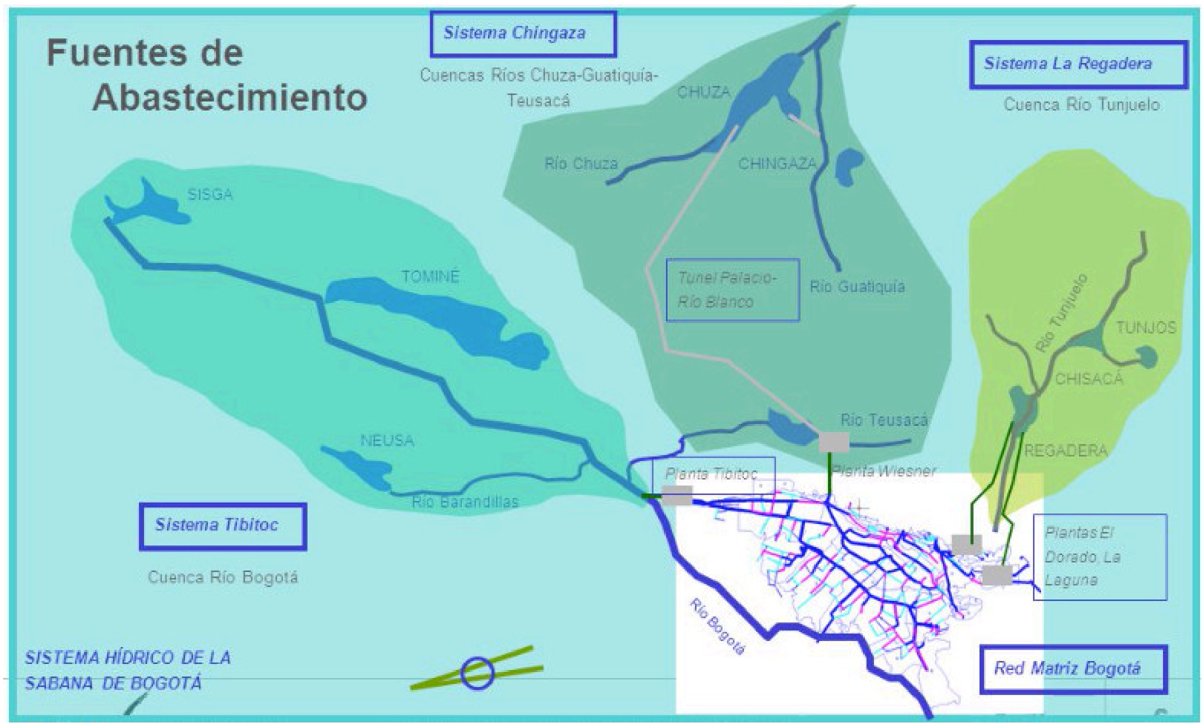


***Figure 18**: Water regulation and supply sources of the Bogotá Savannah hydrological system: The Tibitoc, Chingaza and La Regadera reservoir and water treatment systems. Source: Red Bogotá, accessed: 18.09.2019*

Another water source to the Bogotá river catchment is the extraction of groundwater from several aquifers in the catchment. According to the Regional Water Evaluation (ERA) of the upper Bogotá river catchment the Bogotá Savannah has a groundwater reserve of 73’306 million m^3 (CAR, 2019f). The middle catchment has groundwater reserves of around 105’175 million m^3 and the lower catchment has reserves of around 2’730 million m^3 (CAR, 2019h, 2019g). However, there have been found significant discrepancies between different studies trying to quantify the groundwater reserves in the Bogotá river catchment. (CAR, 2019i) Also for the extraction and use of groundwater in the Bogotá river catchment, different numbers are suggested. While CAR (2008) states that the annual amount of extracted groundwater is 14 million m^3 for the whole area of the upper and mid Bogotá river catchment, or between 7.03 million m^3 and 28-35 million m^3 for the Bogotá Savannah in respective normal and very dry years, it also states that based on data from 2003, on average an annual total of 42.01 million m^3 is extracted from the groundwater in the area of the Bogotá Savannah, of which 11.33 million m^3 is extracted for the water provision of the municipal aqueducts. (CAR, 2008) However Peña-Guzmán et al. (2016) suggest that Bogotá has groundwater concessions for 8-

9 million m^3 in Bogotá and the CAR states that an annual 1.37 million m^3 (or 0.043 m^3/s) of groundwater is extracted in the upper and mid catchment of the Bogotá river, and an annual 3.15 million m^3 is extracted in the lower catchment of the Bogotá river (CAR, 2019i, 2019g). They both agree that around half of the extracted groundwater demand is used for industrial purposes (Peña-Guzmán, Melgarejo and Prats, 2016; CAR, 2019i).
The numbers may differ, but all of the here mentioned values of groundwater extraction in the Bogotá river catchment (4.5-42 million m^3) are in a range of 0.4-3.7 % of the total demand (1123.9 million m^3) or 0.2-1.9 % of the available supply (2186.4 million m^3) of the Bogotá river catchment (CAR, 2019f, 2019h, 2019g), which is low both in the current context as well as in comparison to the projected changes in precipitation future and thus the projected changes in water supply.
Put like that, the total contribution of groundwater to the total available water supply may be small. Non the less, considering that groundwater use is punctually essential especially to local industry in the Bogotá Savannah, the observation of the development of groundwater reserves is of importance. It has been found that the Western part has the highest groundwater use in the Bogotá Savannah and has shown major problems of piezometric level drops (CAR, 2019i). Because of the scarcity of good quality surface water and an increasing water demand for irrigation, groundwater is now used as an alternative hydrological source in the Bogotá Savannah. As a consequence, the extraction of water through more than 4000 wells in the area of the Bogotá Savannah has resulted in a drop of the water table, which has caused negative effects upstream. Large drops in the groundwater table have been observed in the sectors in and around Bogotá with 30 m for the industrial zone of Bogotá and up to 100 m for the sector of the Subachoque valley over the past decades (CAR, 2016), while reductions of up to 50 m of the piezometric level were identified in the Chicú river sub-catchment over a period of only ten years (1998-2007) (CAR, 2008).
So even if the contribution of groundwater is small with respect to the total supply in the Bogotá river catchment, the potential exhaustion of the groundwater in the Bogotá Savannah may not only have repercussions on the water supply in certain sectors and at certain times during the year, but it may also have effects on ecosystem services and infrastructure. Strong reductions in groundwater levels for instance have led to cracks and subsidence on roads and foundations of water tanks and housing constructions in several municipalities of the Western Bogotá Savannah. (CAR, 2008)

As Cundinamarca´s population density is the highest and keeps increasing in the Bogotá Savannah, its water demand for human consumption, irrigation and industry is high. (CAR, 2016) Paired with the country's low capacity for waste water treatment (República de Colombia and MADS, 2015) this leads to expect that anthropologic pressure on the hydrological resource will further increase. Many water bodies in Colombia are contaminated due to the occupation and deterioration of their riparian buffer zones, and the low coverage and efficiency of waste water treatment. (República de Colombia and MADS, 2015) The main water pollutants are organic matter coming from households, and sediments originating from soil erosion and mining activities. Other important contaminants are chemicals resulting from agricultural activity, hydrocarbon remains and heavy metals. (DNP, 2006)

3.2.3 Results

A quick analysis of the catchment's hydrological balance based on data from CAR (2019f, 2019g, 2019h) is presented in **Table 2** for the upper catchment, the mid catchment, the lower catchment and the total catchment of the Bogotá river.

Table 2: Monthly and annual mean hydrological balance in million m^3 for the upper (top left), mid (top right), lower (bottom left) and total (bottom right) Bogotá river catchment. The demand is divided in demand for agriculture (agr.), livestock farming (l.st.), industry (ind.) and domestic use (dom.). Source: CAR, 2019f,g,h

Upper Bogotá river catchment							
	Supply [M m3]	Demand [M m3]					Balance [M m3]
Month	av. sup.	agr.	l.st.	ind.	dom.	total	sup.- dem.
Jan	100.9	51.1	0.1	1.4	0.7	53.3	47.6
Feb	60.2	30.3	0.1	1.3	0.6	32.2	28.0
Mar	63.9	27.8	0.1	1.4	0.7	30.0	33.9
Apr	50.1	17.1	0.1	1.4	0.6	19.2	30.9
May	55.1	14.6	0.1	1.4	0.7	16.7	38.3
Jun	89.5	22.6	0.1	1.4	0.6	24.7	64.9
Jul	78.7	22.1	0.1	1.4	0.7	24.2	54.4
Aug	81.6	21.6	0.1	1.4	0.7	23.7	57.9
Sep	72.9	25.5	0.1	1.4	0.6	27.6	45.4
Oct	62.2	20.3	0.1	1.4	0.7	22.4	39.8
Nov	63.4	18.1	0.1	1.4	0.6	20.2	43.2
Dec	65.5	26.1	0.1	1.4	0.7	28.2	37.3
Annual	**844.0**					**322.5**	**521.5**

Mid Bogotá river catchment							
	Supply [M m3]	Demand [M m3]					Balance [M m3]
Month	av. sup.	agr.	l.st.	ind.	dom.	total	sup.- dem.
Jan	14.4	42.4	0.0	0.0	4.7	47.0	-32.7
Feb	16.0	30.5	0.0	0.0	4.2	34.7	-18.7
Mar	35.8	24.9	0.0	0.0	4.7	29.6	6.2
Apr	40.3	12.5	0.0	0.0	4.5	17.0	23.3
May	46.3	10.1	0.0	0.0	4.7	14.7	31.6
Jun	38.0	16.8	0.0	0.0	4.5	21.3	16.6
Jul	25.7	23.5	0.0	0.0	4.7	28.2	-2.5
Aug	24.6	31.6	0.0	0.0	4.7	36.3	-11.7
Sep	28.8	27.8	0.0	0.0	4.5	32.3	-3.5
Oct	51.3	11.3	0.0	0.0	4.7	16.0	35.3
Nov	56.7	9.9	0.0	0.0	4.5	14.4	42.3
Dec	34.4	20.8	0.0	0.0	4.7	25.5	8.9
Annual	**412.2**					**317.1**	**95.1**

Lower Bogotá river catchment							
	Supply [M m3]	Demand [M m3]					Balance [M m3]
Month	av. sup.	agr.	l.st.	ind.	dom.	total	sup.- dem.
Jan	85.7	50.2	2.8	0.0	2.1	55.1	30.5
Feb	68.9	38.6	2.6	0.0	1.9	43.1	25.9
Mar	84.9	32.9	2.8	0.0	2.1	37.8	47.0
Apr	95.8	19.0	2.8	0.0	2.0	23.7	72.1
May	85.2	17.5	2.8	0.0	2.1	22.4	62.7
Jun	76.0	40.9	2.8	0.0	2.0	45.7	30.3
Jul	74.5	57.5	2.8	0.0	2.1	62.5	12.0
Aug	73.1	59.9	2.8	0.0	2.1	64.8	8.3
Sep	56.5	27.7	2.8	0.0	2.0	32.5	24.0
Oct	72.8	16.7	2.8	0.0	2.1	21.6	51.2
Nov	80.8	17.9	2.8	0.0	2.0	22.7	58.2
Dec	76.2	47.5	2.8	0.0	2.1	52.5	23.7
Annual	**930.3**					**484.4**	**446.0**

Total Bogotá river catchment							
	Supply [M m3]	Demand [M m3]					Balance [M m3]
Month	av. sup.	agr.	l.st.	ind.	dom.	total	sup.- dem.
Jan	200.9	143.7	2.9	1.4	7.4	155.4	45.5
Feb	145.1	99.4	2.6	1.3	6.7	110.0	35.1
Mar	184.5	85.6	2.9	1.4	7.4	97.4	87.1
Apr	186.2	48.6	2.8	1.4	7.1	60.0	126.2
May	186.5	42.1	2.9	1.4	7.4	53.9	132.7
Jun	203.5	80.3	2.8	1.4	7.1	91.7	111.8
Jul	178.8	103.2	2.9	1.4	7.4	114.9	63.9
Aug	179.3	113.0	2.9	1.4	7.4	124.8	54.5
Sep	158.2	80.9	2.8	1.4	7.1	92.3	65.9
Oct	186.3	48.3	2.9	1.4	7.4	60.0	126.2
Nov	201.0	45.9	2.8	1.4	7.1	57.3	143.7
Dec	176.1	94.4	2.9	1.4	7.4	106.2	69.9
Annual	**2186.4**					**1123.9**	**1062.6**

The hydrological balance is always positive except for the dry period months January, February and July, August, September in the mid catchment. The annual balance is lowest in the mid catchment with 95.1 million m^3 , while the balances in the upper and lower catchments are of 521.5 million m^3 and of 446 million m^3 respectively. The annual water supply in the whole Bogotá river catchment is 2186.4 million m^3, while the total demand makes roughly half of that with 1123.9 million m^3 and the balance over the whole catchment is 1062.6 million m^3. (CAR, 2019f, 2019h, 2019g)

As the annual hydrological balances are positive for all of the three catchment sections, the monthly distribution can be regulated with help of the reservoirs mentioned in the upper part of this chapter. While during times of water excess, the reservoirs are filled, during the months that present water demands that are higher than the supply, water can be provisioned by the same water reservoirs.

Table 3 shows monthly and annual hydrological balances for the total Bogotá river catchment based on the adjusted (**Equation 2**) and compared to the values presented by the ERAs.

Table 3: Monthly and annual values for the hydrological balance in the total Bogotá river catchment based on the ERA (Balance ERA) and calculated (Balance calc.) through variables for: precipitation (P), water transferred to the catchment (Tr), extracted groundwater (GW), infiltrated water (Inf.) evaporation (Evap.), evapotranspiration (ETR), water returned to the catchment (Rt), and the demand. Data sources: [1] CAR (2019f, 2019h, 2019g), [2] Acueducto de Bogotá (2013), [3] CAR (2019j), [4] IDEAM (2019)

Total Bogotá river catchment											
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance calc.**	**Balance ERA**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	181.75	26.78	0.38	25.48	4.72	157.15	84.09	143.97	-38.33	44.61
Feb	28	245.01	24.19	0.35	23.02	4.30	186.07	58.40	102.18	12.37	34.73
Mar	31	365.96	26.78	0.38	25.48	4.56	244.16	50.65	90.90	78.69	86.33
Apr	30	492.30	25.92	0.37	24.66	3.99	259.18	29.87	57.57	203.06	124.50
May	31	463.96	26.78	0.38	25.48	4.37	255.67	25.65	51.22	180.04	130.69
Jun	30	309.84	25.92	0.37	24.66	3.76	188.49	46.93	84.65	81.49	110.69
Jul	31	285.71	26.78	0.38	25.48	4.13	173.57	60.36	106.30	63.75	63.07
Aug	31	258.45	26.78	0.38	25.48	4.36	174.90	66.54	116.13	31.30	54.14
Sep	30	288.73	25.92	0.37	24.66	4.13	210.04	48.30	86.82	37.66	65.49
Oct	31	488.59	26.78	0.38	25.48	4.34	258.64	30.28	58.57	199.01	125.06
Nov	30	442.10	25.92	0.37	24.66	4.09	250.19	27.53	53.85	163.12	142.34
Dec	31	260.71	26.78	0.38	25.48	4.45	188.82	54.72	97.35	26.49	68.66
Annual		**4083.10**	**315.36**	**4.52**	**300.05**	**51.20**	**2546.88**	**583.30**	**1049.51**	**1038.65**	**1050.30**
Source		*[1]*	*[2]*	*[1]*	*[1]*	*[3]*	*[1]*	*[4]*	*[1]*		*[1]*

While the annual values are relatively similar for the calculated hydrological balance with 1039 million m^3 and the hydrological balance published by CAR (2019f) with 1050 million m^3, the monthly balances differ more strongly. Generally, in wet periods the calculated balance is higher than the one given by the ERAs and in dry periods it is lower than the one given by the ERAs. This may largely be explained by the regulation of the catchment through the numerous reservoirs flattening the peaks of water availability. To a minor extent it may be due to changes in the water infiltration into the soil, as for the presented simple calculation of the hydrological balance, infiltration rates are assumed to be constant over the annual cycle.

Assuming that the agriculture sector alone grows by an annual 1.5 % for the next two decades and then remains stable would lead to an increase in the agricultural water demand from annual 925.9 million m^3 to 1203.6 million m^3 for the projected periods 1 and 2.
The population of the Bogotá river catchment is around 9.9 million with 8.4 million of them living in the city of Bogotá and 1.5 million living in the rest of the catchment. (CAR, 2016, 2017b) According to Cristancho and Triana (2018) the projected population for Bogotá is about 11 million by 2050. For the following years they suggest growth rates of around 0.5 % per year which would leave Bogotá with around 13.2 million inhabitants by 2090. (Cristancho and Triana, 2018) The annual population growth rate for Cundinamarca was of 1.5 % for the years of 2015-2020. (DANE, 2005) However, it can be expected to drop in the following decades. With an annual growth rate of 1 % up to 2050 and 0.5 % up to 2090 the population for the rest of the catchment excluding the city of Bogotá would be roughly 1.95 million in 2050 and 2.34 million in 2090. This makes a projected population of 13 million for period 1 of 2040-2059 and of 15.5 million for period 2 of 2080-2099.
This leads to a potential increase in the domestic demand. Assuming a proportional increase in the domestic demand depending on the population size the annual domestic demand

would increase from 74.2 million m^3 to 97.4 million m^3 for period 1 and to 116.1 million m^3 for period 2.

Together this results in a change from an annual water demand of 1075.5 million m^3 to a total annual demand of 1350.5 million m^3 for the first and of 1369.2 million m^3 for the second period. These are increases for the total demand of around 25.5 % and 27.5 % for the first and second projection periods.

As the national water study states, the water demand in Colombia increased by 5 % between 2012 and 2016, which results in an annual increase of 1.25 % for the same period. (IDEAM, 2019) Assuming this tendency is also true for the catchment of the Bogotá river and keeps persisting for the next two decades before the growth in the demand stops, the total water demand will also be around 25 % higher by 2040 and for the rest of the century.

Table 4 gives an overview over the projected monthly and annual hydrological balances in the Bogotá river catchment for the scenarios RCP 4.5 and RCP 8.5 and for the time periods 1 (2040-2059) and 2 (2080-2099) based on climate data from the two models CCSM4 and ESM-MPI-MR. Detailed tables with adjusted values for precipitation, evapotranspiration, return flow and demand according to the different projections can be found in **Annex 3**.

Table 4: Monthly and annual values for the hydrological balance in the total Bogotá river catchment calculated according to data from CCSM4 and MPI-ESM-MR for RCP 4.5 and 8.5 during period 1 (2040-2059) and 2 (2080-2099).

Projected hydrological balances [Mm3] for the Bogotá river catchment									
Month	**Hist.**	**RCP 4.5 p.1**		**RCP 4.5 p2**		**RCP 8.5 p1**		**RCP 8.5 p2**	
	calc.	**CCSM4**	**MPI-ESM**	**CCSM4**	**MPI-ESM**	**CCSM4**	**MPI-ESM**	**CCSM4**	**MPI-ESM**
Jan	-38.33	-57.38	-37.17	-68.38	-48.98	-50.24	-129.16	-142.86	-217.12
Feb	12.37	32.72	42.07	-18.08	-62.97	4.10	-24.46	-110.31	-138.25
Mar	78.69	-18.58	7.83	11.37	-31.78	42.89	-46.69	-55.65	-98.35
Apr	203.06	257.69	164.15	190.95	127.66	157.32	178.25	81.31	145.54
May	180.04	216.19	175.26	223.87	194.26	170.65	105.49	203.10	207.08
Jun	81.49	110.26	29.02	121.03	62.36	88.46	52.90	132.05	101.40
Jul	63.75	139.49	61.22	148.70	92.17	109.90	25.00	123.38	-0.74
Aug	31.30	17.43	-31.47	63.23	27.10	13.16	-25.45	-26.45	-72.79
Sep	37.66	15.83	6.58	-15.81	-11.15	13.68	-64.30	-65.26	-122.43
Oct	199.01	287.28	181.91	315.95	190.82	183.56	244.98	116.32	166.72
Nov	163.12	172.58	209.83	35.48	221.92	149.05	200.79	-5.98	330.92
Dec	26.49	-35.38	-32.90	-42.95	-16.83	-103.71	6.94	-93.03	-164.49
Annual	**1038.65**	**1138.14**	**776.33**	**965.36**	**744.58**	**778.81**	**524.29**	**156.62**	**137.51**

The annual hydrological balance is positive for all projections. As CCSM4 projects higher precipitation increases, the balances based on its data are higher. In both periods for RCP 4.5 it suggests balances that are within ±9 % changes from the current volume. The balances based on MPI-ESM-MR in the first and second period for RCP 4.5, however, decrease by 25 % and 28 %. For the first period of RCP 8.5 the annual balance for MPI-ESM-MR decreases by 50 %. And in the second period of RCP 8.5 the balance projected by CCSM4 and MPI-ESM-MR decrease by even 85 % and 87 %.

While all of the projected annual balances are above zero, all projections show some months with negative hydrological balances. The months of the dry season January and December show negative or almost negative balances for all scenarios and time periods. The months of the wet seasons April-June and November-October show positive or almost positive balances for all scenarios and time periods. The months February, March, August and September show more negative balances for the second projection period.

3.2.4 Discussion

As all the annual hydrological balances are positive, the negative monthly balances pose no problem as long as the total annual water volume can be redistributed within the annual cycle. The Bogotá river catchment is strongly regulated and counts with reservoir systems of a total capacity of 1196.45 million m^3. (Acueducto de Bogotá, 2013) This is slightly less than the total annual demand projected for the second period (1369.23 million m^3), but it is enough to store 618 million m^3 water, which is the consecutively accumulated negative balance for December-March in the worst scenario, as well as to store 814 million m^3, which is the accumulated negative balance for the whole year in the worst scenario. While the total retention capacity of the reservoir system may be big enough to assure the storage of the lacking water in dry months, the capacity of the water release and transportation system might become critical. The Tibitoc, Chingaza and La Regadera systems together have a maximum flow capacity of around 21 m^3/s of which 15 m^3/s are currently used. (Acueducto de Bogotá, 2013) This is a monthly potential of 54.4-56.2 million m^3 and a currently used volume of 38.9-40.2 million m^3 that could be added in the months of negative water balance. This is too low for at least one month in all of the future balance projections except for the first period in RCP 4.5 by MPI-ESM-MR.
As seen when comparing the calculated and the observed monthly balances, the calculated negative monthly balances might be overestimated as the calculated monthly distribution is not completely trustworthy. Regardless, it highlights the importance of intra-annual redistribution of hydrological resources. This is further underlined by the fact that at the current moment the hydrological resources are already quite strongly redistributed. Looking at the annual figures based on the ERAs, the hydrological balance is positive for the total catchment of the Bogotá river as well as for the upper, the mid and the lower sub-catchments separately. However, on a monthly scale the mid catchment of the Bogotá river shows negative water balances for the months of January (-32.7 Mio. m3), February (-18.7 Mio. m3), July (-2.5 Mio. m3), August (-11.7 Mio. m3) and September (-3.5 Mio. m3). Hence, while in the total of the Bogotá river catchment, redistribution may not be visible, between the sub-catchments it is already strongly necessary. It is highly probable that adaptations have to be made in the face of temporal inaccessibility of hydrological resources. Especially on a local scale, the need to store water in reservoirs or to economize water in dry periods can be expected.

The projections made in this chapter are based on a series of assumptions and subject to significant uncertainties. The two models CCSM4 and MPI-ESM-MR present relatively big differences in their temperature and precipitation projections. The projections of the future evapotranspiration are based on estimated values for minimum and maximum temperature and the assumption of no changes in the relative humidity of the air. Also, two estimated factors are used to convert the potential evapotranspiration into the real evapotranspiration. Lastly, the projections do not consider that the part of the supply that is transferred from the Orinoco basin through the regulation systems maybe subject to changes in precipitation different from the ones projected for the Bogotá river catchment.

To make projections about the future demand, estimations were made about the future growth in agriculture and about the demographic development. Due to a lack of Colombian census data - the most recent complete population numbers were published in 2005 (DANE, 2005), while the new ones are expected for the second quarter of 2020 - the population projections for Bogotá and Cundinamarca are outdated. Adding to this, economic projections for the development of the agriculture are very difficult to make.
According to the calculations, the demand increases by about 300 million m^3 per year. The precipitation increases by 350-800 million m^3 per year and the evapotranspiration by 300-1500 million m^3 per year. Thus, changes in the projections of the evapotranspiration may have quite a big influence on the values of the hydrological balance. This is of special importance considering that the projected evapotranspiration is a value with a relatively high uncertainty, due to the assumptions that were made in its calculation. The uncertainty of the changes in demand are of less importance as they are of smaller magnitude than the precipitation changes.
The analysis of hydrological data for the Bogotá river catchment and its sub-catchment was further complicated as there is only limited documentation of the data bases used and the calculations made by the regional water evaluations (ERA). Data sources often cannot be tracked back, and the data is regularly outdated or incomplete.

It is also important to mention that only the direct impact of climate change on the hydrological resources was considered. However, the water availability can be expected to be further affected by indirect impacts of climate change. The páramo ecosystem plays a fundamental role in the capture, retention, storage and regulation of the hydrological resources (Van der Hammen *et al.*, 2002; Hofstede *et al.*, 2014) and is the major water provider for the Andean highlands of Colombia (Buytaert *et al.*, 2006). According to Buytaert *et al.* (2006) Bogotá almost exclusively uses water from the páramo. As páramo areas are to be expected to shrink due to climate change, the availability of hydrological resources in the northern Andes will most probably find itself strongly affected. (IDEAM, 2001; WWF *et al.*, 2010) Further impacts on páramos are caused by the effects of livestock farming (e.g. pasturing, trampling or fire clearing) and the planting of pine or eucalyptus trees for example, which leads to the compaction and drying out of soils and the inhibition of the water retention and filtration in the ecosystem. (Van der Hammen *et al.*, 2002; Buytaert *et al.*, 2006) Livestock farming and agriculture as well as industrial and domestic activities also lead to the contamination of water sources. (IDEAM, 2019) As the water treatment capacity in the Bogotá river catchment is limited, pollution may additionally affect the availability of hydrological resources.

In conclusion it must be said that the used approach is very simplified firstly, and that it is almost impossible to make precise decisions based on projections that include so many sources of uncertainty secondly. Nonetheless it can help to look at such simplified and uncertain calculations to gain an understanding of the system functioning and the big picture changes. In this case it can be stated that for a big range of projections in the hydrological resource system there will most probably be sufficient water supply for certain periods of the year, but water shortages for other periods of the year, and that the regulation and intra-annual as well as intra-regional redistribution of water will be fundamental to cope with this situation. In addition to this it will be essential to protect ecosystems that provide water regulating and provisioning services and to avoid the contamination of hydrological resources.

3.3 Climate change impacts on the climate corridors for agricultural cultivation

In order to assess the impacts of climate change on the agroclimatic potential of the department of Cundinamarca, the projected climate changes were used to analyse the relation between the future climate and the climate corridors crops can be cultivated in. In the first part of this chapter the methodological approach to the assessment is explained. The second part contains the results that are discussed in the third part.

3.3.1 Method

The main agriculture-related activity in Cundinamarca is livestock farming for milk and meat production. Besides livestock, the crops of major importance in Cundinamarca are potatoes, panela sugar cane, coffee, and traditional corn. In 2017 potatoes contributed more than 25 % to the agricultural production and together with sugar cane (~15 %), coffee (~13 %) and traditional corn (~7 %) they sum up to ~60 % of the cultivated crops in Cundinamarca. (Minagricultura, 2017)

In order to assess the impacts of climate change on the agroclimatic potential of the department of Cundinamarca it was analysed if the climatic needs of those four main crops would be met in the scope of projected future climatic conditions. The work follows the approach of climate corridors by Orlowsky *et al.* (2017) establishing crop-specific ranges for climatic conditions required for agricultural cultivation. The ranges of climate corridors are compared with present and future projected climate conditions in order to analyse the suitability of a region for the cultivation of a certain crop. Climate change projections for the CCSM4 and the MPI-ESM-MR for the main production regions of the respective crops are presented below together with the temperature and precipitation ranges in which the crops can grow. The climate data points to be included for the projections were chosen based on all the points being inside the main area of production of the respective crops. The projected future climate data was averaged over different sectors in Cundinamarca, titled “Central Cundinamarca” for the potato sector, “North West Cundinamarca” for the sugar cane sector, “Western Cundinamarca” for the coffee sector and “Cundinamarca” for the spread-out corn cultivation areas. The information on the crops’ agroclimatic needs was mainly taken from sources of the Food and Agriculture Organisation of the United Nations (FAO). The optimum range of the climate conditions is the range in which a crop grows best with the highest output for harvest. The absolute range of the climate conditions is the range within a crop can still grow but may present lower growth rates and cause harvest losses. Outside the absolute range the crop stops developing or dies.

3.3.2 Results

While potatoes are cultivated in the centre of Cundinamarca, mainly in the Bogotá Savannah, sugar cane and coffee are grown in the Western and Eastern part of Cundinamarca with the highest numbers in the North-East, and traditional corn is cultivated almost all over the department (see **Figure 19**). (Minagricultura, 2017)

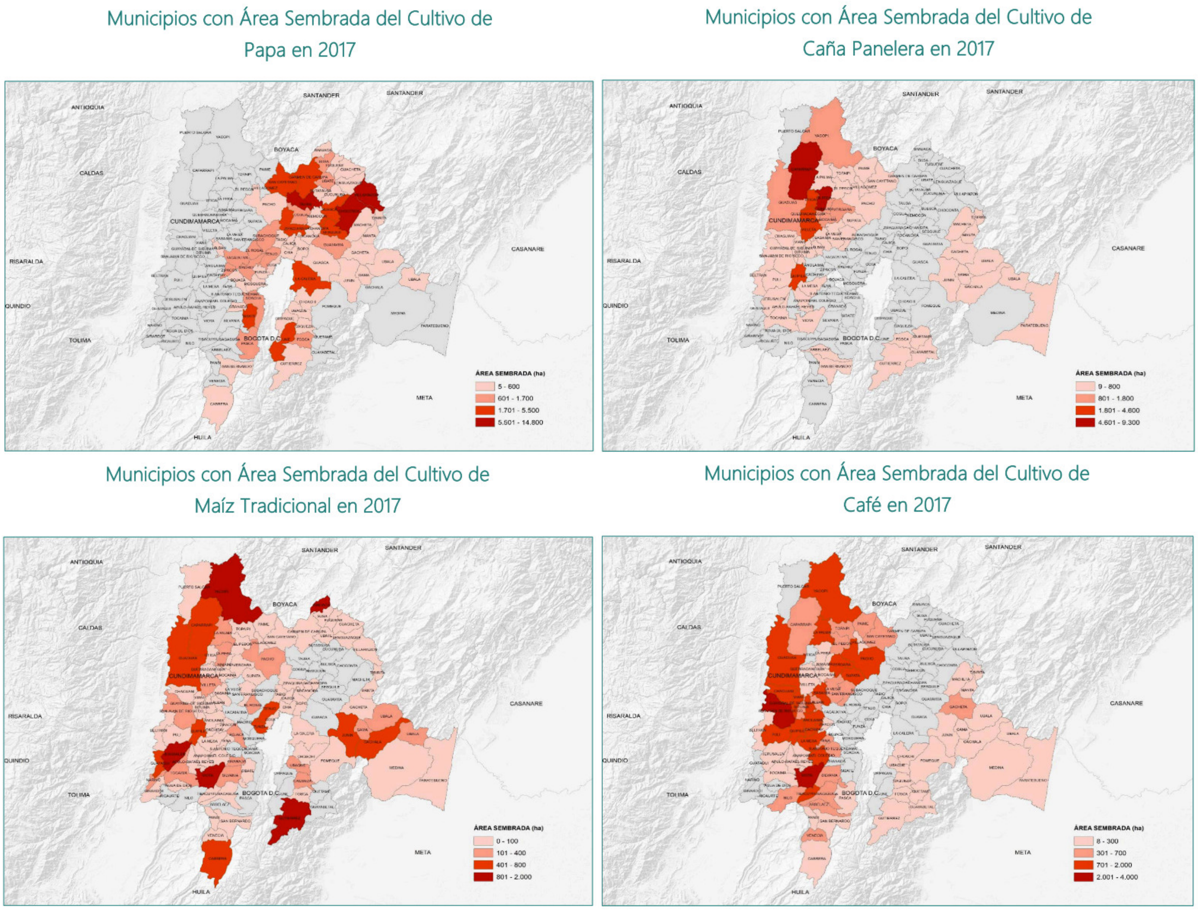


***Figure 19**: Areas of cultivation (increasing with intensity of colouring) for the crops of potato (top left), panela sugar cane (top right), traditional corn (bottom left) and coffee (bottom right) in the department of Cundinamarca for the year 2017. Source: Minagricultura, 2017*

Potatoes have an optimal temperature range for growth of 15-25°C and can still grow in an absolute temperature range of 10-30°C. They grow best in areas with an annual precipitation of 500-800 mm and can grow in an absolute precipitation range of 250-2000 mm/year. (FAO, no date d) The cultivation takes three to four months depending on temperature and solar radiation, and the sowing can be done all year round in high altitude subtropical places.

The current monthly mean temperature in central Cundinamarca is below the optimal but inside the absolute temperature range for potato cultivation (see **Figure 20**). This means that the current average temperature over the average area where most of the potatoes are cultivated is tendentially too low for optimal potato cultivation. As for all future projections the temperature increases, the conditions for all of them move closer to the optimal temperature range for potato cultivation. The projections for RCP 8.5 in the second period are for both models the only ones that are completely inside the optimal range.

The current monthly mean precipitation is above the optimal range for all months except for January and February, but within the absolute range for all months. Future precipitation projections for both models exceed the absolute range during several months for both scenarios and time periods except for the projection for RCP 8.5 in period 1 by CCSM4. For the second period of both RCPs and models, precipitations are projected to be furthest above the absolute precipitation range. The projected periods of the year that present precipitations too high for potato cultivation are especially the months of the rainy seasons, namely April-June and October-November.

For most projections, potato cultivation will thus become limited to the months of November-April. The dry season of July-September might become too short for potato cultivation, as potatoes need 3-4 months growing time before they can be harvested.

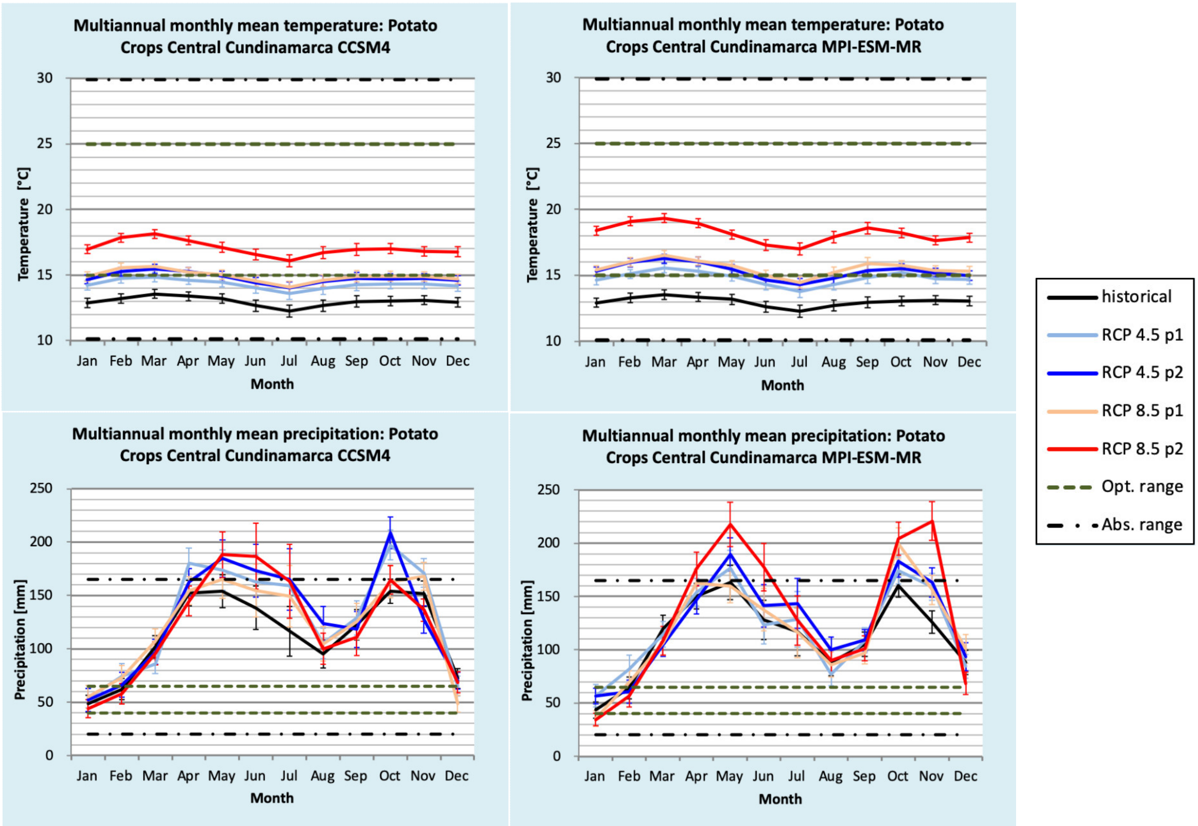


Figure 20*: Historical and projected monthly mean temperature (top) and precipitation (bottom) for central Cundinamarca by the models CCSM4 (left) and MPI-ESM-MR (right) for the periods 2040-2059 (p1) and 2080-2099 (p2) and the representative concentration pathways RCP 4.5 and RCP 8.5 represented as solid lines with their standard deviation together with the optimal and absolute climate corridor ranges for the potato crop.*

Sugar cane grows best in the optimal temperature range of 24-37°C and can still grow in a temperature range of 15-41°C. Its optimal precipitation range is of 1500-2000 mm per year and its absolute precipitation range of 1000-5000 mm per year. It is cultivated all year round and grows 9 to 24 months. (FAO, no date c)

The current monthly mean temperature in north-western Cundinamarca is slightly below the optimal but inside the absolute temperature range for panela sugar cane cultivation (see **Figure 21**). This means that the current average temperature over the area where most of the sugar cane is cultivated is slightly too low for optimal cultivation. As for all future projections the temperature increases, the conditions for all of them move inside the optimal temperature range for sugar cane cultivation.

The current monthly mean precipitation is outside the optimal range for all months, but within the absolute range for all months except for January, where precipitation levels are slightly too low. This general tendency does not change for any future precipitation projections. Projections for both models stay outside the optimal range but inside the absolute range for most months of the year for both models, both RCPs and both time periods.

In January precipitation keeps being too low for even the absolute range except for the first period of RCP 8.5 in CCSM4 and the first and second period of RCP 4.5 in MPI-ESM-MR. In the second period of RCP 8.5 for MPI-ESM-MR the precipitation almost reaches the maximum limit of the absolute precipitation range during the first annual rainy season in the month of

May. For period 1 of RCP 4.5 and period 2 of RCP 8.5 of MPI-ESM-MR the precipitation is within the optimal range in December. For period 1 of RCP 4.5 it is also within the optimal range in February and August. For CCSM4 precipitation is within the optimal range only during March for period 1 of RCP 4.5.

As the projected precipitation maximum and minimum peaks are becoming more pronounced, sugar cane growth might become more limited during the months of the rainy season. This is of importance because the sugar cane growing period before harvest takes up to two years.

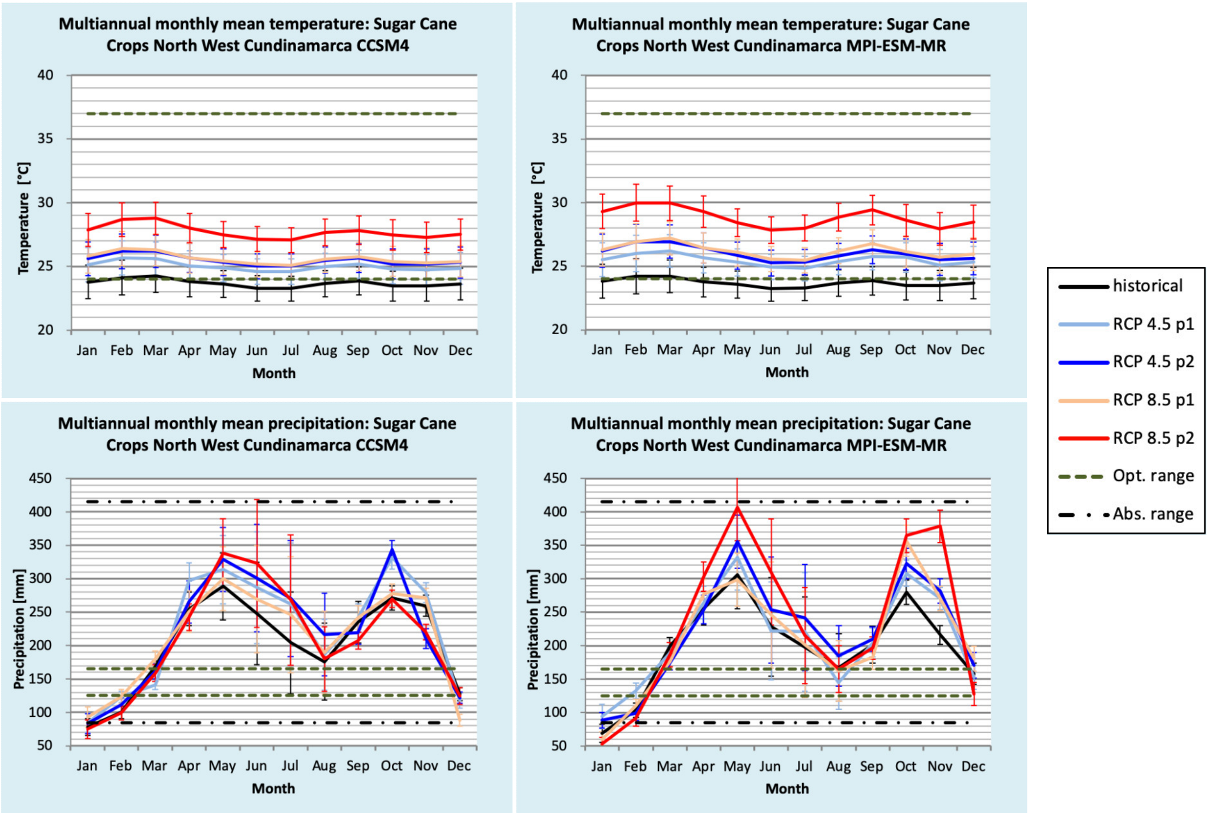


***Figure 21**: Historical and projected monthly mean temperature (top) and precipitation (bottom) for central Cundinamarca by the models CCSM4 (left) and MPI-ESM-MR (right) for the periods 2040-2059 (p1) and 2080-2099 (p2) and the representative concentration pathways RCP 4.5 and RCP 8.5 represented as solid lines with their standard deviation together with the optimal and absolute climate corridor ranges for the sugar cane crop.*

Coffee has an optimal temperature range of 14-28°C and can still grow in an absolute temperature range of 10-34°C. It has an optimal precipitation range of 1400-2300 mm per year and an absolute precipitation range of 750-4200 mm per year. The precipitation should best be equally distributed over the year. The crop cycle of coffee takes 7-11 months with the main coffee harvest in Colombia being from March through June and the secondary coffee harvest being in October and November. (FAO, no date a; Cenicafé, 2016)

The current monthly mean temperature in western Cundinamarca is within the optimal temperature range for coffee cultivation (see **Figure 22**). For all future projections, temperature stays in the optimal range except for the second period in RCP 8.5 based on MPI-ESM-MR. For this projection the temperature exceeds the maximum limit of the optimal range in the months of January-April and August-September by no more than 1°C but stays within the absolute temperature range.

The current monthly mean precipitation is within the optimal range during the months of March, June, July and September. It is too low in the months of the dry period in December-

February and August, and too high for the months of the wet period in April-May and October-November. For these months it is within the absolute temperature range. The precipitation stays within the absolute range for all scenarios and periods except for the second period of RCP 8.5 in MPI-ESM-MR for which the absolute maximum is exceeded in November and reached in May and October, and the absolute minimum is reached in January. While in the current climate situation, the precipitation in August is slightly too low for the optimum range, in all future projections for CCSM4 and in the second period for both scenarios in MPI-ESM-MR it is in the optimal precipitation range. The months that already present precipitation too high for the optimal range in the current situation, move away even further from the optimal range in the future projections.
The temperature changes seem to be of no direct limitation to the cultivation of coffee. The projected precipitation changes will limit the cultivation of coffee only for the case of the second period for RCP 8.5 by MPI-ESM-MR.

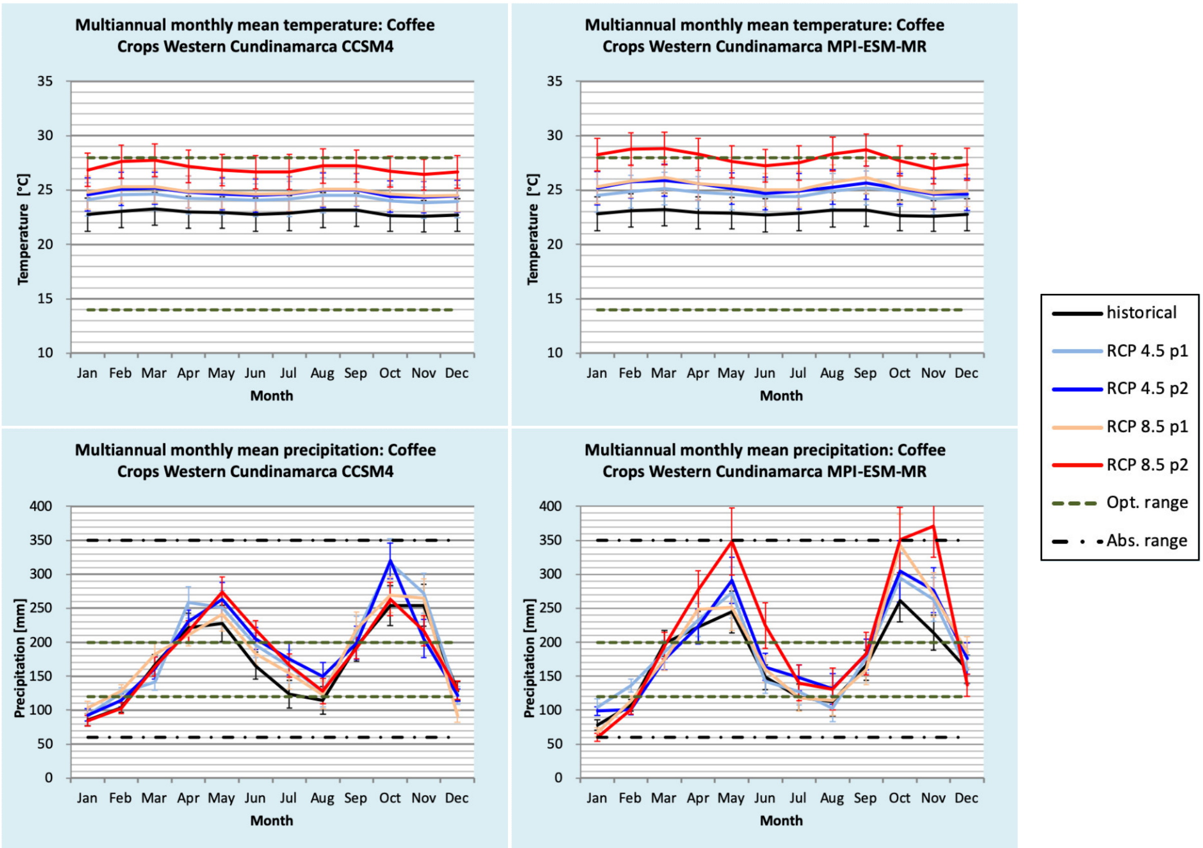


***Figure 22**: Historical and projected monthly mean temperature (top) and precipitation (bottom) for central Cundinamarca by the models CCSM4 (left) and MPI-ESM-MR (right) for the periods 2040-2059 (p1) and 2080-2099 (p2) and the representative concentration pathways RCP 4.5 and RCP 8.5 represented as solid lines with their standard deviation together with the optimal and absolute climate corridor ranges for the coffee crop.*

Traditional corn has an optimal temperature range of 18-33°C and can still grow in an absolute temperature range of 10-47°C. It has an optimal precipitation range of 600-1200 mm per year and an absolute precipitation range of 400-1800 mm per year. (FAO, no date b) It's crop cycle is 2-12 months in general and lasts from February until September in Colombia with a growing season from April through July. (FAO, 2018)

The current monthly mean temperature averaged over the department of Cundinamarca is within the optimal temperature range for corn cultivation (see **Figure 23**). For all future projections, temperature stays in the optimal range and even moves away from the lower

limit further to the centre of the optimum range.
The current monthly mean precipitation is in the optimal range only for January and even exceeds the absolute maximum for the wet season months of March-June and September-November. More than half of the year is thus too wet for corn cultivation. This tendency is aggravated in all projected scenarios as the maximum precipitation peaks increase for all periods and RCPs. The month of July that is still within the absolute range under the present climate, is projected to exceed the absolute range for all projections by CCSM4 and for the second period for both RCPs by MPI-ESM-MR. For the second period of RCP 4.5 in CCSM4 all months except for December-February exceed the maximum limit of the absolute range.
While the projected development of the temperature averaged over the department of Cundinamarca may be expected to be beneficial or have no consequences for corn in terms of its climate corridor, the projected precipitation values move almost completely out of the absolute temperature range of the climate corridor for corn.

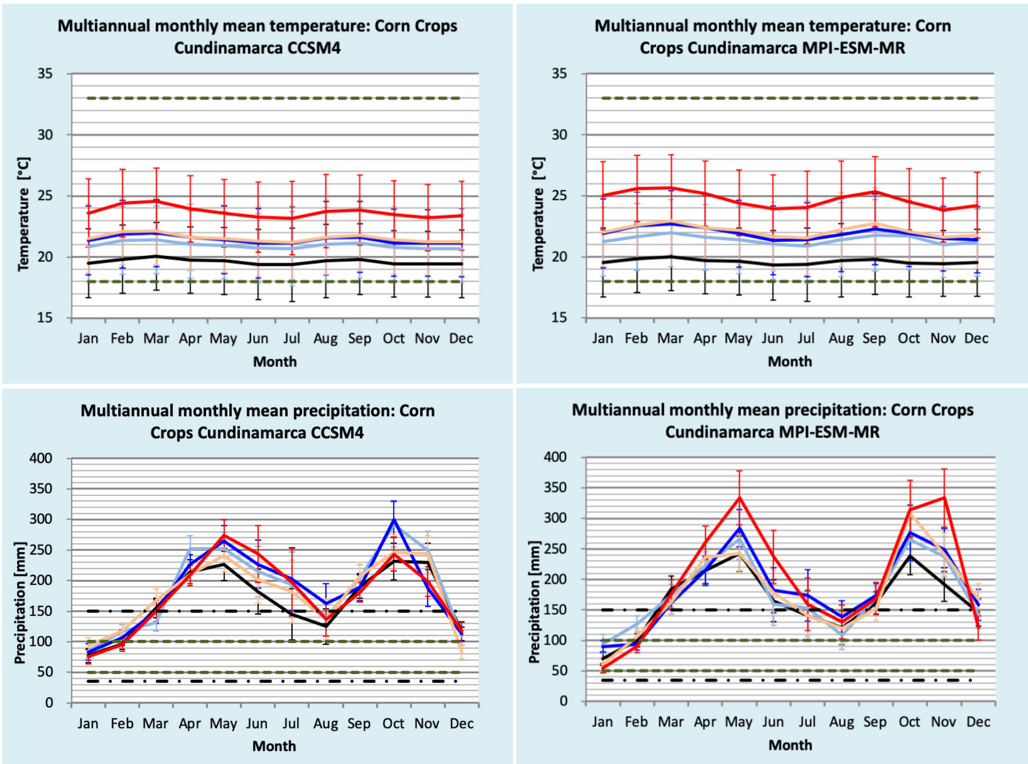


__Figure 23__: Historical and projected monthly mean temperature (top) and precipitation (bottom) for central Cundinamarca by the models CCSM4 (left) and MPI-ESM-MR (right) for the periods 2040-2059 (p1) and 2080-2099 (p2) and the representative concentration pathways RCP 4.5 and RCP 8.5 represented as solid lines with their standard deviation together with the optimal and absolute climate corridor ranges for the traditional corn crop.

3.3.3 Discussion

Seemingly an increase in temperature (for all future temperature projections) will benefit the potato cultivation in Cundinamarca. According to all of the future precipitation projections the potato cultivation will become limited to the months of November-April and potentially July-September as the precipitation will be too high during the rest of the year. However, since for potato cultivation, the temperature is the main limitation (FAO, no date d) the general projected climatic situation seems rather positive for potato cultivation. Also, higher temperatures may lead to higher evapotranspiration and thus to a larger plat water demand, and increased precipitation volumes may be an advantage in that case.

For the sugar cane cultivation in Cundinamarca too, the temperature increase expected by all future projections seem to present a benefit. According to some of the future precipitation projections sugar cane cultivation might become slightly limited during the months of the rainy season as the precipitation approaches the maximum of the absolute range and in January of the dry season when precipitation is slightly below the minimum of the absolute range. These short periods of water scarcity and potential water excess are of special importance as the growing period of sugar cane can take from 9 months up to two years. However, the current monthly precipitation over the average area of sugar cane cultivation is already too low in January and this does not seem to be a problem. It is thus questionable if it will be a limiting factor in future.

The coffee cultivation seems to find itself limited only by the precipitation excess in the scenario of the second period for RCP 8.5 by MPI-ESM-MR. As the coffee crop cycle takes 7-11 months, in this scenario the month of November with exceeding precipitations could be avoided by cultivating from December-October. However, the main coffee harvest in Colombia is from March through June, meaning that the growing period starts around September and could be affected by the excessive precipitations in November. The secondary harvest is in October and November. Hence, in such a case it might be necessary to switch to relying only on the secondary harvest in October and November and adapt the harvesting time in order to have no months with excessive precipitation during the growth season. Generally, for coffee to grow best, precipitation should be equally distributed over the year. As for all the future precipitation projections the maximum peaks become more pronounced and the annual precipitation distributes less evenly, future climate can be expected to be rather disadvantageous for coffee cultivation. In addition to this, climate change has been shown to be contributing to the propagation of different pests and diseases that affect the cultivation of coffee. For instance, Avelino *et al.* (2015) investigated the causes of the coffee rust epidemics in Colombia and Central America between 2008 and 2013. They state that the optimal range for coffee rust development is 21-25°C for germination and 22-28°C for the latency. The current temperature as well as all of the future temperature projections for the major coffee growing region in Cundinamarca are within this optimal range for coffee rust. Avelino *et al.* (2015) also state that rainfall distribution is an important factor in coffee rust epidemics and that an earlier start of the rainy season most probably induced the coffee rust epidemic in Nicaragua in 2012. As the precipitation pattern is also shown to slightly shift towards earlier months of the year in some projections, this may be of additional importance for Colombia. According to Jaramillo *et al.* (2009) the most important pest of coffee throughout the world, the coffee berry borer, develops fastest at a temperature of 27-30°C. This means that for the case of Cundinamarca the pest pressure can be expected to increase under future climate conditions.

The projected increase of the temperature averaged over the department of Cundinamarca may be expected to be beneficial or have no consequences for corn in terms of its climate corridor. The precipitation on the other hand is projected to move almost completely out of the absolute temperature range of the climate corridor for most scenarios. However, already in the current situation the precipitation seems to be too high for the cultivation of corn during most of the year. The crop cycle can be 2-12 months and generally lasts from February until September, which means that it is harvested before the second rainy season. 5 of these 8 months, namely March-June and September, present too much precipitation for corn cultivation. These values may be explained by the fact that an average of the climate for the whole department of Cundinamarca was taken to make the projections. This was done because corn is cultivated in municipalities all over the department (see **Figure 19**). However,

the average precipitation over the complete department is probably not an optimal representation of the precipitation in corn growing areas. It can be assumed that the differences in the local distribution of corn as well as in the distribution of precipitation is quite big. Specific municipalities of smaller surface would have to be evaluated in order to get representative current climate values and to be able to make future climate projections valid for the corn growing region.
It is also important to mention that the presented projections are based on monthly mean values and do not consider daily or even monthly maximum or minimum values. This may be useful to capture the general tendencies of the temperature and precipitation, but it does not include extremes that may also be limiting for crop cultivation.

In conclusion, it is important to note that while the direct impacts of temperature and precipitation clearly are limiting factors for agricultural production, they are not the only ones. Increasing temperatures themselves may not be a problem for some of the above-mentioned crops. However, they may lead to other effects that may be limiting to the success of a crop – so called cascading effects. Hence, even if the climatic situation is still within the range of the suggested climate corridor, the changes in temperature and precipitation might still have impacts that have consequences for crop cultivation. In the case of coffee cultivation for example, the higher temperatures and changes in the precipitation distribution may not exceed the climate corridor for the crop, but it may benefit the prevalence of diseases like coffee rust and pests like the coffee berry borer and the leaf miner. (Federación Nacional de Cafeteros de Colombia, 2010) High monthly precipitation volumes, as another example, may not directly be a problem for certain crops with climate corridors of large absolute precipitation ranges, but they may lead to soil erosion through intense precipitation events. If is therefore important to consider that even if a certain crop can theoretically still be cultivated in the mentioned sectors when looking at the sector's agroclimatic potential according to the crop's climate corridor, climate change may cause other impacts that end up limiting the cultivation of said crop.
This is of special importance, considering that due to problems linked to water scarcity, drainage, soil erosion and low fertility, only 3 % of the areas of the CAR hold an aptitude for intensive agricultural systems, but that roughly 60 % of the territory is already used for cultivation and livestock farming, causing a strong overexploitation of the soil. (CAR, 2016) Thus, beside potential climatic limitations of the agriculture, factors like unapt and overexploited soils can also be expected to be of increasing limitation in the future.

4 Climate change adaptation

This chapter addresses the scope of climate change adaptation in Colombia and especially in the department of Cundinamarca. The following three sections approach climate change adaptation on three different levels.

1. The first section addresses the level of national and regional strategies and guidelines of climate change adaptation.
2. The second section addresses the level of the regional adaptation measures, and specifically the analysis of adaptation measures and projects in Cundinamarca.
3. And the third section addresses the level of evaluation of implementation and follow-up of adaptation measures on a local scale.

4.1 National and Regional strategies and guidelines to climate change adaptation

This section consists of a summary and explanation of the institutional and legal environment of the most relevant organs related to and concerned with the matter of climate change adaptation. It contains subchapters about the historical development of climate change adaptation in Colombia, about the country´s climate change relevant institutions, its relevant frameworks and planning documents, and its relevant plans and projects.

4.1.1 Historical development

Colombia's approbation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 set the formal start of the country's engagement in climate change mitigation and adaptation (UNDP and IDEAM, 2010a). In The National Strategy for Sales of Environmental Services of Climate Change Mitigation (Estrategia Nacional para la Venta de Servicios Ambientales de Mitigación de Cambio Climático) published in 2003 by the National Council of Economic and Social Politics (CONPES), the country's most climate change sensitive ecosystems were identified and the first adaptation measures were formulated (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017). Even before that in 1993, the National Environmental System (SINA) was organized as an ensemble of orientations, norms, activities, resources, programs and institutions that allow the management and conservation of the environment and its natural resources. It creates the politics and strategies of territorial law and environmental monitoring, while addressing the goals of vulnerability reduction, increase of adaptive capacity to climate change, conservation, innovation and efficient use of natural resources and the improvement of environmental quality. It is directed by the Ministry of Environment and Sustainable Development (MADS) through the National Agency of Environmental Licences (ANLA), the National Nature Parks (PNN) and the scientific institutes IDEAM, IVAH, INVEMAR, SINCHI and IIAP on a national level. On a regional and local level it is constituted by the Autonomous Regional Corporations, by the environmental authorities of the main cities, the departments, districts and municipalities. (República de Colombia and MADS, 2015) All these institutions make up the environment of climate change issues in present day Colombia. In 2016 the National Climate Change System (SISCLIMA) was established through a decree. (MADS, 2016a) It is the ensemble of public and private entities, policies, norms, processes, resources, plans, strategies, tools, mechanisms and information that contribute to climate change mitigation and adaptation. The SISCLIMA pushes the conformation of regional climate change nodes that are to promote, support and accompany the implementation of strategic policies, plans, projects and actions to climate change on a regional basis to the present day. (MADS, 2016a)

4.1.2 Relevant institutions

Colombia's institutional environment consists of centralized, decentralized and autonomous organs, of which the most important ones to the scope of climate change adaptation are listed as follows:

Centralized institutions:

- Ministry of Environment and Sustainable Development (MADS)
- National Agency of Environmental Licences (ANLA)
- National Nature Parks (PNN)

Decentralized institutions:

- National Environmental Fund (FONAM)
- Institute for Hydrology, Meteorology and Environmental Studies (IDEAM)
- Research Institute on Biological Resources Alexander Von Humboldt (IVAH)
- Institute of Marine and Coastal Research (INVEMAR)
- Amazonian Institute of Scientific Research (SINCHI)
- Environmental Research Institute of the Pacific (IIAP)

Autonomous institutions:

- Regional Autonomous Corporations of Sustainable Development (CARs)

The Ministry of Environment and Sustainable Development (MADS) is the public entity in charge of defining national environmental politics and of promoting recovery, conservation, protection, management, code, use and exploitation of renewable natural resources in order to secure a sustainable development. The National Agency of Environmental Licences (ANLA) makes sure that the evaluation, monitoring and control of projects and activities subjected to licencing, permits or other environmental processes are conducted transparently, objectively and appropriately. And the National Nature Parks (PNN) manage the areas of the national nature park system and coordinate the National System for Protected Areas (SINAP) in order to conserve biological and ecosystem diversity.

The research institutes IDEAM, IVAH, INVEMAR, SINCHI and IIAP are decentralized institutions that act as scientific support that creates knowledge and coordinates research.

And the Autonomous Regional Corporations of Sustainable Development are the departmental corporations in charge of the execution and implementation of environmental politics, programs and projects defined by the Ministry of Environment and Sustainable Development (MADS). Each of the Country's departments has a Regional Autonomous Corporation which in Cundinamarca is the Regional Autonomous Corporation of Cundinamarca (CAR). (República de Colombia and MADS, 2015)

4.1.3 Relevant frameworks and documents

Some of the relevant reports and documents and their importance in the scope of climate change adaptation in Colombia are presented in this sub-chapter. There are general documents that constitute the structural base of national and regional organization and administration, as well as documents specific to environmental matters, that include issues of climate change and adaptation. In both categories there are documents valid on national scale as well as documents valid on regional scale.

General planning documents:

- Bicentennial Vision Colombia
- National Development Plans (PND)
- Regional Development Plan of Cundinamarca
- Sectorial Strategy Plans (PES)
- Watershed Regulation and Management Plans (POMCA)
- Regional Environmental Management Plans (PGAR)

The Bicentennial Vision Colombia as well as the National Development Plans (PND) are elaborated by the National Department of Planning (DNP), while the Sectorial Strategy Plan (PES) for the sector of environment and sustainable development are prepared by the Ministry of Environment and Sustainable Development (MADS), and the Regional Development Plan of Cundinamarca, the Regional Environmental Management Plans (PGAR) as well as the Watershed Regulation and Management Plans (POMCA) are prepared by the Regional Autonomous Corporations (CAR).

Visión Colombia II Centenario

The Bicentennial Vision Colombia is a summarizing document about Colombia's past and present and a starting point that aims at opening up a discussion about the path Colombia is to choose in its future and the society it wants to build for 2019. It discusses the country's fundamental long-term goals in politics, academia, development, social issues and many more. The document includes a chapter for sustainable development with the vision of a Colombia that by 2019 achieves an economic and social development based on sustainable use of the environment, natural resources, biodiversity and its services, that incorporates the participation of the society in its matters. Environmental management should thus be based on efficiency, effectiveness, equity, transparency, participation, diversity, complementarity and sustainability. It underlines the necessity to protect environmental conservation areas in order to avoid that those areas offer a stage for illegal cultivation, terrorism, and chaotic and destructive colonisation of tropical wet forest and páramos. It also mentions the strong relation between the environment and economic competitiveness as well as the strategic importance of forest ecosystems thanks to their biodiversity and resources. It recognizes the protection of biodiversity, forests, páramos, water and air as one of the country's main challenges. Based on those considerations the Bicentennial Vision of Colombia elaborated the following environmental objectives including soils, ecosystems, hydrological resources, atmospheric resources, solid waste, and hazard risk management:

Soil and ecosystems:

- Implementation of strategies, actions and mechanisms for the prevention, recuperation and detention of soil degradation, with focus on regional action plans
- Maintenance the country's forest coverage
- Conservation of biodiversity and ecosystems through a strengthening of the National System of Protected Areas (SINAP)
- Promotion of sustainable biodiversity use

Hydrological resources:

- Vulnerability reduction of the hydrological supply, and ensuring the water supply for all of the country's settlements
- Promotion of the rational and efficient water use in rural and urban productive sectors

- Achieving that 50 % of environmental laws fulfil regulations and standards

Atmospheric resources:

- Meet the particle standards in all cities and industrial corridors
- Contribute to the reduction of global climate problems and implement technologies of clean production

Solid waste:

- Reduce problems of pollution, environmental risk and health linked to the generation, use, treatment and disposal of hazardous solid waste

Hazard risk management:

- Improve information and early warning systems for hazard prevention and increment risk management information that contributes to the generation of public policy
- Improve hazard risk management through planning tools
- Reduce the state´s fiscal vulnerability in the face of disasters

(DNP, 2006)

The Bicentennial Vision Colombia in this sense suggests measures for environmental health and services, however it does not specifically mention adaptation to climate change. The objectives and strategies it proposes in its sustainable development chapter are concentrated on natural resources and hazard risk management aiming at ecosystem functioning and development planning, but not focused on climate change adaptation.

National Development Plans (PND)

The National Development Plan (PND) 2010-2014 integrated the National Plan of Climate Change Adaptation (PNACC), the Colombian Strategy for Low Carbon Development (ECDBC), the National Strategy for Reducing Emissions from Deforestation and Forest Degradation, and the role of Conservation of Forest Carbon Stocks, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks (ENREDD+), and the Strategy for Financial Protection from Disasters, as national strategies to climate change adaptation. (DNP, 2011b)

The National Development Plan (PND) 2014-2018 pushed the knowledge management of climate change processes and impacts, as well as the development planning for climate change adaptation and introduced strategies for progressing in climate change adaptation (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017). As one of its six central axis it developed the Green Growth Strategy, which focuses on growth that is compatible with climate and suggests climate change mitigation as well as adaptation actions. In terms of adaptation to climate change the Green Growth Strategy concentrates on the reduction of vulnerability to climate change, on the protection, conservation and sustainable use of natural capital and on the improvement of environmental quality. (República de Colombia and MADS, 2015)

The National Development Plan (PND) 2018-2022 concentrates heavily on planning instruments, strategies for complementarity and harmonisation between tools, and the elaboration and evaluation of environmental indices in order to strengthen the country´s sustainability and its resilience to climate change. As some of its main objectives in the scope of resilience, hazard risk management and climate change adaptation it lists the knowledge generation of future risks for development planning, the reassurance of territorial and sectorial joint responsibility in hazard risk management and climate change adaptation, the mobilisation of financing for hazard risk management and climate change adaptation, and an effective disaster management and adapted reconstruction. (DNP, 2019)

Strongly motivated by the damages caused by the La Niña phenomenon of 2010-2011, the **PND 2010-2014** states the necessity of the elaboration of research on climate change adaptation with a focus on studies of identification, pre-investment and structuration of infrastructure and strategic projects. It pushes the consideration of climate change adaptation in national politics through its incorporation in relevant political documents and organisations and underlines the importance of identification and prioritization of climate change adaptation measures through vulnerability analysis. It suggests the establishment of a National Plan of Climate Change Adaptation (PNACC) and sectorial strategies for climate change adaptation in which adaptation measures should be identified. It especially suggests politics that encourage preventive management based on infrastructure in the transportation system and the urban rain water management. (DNP, 2011b)

The big majority of suggested adaptation measures by the **PND 2014-2018** is based on political planning, organization and design of strategies and plans, and directed towards the reduction of vulnerability in different sectors. The PND 2014-2018 mainly suggests the implementation of sectorial politics to ensure climate change adaptation and hazard risk management. It pushes the development of normative instruments as well as the development of management and climate change adaptation plans in different sectors like the waste water treatment sector, the agriculture and livestock sector, the health sector and others, as well as the incorporation of hazard risk management into planning in strategic sectors like the housing, transportation, agriculture, justice and security, and mining and energy sector. It implies the inclusion of climate change in regional planning like the municipal POMCAs and mentions the importance of education and knowledge management in climate change matters. It directs the MADS and IDEAM to strengthen websites as tools to information access, and to design communication, capacitation, sensitisation and formation tools in climate change matters.

It contains a special chapter on the country´s Green Growth Strategy, that is based on sustainable growth and low carbon use, sustainable use of natural resources and improvement of environmental governance, and resilient growth and the reduction of vulnerability to climate change linked hazard risks. Even if the chapter does not name climate change adaptation as one of its main dependencies, many of the suggested developments are named to be fundamental for a well-functioning climate change adaptation.

The objectives of sustainable growth and low carbon use intend to improve environmental performance of productive processes by efficient use of natural resources. Proposed strategies include the concentration of agriculture in areas that are apt for it, livestock farming in silvopastoral systems and an efficient water use in order to improve the soil quality and the water retention, increase the fodder amount and generate income through production of wood, meat and milk. It instructs the organization of sustainable urban drainage systems in the municipal POTs.

The objectives of sustainable use of natural resources and improvement of environmental governance are based on the biodiversity and its ecosystem services that are the base for social and economic activities as well as for climate change adaptation. They intend to maintain the capacity of ecosystems by their conservation, restoration and the reduction of their degradation. One strategy of importance in climate change adaptation is the plan to consolidate a political frame for climate change aiming at its integration into environmental, territorial and sectorial planning. Proposed actions are the articulation of a national plan for climate change adaptation (PNACC), the strengthening of regional capacities and environmental authorities in order to teach identification of adaptation measures based on ecosystems, strengthening the management of information and knowledge in climate change issues through information creation (scientific research), the design and implementation of an agroclimatic early warning system in priority zones, the development of a financing system in climate change matters, the strengthening of CARs, environmental licencing, homogenisation of vocabulary, research, design education strategy, foster participation through education, and an improvement in the interaction between environmental authorities, sectors and territorial entities to reassure compliance with environmental regulation.

The objectives of resilient growth and reduction of vulnerability to climate change associated hazard risks are strongly linked to climate change adaptation. In risk management the main actions suggested are the strengthening of the National System for Disaster Risk Management (SNGRD) orientation and coordination agencies through their incorporation into the national committee of risk management and the formulation, socialization and follow-up of the National Hazard Risk Management Plan (PNGRD). The proposed actions include the monitoring, updating and formulation of hazard risk maps in flooding, flash floods, and volcanoes as well as the incorporation of hazard risk management in POTs of municipalities. (DNP, 2016)

According to the **PND 2018-22** the most important achievements already completed in the process of the former PNDs are the formulation and adoption of the PNGRD and the formulation of the Integral Sectorial and Territorial Climate Change Management Plans (PIGCCS & PIGCCT) so climate change intervention disposes of tools for the orientation of planning and investment processes. The country also counts with formerly modernized hydro-meteorological and environmental monitoring webs.

The PND 2018-22 mentions climate change adaptation to be one of the big topics and challenges that affect Colombia. It mentions challenges and weaknesses in several areas that affect the country´s capacity in adaptation to climate change. Weak coordination between concerned sectors (e.g. UNGRD, MinVivienda and MADS), lacking investment prioritization of disaster risk reducing interventions, lacking mechanisms of follow-up and evaluation to the implementation of adaptation tools, and low effectiveness of interventions at regional scale pose problems to hazard risk management and adaptation to climate change. Low financial allocation in the environmental sector (<0.5 % of national budget over the past years), existence of environmental systems with similar competences (e.g. SINA, SNGRD, SISCLIMA) but no benefits of integration and synergy, weak coordination between national institutions and decentralized execution, often unclear institutional leadership and lacking transparency, weak sectorial and environmental information systems, and illegal activities such as illicit resource extraction and deforestation caused by socio-environmental conflicts hinder the effective operation of environmental institutions.

The plan contains a sustainability chapter that elaborates resilience in the face of climate change and the country's environmental institutions as important factors for a sustainable and climate change adapted Colombia. Similar to the PND 2014-18, it mainly concentrates on planning instruments, strategies for complementarity and harmonisations between tools, and the elaboration and evaluation of environmental indices.

The subchapter about resilience, hazard risk management and climate change adaptation lists as its main objectives the knowledge generation of future risks for decision taking in development planning, the reassurance of territorial and sectorial joint responsibility in hazard risk management and climate change adaptation, the mobilisation of financing for hazard risk management and climate change adaptation, and an effective disaster management and adapted reconstruction. For knowledge generation it suggests the realisation of hazard studies un municipal scale, the development of methodologies for elaboration of exposure and vulnerability, and the implementation of early warning systems. For climate change monitoring and evaluation, it suggests the design and implementation of a climate change information system to display goals, indicators, implementation and evaluation of national progress and it commits to establishing methods of defining medium and long-term national goals in climate change and monitoring of NCD goals according to the UNFCCC lineaments. For joint responsibility in climate change adaptation the PND commits different institutions like the SNGRD, UNGRD, IDEAM, MinVivienda, MinAgricultura, MinAmbiente (MADS), MinHacienda, MinMinas, MinTransporte and MinCIT to participate in the design and implementation of strategies for the implementation of climate change adaptation initiatives in sectors like productive systems of agriculture and livestock farming, the design of transportation infrastructure, and the design of buildings and sanitation infrastructure. The PND suggests the design of a national strategy to strengthen communities in climate change adaptation management, and the implementation of a National Program of Technical Assistance. The DNP states it will formulate tools to promote climate change adaptation in investments projects and that the MADS will direct sectors and environmental authorities in the implementation of climate change adaptation measures in territories, communities or vulnerable ecosystems. The DNP, MinAmbiente, IDEAM and UNGRD will design a public policy to reduce climate variability risks. For the objective of mobilisation of financing the DNP proposes studies to assess the country´s needs in adaptation and the elaboration of prioritization criteria for the financing of projects. It suggests tools of financial protection in the face of disasters in the sectors of agriculture, transportation, energy, water and sanitation infrastructure. For resilient and climate change adapted recovery a strategy for will be formulated, defining coordination tools, management responsibilities and resource management.

The subchapter about environmental institutions mentions as its main objectives the strengthening of institutionality and of regulation of financing in the environmental sector, the strengthening of coordination and articulation mechanisms, the implementation of education and participation strategies for management and monitoring of socio-environmental conflicts caused by access and use of natural resources, and the improvement of information management between different sectors. It is of importance to mention that for the years 2014-2017 74 % of the resources in the environmental sector were destined to hazard management, 20 % were destined to risk reduction, 4 % to governance and only 2 % to research activities. Also, it is worth mentioning that for the years 2011-2016 the annual budget destined to climate change was only 15 % of the budget destined to disaster management.

To strengthen institutionality and financing the PND suggests a reformation of the CARs and a modernisation of the SINA, and especially the ANLA and IDEAM. Financing tools will be evaluated to find new financial sources and to improve the distribution of existing sources, following OECD recommendations about public expenditure in the environmental sector and transparency and efficiency in resource use of the CARs will be promoted. Environmental licencing and the evaluation of permits is suggested to be simplified, accelerated and made more effective. To strengthen coordination and articulation the MADS will establish intersectoral agendas in order for environmental and productive sectors to work together more closely, set up a strategy of harmonization in policies, procedures, permits, norms and planning tools, and it will coordinate the implementation of its Nationally Determined Contribution (NDC). In order to tackle socio-environmental conflicts, public audiences, citizen reviews, work with locals and indigenous authorities will be promoted and a communication strategy towards environment friendly habits as well as a proposal in education and specialisation of judges in environmental issues will be structured. To improve the information management the PND suggests the implementation of an environmental planning and management information system for the CARs and the elaboration of information systems as well as performance indices in different sectors. While the IDEAM will consolidate a national information, monitoring and restoration system, the SINA will strengthen information generation for decision taking and the MADS and research institutions will implement regional and sectorial research and capacitation programs to ensure environmental monitoring in Colombia. The different institutes will define mechanisms of easy access of sectors, territories and the civil society to information about natural resources, climate change and hazard risk management. Some of the practical goals are the increase of the CAR's performance index from 84 % to 90 %, the implementation of climate change adaptation initiatives in 100 % of the departments, the complete implementation of the national climate change information system, an increase in prioritized agriculture and livestock farming systems that implement CCA initiatives from 260.000 ha to 398.175 ha, the implementation of 8 intergovernmental agreements and agendas, and an increase of the environmental licence solicitations solved within established time from 75 % to 95 %.

Regional Development Plan of Cundinamarca 2016-2020

The regional development plan of Cundinamarca 2016-2020 is based on a long-term vision and a territorial and participatory approach and it includes four strategic axis which are "Cundinamarca 2036", "social fabric", "sustainable competitiveness", and "integration and governance". While all four axes to some degree integrate the issue of adaptation to climate change, the axis "Cundinamarca 2036", aimed at a long-term improvement of quality of life based environmental education, is especially focused on the changes in the natural basis of human activity. It considers water a fundamental basis and a motor for sustainability, and mentions the importance of an integrated management for its protection and conservation in the face of climate change. (Gobernación de Cundinamarca, 2016)

In terms of climate change five central points were incorporated in the departmental development plan of Cundinamarca:

1. Vulnerability of hydrological regulation for 2050
2. Impact on biodiversity
3. Increases in temperature and precipitation
4. Landslides, inundations and forest fires
5. Information and knowledge

Based on those five points and on data from the Integrated Regional Plan for Climate Change in Bogotá – Cundinamarca (PRICC), the Development Plan of Cundinamarca suggests climate change adaptation strategies for different sectors. For hydrological resources it suggests the protection of headwaters of catchments, the reuse of water, the implementation of rain water storage systems, the elaboration of an integrated management plan for groundwater, the implementation for drought plans, the avoidance of pollution of hydrological sources, the estimation of environmental flow and maximal inundation, and the strengthening of water concession mechanisms. For biodiversity and ecosystem services it suggests the strengthening of protected areas, the definition of strategies for the reduction of vulnerability in fishing due to climate variability, the conservation of water supplier ecosystems like páramos and water recharge zones, and the implementation of a payment system for environmental services (PSA). For basic infrastructure it suggests the improvement of soil stability, the follow-up and evaluation of projects and infrastructures, the evaluation of hydroelectric potential in climate change scenarios, the promotion of renewable energy sources and the capacitation of municipalities in territorial law and climate change. For agriculture it suggests the elaboration of local production and consumption strategies, the collection and storage of water for irrigation, the protection of crops in dry and cold seasons, and the modernization of irrigation technologies. For health it suggests the promotion of campaigns about vector diseases and the decontamination of water and its sources. And for human habitat it suggests the creation of urban forestry parks and the implementation of thermo-regulating surfaces. (Gobernación de Cundinamarca, 2016)

Also, the risk management has an important position in the Development Plan of Cundinamarca. One of its goals is to implement risk management in all 15 provinces in the department of Cundinamarca by 2020. In order to do so it asks for

- the cooperation of municipalities and the CAR in risk knowledge
- the creation of a public policy of risk management in Cundinamarca, the updating of the departmental integrated risk management plan and the implementation of five projects
- the cooperation with municipalities for prioritization and implementation of at least one project oriented towards risk mitigation
- efficient and timely assistance in cases of emergencies and disasters
- the promotion of risk management in politics, plans, programs and activities in territorial entities in order to reduce vulnerability
- the strengthening of planning tools integrating risk management as a transversal axis in territorial planning
- the preparation of inter-sectorial risk management scenarios in order to work together with other departmental ministries, the UNGRD and interested groups
- the strengthening of risk management centres through resources and strategic alliances with national and international organisms
- the planning of 5 geographically strategic zones for the reduction of response time in order to guarantee timely assistance in cases of emergencies or disasters

In order to achieve sustainability in the use of hydrological resources the plan suggests the strengthening of its management tools for its conservation and protection. It suggests the generation of seven actions of regional strategic importance to contribute to the protection or recovery of the ecologic structure, the development of three strategies of climate change adaptation or mitigation, and the adoption of a regional water supply plan. It also searches to amplify the strategic areas to implement actions of strategic planning for conservation and restoration of supplier catchments, the use of groundwater, and the storage of rainwater in order to manage water supply for present and future populations. It suggests the implementation of areas with maintenance strategies and the acquisition of areas for protection of supplier catchments in the Rio Bogotá catchment, the implementation of payment schemes for environmental services, reforestation, clean production strategies, the implementation of projects for the recovery of lakes, lagoons and wetlands, the formulation of plans for efficient water use, technological projects for the recovery of the Rio Bogotá, the elaboration of maps of supply sources at risk, the formulation of a regional water supply plan, the co-financing of feasibility studies of new reservoirs, the co-financing of the Calandaima reservoir, the structuring of eight projects of groundwater exploitation, and the updating of the drinking water and basic sanitary service diagnostic.

In order to secure ecosystem services, it suggests the implementation of conservation actions in the ecologic corridors Chingaza-Sumapaz and Sumapaz-Guerrero for connectivity, and the promotion of projects of conservation of flora and fauna.

And in order to become resilient to climate change, it suggests the development of four projects of climate change adaptation or mitigation in agreement with the PRICC, the compensation of CO_2 and reforestation for human consumption and use.

Sectorial Strategy Plans (PES)

In 2010 the presidential administration decided that Sectorial Strategy Plans (PES) have to be designed for different sectors by the corresponding entities. The Sectorial Strategy Plan for Environment and Sustainable Development 2015-2018 has as a main objective the country's sustainable low carbon development. It aims to protect and secure sustainable use of natural capital, to improve environmental quality and governance, and to reduce vulnerability to hazard risks and climate change. It recognizes the PND 2014-2018's Green Growth Strategy as central and identifies the country's environmentally unsustainable economic growth, ecosystem degradation, pollution and environmental conflicts, and increasing risk conditions as the main problems in the sector of environment and sustainable development. (República de Colombia and MADS, 2015)

Based on the PND 2014-2018's Green Growth Strategy, the PES for Environment and Sustainable Development 2015-2018 elaborated different strategies to those problems. In order to move towards a sustainable, low carbon growth it suggests the transformation of sectors towards more efficient and inclusive paths and the improvement of sectorial management to reduce impacts on environment and health associated with economic development. For achieving a sustainable use of natural capital and improving environmental quality and governance it suggests the generation of comprehensive territorial laws for sustainable development, the strengthening of environmental achievements in the productive sectors, the consolidation of a political frame of climate change to integrate into environmental, territorial and sectorial planning, and the strengthening of institutions and governance, education and research, as well as knowledge generation. Aiming at hazard risk and climate change vulnerability reduction it suggests the strengthening of risk management processes and development planning through the inclusion of climate change adaptation issues. In order to enable the protection and conservation of territories and ecosystems it focuses on mitigation and adaptation to climate change, environmental laws, and REDD+ mechanisms in territories of indigenous and gypsy towns and suggests the elaboration of strategies with indigenous and gypsy towns. (República de Colombia and MADS, 2015)

Watershed Regulation and Management Plans (POMCA)

The Watershed Regulation and Management Plans (POMCA) are a legislative tool of land use planning responsible for the organisation of human settlements and activities in agreement with environmental sustainability goals and quality of life. (UNDP and IDEAM, 2010c) They are aimed at the management and conservation of the country's natural capital, the restoration of environmental quality, and the reduction of the territory's vulnerability to climate change. (República de Colombia and MADS, 2015)

While the POMCA of the Bogotá catchment from 2006 (CAR, 2006) did not include climate change related components, the newer POMCA versions from 2019 are adjusted to incorporate risk management as an environmental determinant in land use planning. The up-to-date POMCA of the Bogotá river catchment contains a volume on risk management (CAR, 2017f) that integrates hazard, vulnerability and risk analysis. The chapter suggests several non-structural projects concerning hazards like inundations, flash floods, landslides and wildfires. The POMCA asks for an up-dating and extension of hydro-climatic monitoring network for early warning and climate change adaptation purposes. It compels the municipalities to elaborate detailed hazard, vulnerability and risk studies in order to enable efficient land use planning and to identify priority areas for intervention in case of high risk. And it suggests the adjustment and updating of the Municipal Disaster Risk Management Plans (PMGRD) based on those studies to make efficient choices in the planning of human activities, reduction of risk and emergency actions. It demands technical training for municipal civil servants in charge of disaster risk management and strengthening of responsive capacity of fire fighters and emergency forces at a regional scale to deal with forest fires. It also suggests an increase in communal participation in risk management in order to access local knowledge, culture and habits and to foster participatory projects. Considering that the SINGRD still presents problems of redundancy, dispersion and lack of articulation, the POMCA 2019 of the Bogotá river catchment asks for the creation of an integrated regional disaster risk and climate change information system to generate updated, standardized and easily available information. Beside the mentioned projects it also suggests structural measures that include road stabilisation, improvements in local sewage systems, flood protection, resettlement of homes in high risk zones and similar. One of the most important projects will be the hydraulic adaptation of the Bogotá river that is aimed at flood prevention. (CAR, 2017f)

Regional Environmental Management Plan (PGAR) 2012-2023

Similar to the POMCA the Regional Environmental Management Plan (PGAR) is a territorial planning tool that aims at sustainable development and at the protection and conservation of natural resources. (CAR, 2012) It is based on the political framework strongly linked to the Millennium Development Goal No. 7 of "ensuring environmental sustainability". The PGAR 2012-2023 of Cundinamarca mentions general national objectives to guarantee environmental sustainability of which some are mentioned here: In order to incorporate the principles of sustainable development into national politics and programs and to reverse the environmental resource losses, it suggests an annual reforestation of 23.000 ha, the elimination of 10 % of the base line hydrochlorofluorocarbons (HCFC), as well as the consolidation of protected areas by the National Natural Park System, an increase of the area to 1'000'000 ha and the formulation of management plans for all the areas. In order to reduce the percentage of people without sustainable access to drinking water and basic sanitary services, it suggests the incorporation of at least 7.3 Mio. inhabitants to the aqueduct infrastructure, the incorporation of 7.7 Mio. inhabitants to an urban sewage system and 1 Mio. inhabitants to an alternative rural basic sanitary system. In order to considerably improve the life quality of inhabitants in slums it suggests to decrease the number of households in precarious settlements to 4 % by 2020. (CAR, 2012)

On the regional basis of the department of Cundinamarca, considering the above-mentioned guidelines the PGAR 2012-2023 strongly focuses on environmental sustainability and the interaction dynamics between the CAR, the productive sectors and the territorial entities based on co-responsibility, solidarity between producers and gradualness. The PGAR 2012-2023 identifies three strategic lines for the orientation of the planning of regional actors:

1. Social innovation and regional identity

2. Social fabric for joint environmental responsibility
3. Protection and sustainable use of natural elements with territorial expression (CAR, 2012)

The strategic line of social innovation and regional identity aims at the empowerment of the community for collective solutions, self-help, and participation, at the recognition and construction of a regional identity including cultural, social, geographical and economical elements to strengthen the regions competitiveness, and at environmental sustainability. It contains the three axes of environmental culture, regional leadership, and incidence of territorial models.

The objective of the environmental culture axis is the promotion of a regional model of environmental sustainability that values and strengthens local cultural expressions. Specifically, it suggests that the environmental authorities design and apply a knowledge management model for the appropriation of the environmental value of its territory. It asks the CAR to administrate an environmental information system that supports territorial decisions. It requests that at least six social groups have the regional vision of environmental sustainability as their prospective framework and they are clear about their responsibilities. And it suggests the environmental culture to be considered as regional identity and included in daily life and public decision making.

The objective of the regional leadership axis is to motivate the construction of regional environmental identity through determined leadership that formulates and adopts policies, norms and instruments for mutual cooperation. Specifically, it suggests that by 2023 the CAR be transformed into an entity that provides, recognizes and revitalize regional capacities, and that the CAR together with regional actors formulated political proposals, norms and instruments for environmental management.

The objective of the incidence of territorial models axis is to dispose of a system that models regional environmental information at detailed scales in order to effectively appropriate the concept of territoriality and the perspectives of territorial competitiveness. Specifically, it suggests the territorial models of departments and municipalities include the integrated environmental modelling of the CAR, and the territorial, national, local and academic entities interact with the information system of the CAR. It suggests the inclusion of the indigenous ancestral environmental vision and territorial models that proactively summon environmental authorities to participate in their processes. (CAR, 2012)

The strategic line of social fabric for environmental co-responsibility aims at the generation of relational and social capital for cooperation, conscience, civil commitment and responsibility. It contains the two axis of governability, and inter-institutional and social interaction spaces.

The objective of the governability axis is to strengthen the regional institutional capacity in order to increase effectiveness of authority´s action. Specifically, it suggests the implementation of defined strategies for 10 structural situations that at this moment present weak environmental governability. It also suggests coordination alliances with security agencies and the police for assistance to environmental concerns.

The objective of the inter-institutional and social interaction spaces axis is to generate a stronger direct relation between environmental authorities and organizational processes in the community for more effectiveness in communication and interaction. Specifically, it suggests for the watershed board to include the different articulation instances between actors in the jurisdiction. It suggests that by 2023 20 economical sub-sectors have agreements of environmental management for their activities. And that by that time community organizations and indigenous towns interact directly with the environmental authority. (CAR, 2012)

The strategic line of protection and sustainable use of natural elements with territorial expression aims at the reduction of conflict and the protection of environmental functioning to improve the living conditions. It contains the three axis of watershed approach, environmental determinants and mainstreaming of risk management and climate change.
The objective of the watershed approach axis is to plan and manage the territory with a focus on the hydrological catchment in order to better understand the inputs and outputs and their consequences to the hydrological system. Specifically, it suggests the updating of POMCAs and environmental management plans of prioritized micro-catchments. It suggests the reduction of soil erosion, the compliance with the quality objectives of streams, the reduction of deforestation and the detaining of the expansion of agricultural activity, as well as the effective management of the system of protected areas. It also suggests the reduction and reuse of solid waste produced through economic activity.
The objective of the environmental determinants axis is to guide the territorial law according to environmental determinants based on the ecological structure of the territory. Specifically, the axis suggests the adoption and protection of the ecologic structure, the establishment of 105 territorial law agreement processes linked to the environmental determinants and followed by the municipalities and the CAR. It suggests the sharing of responsibility for environmental sustainability between territorial entities and environmental authorities. And it asks for the increase of representativeness of protected areas in 25 % of ecosystems.
The objective of the mainstreaming of risk management and climate change axis is to generate knowledge and develop measures to mitigate the risk and adaptation to climate change. Specifically it suggests the elaboration of vulnerability studies and of climate change adaptation measures for prioritized zones, and the prevention and adaptation measures be respected and backed up by the territorial entities. (CAR, 2012)

While the PGAR strongly focuses on environmental sustainability it does not specifically deal with climate change adaptation but on the general territorial planning of the region under jurisdiction of the CAR.

Climate change specific documents:

- Document CONPES 3700 of 2011
- National Communications of Climate Change
- National Politics for Climate Change (PNCC)

Institutional efforts to implement a general framework for climate change adaptation in Colombia have resulted in the formulation of the document CONPES 3700 (DNP, 2011a), three National Communications of Climate Change (IDEAM, 2001; UNDP and IDEAM, 2010a; IDEAM, UNDP, MADS, DNP and Cancillería, 2017) and the National Politics for Climate Change (MADS, 2017).

Document CONPES 3700 of 2011: Institutional strategy for the organization of politics and actions to climate change

The document CONPES 3700 presents a strategy to integrate economic and social development issues caused by climate change into sectorial and territorial planning and proposes the structure for institutional articulation in climate change matters. (DNP, 2011a)

In its diagnostic chapter it presents two main problems in this aspect:

- the disarticulation of planning and development of coordinated actions in the face of climate change
- the ignorance or lack of information

(DNP, 2011a)

It defines the need to establish a National System of Climate Change (SISCLIMA) and a group of articulated mitigation and adaptation strategies, and suggests the creation of the National Climate Change Adaptation Plan (PNACC), the Colombian Strategy of Low Carbon Development (ECDBC), the national strategy for the reduction of emissions due to deforestation and forest degradation in developing countries, and the function of conservation, sustainable forest management and the increase of forest carbon reserves in developing countries (ENREDD+), and a financial disaster protection strategy. (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017)

The CONPES 3700 established the lineaments for the design and formulation of the institutional strategy for the articulation of policies and actions of climate change matters, which are presented in the following:

- Institutional strengthening: inter-sectorial coordination, institutional strengthening, institutional complementarity
- Research and knowledge management: information for decision making, environmental communication and education
- Economic cost effectiveness: cost effectiveness, economic incentives, equity
- Integrated focus of politics, plans and programs
- Territorial articulation: regional harmonization
- Social participatory focus: present and inter-generational responsibility, participation and appropriation
- Follow-up, monitoring and evaluation

To the present day the institutional strategy for the articulation of climate change policies and actions and its lineaments established by the CONPES 3700 is the first institutional document to suggest a basis for the creation of climate change adaptation paths. (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017)

National Communications on Climate Change

The National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) are collective documents that summarize national and regional information about climate change and provide tools for the dissemination of supplies for decision making in climate change matters. (DNP *et al.*, 2016) All three national communications released to the present day contain information about climate change adaptation.

The **1st national communication on climate change** published in 2001 analyses and presents the national inventory of greenhouse gases for 1990-1994. It identifies the ecosystems most susceptible to climate change and suggests the first climate change adaptation measures for Colombia. (DNP, 2011a) Its chapter on vulnerability and adaptation contains vulnerability analyses of the coastal and insular areas, the hydrological resources, the vegetation covers, the continental ecosystems, the páramo ecosystems, the glacial areas, the agricultural sector, the desertification of soil, and the human health. In order to counteract environmental and ecosystem degradation it very broadly mentions the need to limit human activity and to establish areas of conservation. However, it does not suggest specific climate change adaptation measures except for the human health sector. As adaptation measures against vector diseases it suggests public education, vigilance and monitoring, ecosystem interventions, biological control, chemical control, development of infrastructure, and health interventions. (IDEAM, 2001)

The **2nd national communication on climate change** published in 2010 contains a chapter about climate change adaptation that is based on the following lineaments:

- Strengthening of research management and knowledge transference
- Strengthening of risk management
- Improvement of land use as a strategy to reduce vulnerability
- Reduction of environmental, economic and social impacts
- Improvement of adaptive capacity of the most vulnerable communities
- Design and implementation of an institutional agreement about adaptation
- Valuation and protection of the productive ground based on biodiversity goods and services
- Strengthening of cooperation and resource management for adaptation (UNDP and IDEAM, 2010c)

It contains descriptions of several relevant climate change adaptation projects like the National Pilot Project of Climate Change Adaptation (INAP) that will be elaborated in a section of the following chapter about relevant adaptation plans and projects.

The **3rd national communication on climate change** published in 2017 contains a chapter about climate change adaptation in which it states that for the department of Cundinamarca in 2010-2015 a total of 1150 adaptation measures were counted, which makes Cundinamarca the second highest ranked department in adaptive actions right after Antioquia. Of those measures the mayor part belongs in the environmental sector with 71.4 % hydrological resources actions and 21.5 % biodiversity and forestry governance actions, a minor part belongs in the transport sector with 2.8 % actions in urban development and passenger transportation, as well as in a transversal sector with 0.4 % of actions in hydrological resources.

Some of the relevant adaptation actions were

- the acquisition of zones of hydrological reserves and natural reserves
- the implementation of projects in the scope of the PRICC
- the creation of conservation corridors or new areas for assisted migration, maintenance of local micro-climates and runoff regulation
- vegetation coverage: green facades and roofs, and rooftop water reservoirs
- the implementation of control actions of appropriate soil use
- rainwater management
- payment schemes for environmental services in conservation
- the adaptation and implementation of the banCO2 model (bank of environmental services) for the capital region
- the renaturation of rivers
- ecological restoration and the conservation for a zone of humid sub-Andean forest or of dry forest in the west of the department (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017)

For the country's capital Bogotá, the numbers of adaptive actions starting in the year 2011 went from 5 to 15, 18, 18 and up to 31 actions in 2015. There were 17 adaptive actions taken in the sector of biodiversity and forest governance, 37 in the sector of hydrological resources and 26 in the sector of urban development and passenger transport. Some relevant actions were the acquisition of zones of hydrological reserves and natural reserves, the conservation and reforestation of micro-catchments and the protection of their sources, the conservation, protection, restoration and sustainable use of ecosystems, as well as reforestation and erosion control. However, the adaptation measures at that time were mainly based on reforestation and erosion control. (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017)

Under the national Green Growth approach of the PND 2014-2018 the ministries of internal revenue, of agriculture and rural development, of mining and energy, of transportation, of health and social protection, of housing, of city, territory and commerce, and of industry and tourism were ordered to elaborate and implement sectorial plans of climate change adaptation. Following this establishment, the sectors worked out different adaptation processes of which the most important are listed here.

The energy and mining sector developed studies to identify risks and adaptation measures facing climate change events that may threaten the sustainability of its industry. The first initiatives included the determination of vulnerability and adaptation options of the energy sector, the implementation of a roadmap for adaptation in the energy sector, the identification of vulnerability factors in the mining sector and adaptation measures, the identification of the most important climate hazards for the hydrocarbon sector, and prospective climate hazard scenarios. Later followed the identification of climate change risks associated with the generation and transmission of electricity and with the carbon industry, climate change vulnerability and adaptation measures of hydroelectric systems in the Andes and many more.

The transportation sector presented a climate change adaptation plan for the main traffic lines in Colombia that aims at a climate compatible development. The plan contains strategies for roads adapted with innovation, information and knowledge management, strengthening of institutional capacities, sensitization, education and communication, and normative up-dating.

The health and social protection sector elaborated lineaments for the formulation of climate change adaptation plans in order to anticipate health effects related to climate change impacts. It considers amongst others the quality of air and water, zoonosis and vector diseases for the definition and prioritization of strategies and decision making.

The housing sector prepared a consulting process supported by USAID about historical vulnerability analysis for the climate change plan in the housing sector. (IDEAM, UNDP, MADS, DNP and CANCILLERÍA, 2017)

National Climate Change Policy (PNCC)

The National Climate Change Policy (PNCC) is the response to the country's need of articulated multilevel lineaments for the climate change strategies put up by the government over the past years. Its goal is the incorporation of climate change management into public and private decisions in order to progress towards a climate resilient development that reduces climate change risks and takes advantage of the opportunities climate change generates. (MADS, 2017)

It proposes five general and sectorial territorial strategies for climate change adaptation and mitigation:

1. Climate resilient and low carbon urban development
2. Climate resilient and low carbon rural development

3. Climate resilient and low carbon development of the mining and energy sector
4. Climate resilient and low carbon development of strategical infrastructure
5. Management and conservation of ecosystems and their services

In order to implement those strategies, it defines four instrumental lines:

- Information, science, technology and innovation
- Education, formation, and civil sensitisation
- Planning of climate change management
- Financing and economic tools

And it presents action lines to work on the five territorial strategies:

1. Rural development:

- Promote agriculture, livestock, forestry and fishing systems that are more adapted to high temperatures, droughts and inundations
- Generate and divulgate strategic agroclimatic information for planning, insuring and early warning
- Promote integrated action in communities to foster efficient soil use, vegetation conservation, restoration of degraded areas, the implementation of agroforestry systems, family agriculture, reduction of deforestation, and technology transfers
- Provide productive alternatives to illegal cultivation, mining and occupation in order to increase forest carbon reserves and appropriate land use
- Incorporate climate change adaptation and mitigation options into the systems of technical assistance in the agriculture and livestock sector
- Promote a climate resilient and low carbon development and law in the urban context of energy, transportation, tourism
- Promote sustainable forest use and natural resource use, forest and riverbank conservation, and the restoration of degraded areas
- Revise subsidies that lead to a decrease in ecosystem services
- Incorporate climate change evaluations and efficient water use into planning and rehabilitation of land adaptation infrastructure

2. Urban development:

- Equip cities with infrastructure resilient to inundations and sea level rise
- Reduce risk of water scarcity through incentives to efficient water use and reduction of losses
- Offer alternatives of efficient, climate resilient and low carbon public and private transportation
- Motivate the reduction of waste generation, reuse, recycling and energy production
- Motivate energy efficiency, and sustainable, resilient and low carbon construction
- Reduce cities' flood exposure and transportation emissions through urban planning and interconnected agglomeration
- Promote the conservation of ecologic structure and landscape management through the creation of public green spaces
- Generate scientific knowledge that allows to quantify CO_2 uptake by coastal and marine zones

3. Mining and energy:

- Integrate climate change adaptation matters into politics, tools and regulations of the expansion of the electricity network
- Evaluate the use of biofuels with low carbon footprints that improve food security, water resources and biodiversity
- Promote tools for the low carbon demand management in different sectors
- Motivate diversification in the energy sector and promote renewable energy
- Promote appropriate management of fugitive emissions in the mining and hydrocarbon sectors

4. Strategic infrastructure:

- Incorporate climate change matters into the design of transportation infrastructure
- Evaluate the vulnerability of existing transportation infrastructure and implement options to reduce climate risk (e.g. maintenance guides)
- Promote the avoidance of unnecessary trips, the efficiency of transportation loads, and the efficiency of energy use
- Promote joint climate risk management in private-public alliances
- Consider tools to internalize climate change costs in the transportation sector

5. Ecosystem conservation:

- Promote the conservation and restoration of ecosystems supplying environmental services that favour socio-economic climate change adaptation like hydrological regulation, flood protection; and push CCA measures based on ecosystems
- Incorporate climate change impact scenarios into management, conservation and restoration of priority ecosystems
- Incorporate ecosystem management and conservation actions into territorial planning and sectorial development
- Strengthen forestry governance to avoid deforestation and forest degradation
- Motivate the development of urban systems that save natural resources
- Promote territorial strategies and agreements to resolve conflicts about access to ecosystem services between economic sectors and communities
- Evaluate and strengthen the institutional capacity of environmental authorities to guarantee the implementation of the mentioned objectives (MADS, 2017)

The summarizing **Table 5** illustrates the climate related main concerns and the most important suggested climate change adaptation measures and strategies of the planning documents described in this chapter.

Table 5: Summary of the climate related main concerns and the suggested climate change adaptation measures for some of Colombia´s general planning documents and specifically climate change related documents.

x **Main concerns** ▭ **Suggested CC adaptations**	Bicentennial Vision Colombia 2019	PND 2010-2014	PND 2014-2018	PND 2018-2022	Regional Dev. Plan CAR 2016-2020	PES 2015-2018	POMCA Rio Bogotá 2019	PGAR 2012	CONPES 3700 2011	Nat. Comm. on CC 2010&2017	PNCC 2017
Document addresses CCA	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
CC and CCA research and information									x		
CC and CCA information management				x							
Implementation of CCA in politics and planning									x		x

intersectoral agendas											
territorial/regional planning									x		
sectorial planning											
elaboration of CCA plans											
measures in productive sectors											
follow-up and evaluation of projects											
Sustainable/resilient development	x		x	x	x	x		x			x
local production and consumption											
diagnostic and improvement in drinking water and sanitary services											
promotion of renewable energy											
urban forestry parks and thermo-regulating surfaces											
Sustainable use of natural resources	x		x		x	x		x			
efficient water use											
reuse of water and rainwater storage											
modernization of irrigation technology											
soil stability and erosion reduction											
Biodiversity and ecosystem protection	x		x		x	x					x
maintenance of forest coverage											
strengthening of protected areas											
ecologic corridors for connectivity											
protection of springs and streams											
reduction of contamination											
reduction and reuse of solid waste											
Hazard risk management	x		x		x	x	x				x
vulnerability analysis and reduction		x	x							x	
information generation											
information management											
elaboration of planning tools											
disaster recovery plans											
climate resilient infrastructure		x			x						x
agroclimatic early warning system											
flood protection											
resettlement from high risk zones											
Improvement of env. Governance			x	x							
strengthening of institutionality				x				x			
cooperation											
territorial & sectorial co-responsibility											
compliance with regulations/standards											
strengthening of SINAP											
reformation of the CARs											
modernisation of the SINA (especially ANLA, IDEAM)											
Administration and regulating											
improve financing and investment				x							
developing normative instruments and performance indices											
simplification of environmental licencing and permit evaluation											
water concession mechanisms											
environmental determinants											
Environmental education					x						
communal participation	x				x			x			
communication and sensitization											
training of municipalities											
strengthening communities											
inclusion of communities in planning											
create regional identity											

The main concerns mentioned most by Colombia´s general and climate change specific planning documents are sustainable and resilient development (7/11), hazard risk management (6/11), sustainable use of natural resources (5/11) and biodiversity and ecosystem protection (5/11).
The CCA measures most suggested (additional to the main concerns) are CC and CCA research and information (10/11), vulnerability analysis and reduction (8/11), territorial and regional planning (7/11), communal participation (7/11), communication and sensitization (7/11), CC and CCA information management (6/11), hazard risk information generation and management (6/11), sectorial planning (6/11), strengthening of institutionality (6/11), improvement of financing and investment (6/11), measures in productive sectors (6/11), implementation of CCA in politics and planning (5/11) and maintenance of forest coverage (5/11).
Interestingly, the follow-up and evaluation of projects is only mentioned twice, namely in the Regional Development Plan 2016-2020 of the CAR 2016-2020 and in the CONPES 3700 of 2011.

4.1.4 Relevant climate change adaptation plans and projects

Beside the documents that build the institutional base for climate change matters on national and regional levels, several plans and projects concerning adaptation to climate change have been elaborated and implemented in Colombia over the past decade. The most prominent ones of high importance for Colombia and especially for the department of Cundinamarca are

- the Territorial Approach to Climate Change (TACC)
- the National Strategy for Education, Formation and Sensitization in Climate Change
- the National Plans for Climate Change Adaptation (PNACC)
- the guide to climate change adaptation based on ecosystems in Colombia (AbE)
- the Regional Integral Climate Change Plan for the Capital Region of Bogotá-Cundinamarca (PRICC)
- the 4-year Action Plan for Cundinamarca (PAC)
- and the Integrated National Adaptation Project (INAP).

Territorial Approach to Climate Change (TACC)

The United Nations Development Program´s (UNDP) Territorial Approach to Climate Change (TACC) aims at the supporting of national and sub-national governments in formulating, financing and implementing strategies for sustainable economic growth. In its scope the UNDP promotes the identification of mitigation and adaptation activities and suggests projects in line with national and regional climate policies and goals. The TACC initiative is implemented in Colombia, Senegal, Uganda, Uruguay and Peru. (UNDP, 2012) In Colombia the TACC supports a project in the capital region of Bogotá-Cundinamarca consolidating national capacities to promote environmental sustainability, disaster risk management and sustainable territorial planning. The project aims at the training and support of public institutions and the civil society in order to reduce the negative effects of climate change, to face the reduction of the ozone layer, the solid waste and organic pollutant management, and to make them pay special attention to conservation, restoration and sustainable use of strategical ecosystems, and the rational and efficient use of energy. Its goal is to help integrate climate change into territorial development planning through collective construction of an Integrated Regional Climate Change Plan (PRICC) containing investment strategies and plans that motivate climate change robust development options. The project focuses on awareness raising about climate change implications at the decision-making level and supports the development of Integrated

Regional Climate Change Plans (PRICC) that identify and prioritize no-regret options for climate change mitigation and adaptation like disaster risk management and the improvement of emergency response systems. (UNDP and IDEAM, 2016)

National Strategy for Education, Formation and Sensitization in Climate Change

The goal of the national strategy for education, formation and sensitization in climate change, published in 2010, is to establish guidelines for the implementation of programs and projects that promote the access to information, the public awareness, training, education, research and participation to contribute to the creation of capacities in climate change matters at local, regional and national scale. (IDEAM, 2010) Its main strategic axes and objectives are

- Information access: the promotion of public access to information on causes, consequences and impacts of climate change, and actions to face it
- Public awareness: the promotion of awareness building in individuals and communities, fostering changes in habits and behaviours in the face of new climate dynamics
- Training: the promotion of the development of capacities, scientific competences, and skills in human resources to face climate change issues
- Education: the incentive of inclusion of climate change topics into formal primary, secondary, technical and superior education
- Research: the strengthening of permanent research and knowledge generation about social, economic and environmental aspects of climate change
- Participation: the promotion of public participation in planning, execution, monitoring and evaluation of climate change programs and projects

The strategic axes, objectives and actions suggested in the national strategy for education, formation and sensitization in climate change are listed in the following **Table 6**.

Table 6: Strategic axes, objectives and actions modified after table 4-9 in the National Strategy for Education, Formation and Sensitization in Climate Change (IDEAM, 2010).

Strategic axes	Objectives	Actions
Information access	Improve the climate change information offer on public websites	• create a national website about CC • create spaces for CC information on websites of national and regional authorities
	Socialize the results of national communications in a clear language for decision makers	• produce divulgation material
	improve precise and timely information access to decision makers and environmental authorities	• publish CC research results on the SIAC platform • produce Spanish summaries of important CC documents like the IPCC
	promote programs of social responsibility in the media	• incorporation of CC topics in the media • sensitization campaigns about social responsibility in the face of CC
	promote the exchange of projects and experiences in CC	• create a bank of CC experiences on a national website
	facilitate the access to CC information for sectors, producers and companies	• promotion of existing information media • accompanying of trade unions and producers
Public awareness	CC sensitization and awareness building in the population	• celebration about facing CC on the national day • realize educational communication campaigns about CC

		• produce educational material about CC for children • realize academic and cultural events about CC • realize competitions in CC matters (e.g. paintings, photography etc.)
	promote programs about economising natural resources	• programs of efficient use of natural resources in public entities
Training	promote the incorporation of CC issues in territorial planning	• realize yearly training event for environmental entities
	promote appropriate coverage of CC issues in the news	• realize trainings for reporters and journalists
	promote the incorporation of CC issues in decision making and education	• realize CC training events for decision makers • realize CC training events for teachers and professors
	promote the participation of children and youngsters in CC initiative	• realize CC training events for kids and youngsters
	promote the incorporation of traditional and local knowledge into adaptation projects	• realize CC training events for local ethnical communities
Education	promote the incorporation of CC topics into formal educational strategies	• accompanying of educational strategies • develop educational material about CC in Colombia
	promote the creation of academic programs about CC	• design academic programs that include CC • create environmental university projects including CC
Research	analyse the level of public awareness about CC	• define a base line in CC awareness • realize national survey about CC awareness
	increase the realization of social, economic and environmental research in CC matters	• realize research projects in line with the priorities defined by the national communications and regional needs • create research lines in universities • create research catalogues for CC matters • organize contest for Bachelor's thesis in CC topics • create internships around CC topics
	promote ethno-research about CC	• realize research projects that include local community traditions and knowledge
Participation	promote inter-institutional coordination in CC matters	• reunions of 15 technical groups • establish inter-ministerial agendas about CC
	promote regional work and projects in CC topics	• creation of regional nodes of CC
	promote the participation of communities in CCA processes	• create social networks that work in CC
	promote the participation of children and youngsters in CC programs	• realize events, activities, meetings etc. for children and youngsters
	promote social corporate CC responsibility programs	• create social corporate CC responsibility programs • include companies into these programs

National Plans for Climate Change Adaptation (PNACC)

The PNACC is an instrument that establishes strategies and offers tools for prioritization of adaptation actions and interventions in national, regional and local planning that focus on long-term sustainable objectives. (UNDP and IDEAM, 2010a)

The **National Adaptation Plan to Climate Change (PNACC) 2012** about Conceptual Adaptation Bases is part of one of the national strategies dealing with climate change in line with the National Development Plan 2010-2014. Its objective is to reduce the risk and the socio-economic and ecosystem impacts associated with climate change and variability. (DNP, MADS and UNGRD, 2012) It aims at reducing the vulnerability of settlements, ecosystems and productive sectors, and at increasing social, economic and ecosystem capacity to respond to climate hazards. (CAR, 2016)

The PNACC 2012 stresses planned adaptation as it is more cost-effective than the reaction to climate change impacts. Hence the country's planning instruments like the PNDs and the POMCAs should incorporate climate change management. It suggests the promotion of activities that generate benefits for the whole population or that favour the most vulnerable. It considers climate change adaptation a strategy to guarantee long-term competitiveness and asks the country to take advantage of the opportunities generated by the regional changing climate. It affirms adaptation action is local, should be participatory and focus on territorial priorities. However, all territorial levels, all sectors and the population have to financially commit to the adaptation to climate change. It stresses the integrated vision of adaptation recognising different perspectives (e.g. communities, ecosystems, infrastructure etc.) and suggests that disaster risk management and climate change adaptation be seen as complementary strategies. In the PNACC 2012 five strategic lines for planned adaptation are defined:

- Raising awareness about climate change
- Generating information and knowledge to measure climate risks
- Planning of land use
- Implementing adaptation actions
- Strengthening reactive capacity (DNP, MADS and UNGRD, 2012)

In order to do so it provides the following methodologies:

- Generation of knowledge about potential risks and present impacts
- Taking advantage of opportunities associated to climate change and variability
- Incorporation of climate risk management in sectorial and territorial development planning
- Identification, prioritization, implementation, evaluation and follow-up of adaptation measures to reduce vulnerability and exposure of socio-economic systems in the face of climatic events (DNP, MADS and UNGRD, 2012)

The **National Adaptation Plan to Climate Change (PNACC) 2016** about Priority Action Lines for Adaptation to Climate Change is meant to be a guide for decision making, knowledge management, the civil society, the media and any other actor wanting to take part in climate change adaptation in Colombia. (DNP *et al.*, 2016) It defines prioritized action lines for climate change adaptation directed towards the moderation of losses or expected damages, as well as towards the taking advantage of beneficial opportunities. Its specific objectives concerning adaptation in Colombia are

- Management of climate change knowledge and its potential consequences over communities, biodiversity and its ecosystem services, and the country's economy
- Incorporation of climate change adaptation in sectorial and territorial development planning

- Promotion of development transformation towards climate change adaptation based on competitiveness, sustainability and equity (DNP *et al.*, 2016)

Based on those three objectives the PNACC 2016 presents the following **Table 7** of strategies and action lines:

Table 7: Objectives, strategies and action lines modified after „strategies to climate change adaptation“ (DNP et al., 2016).

Objectives	Strategies	Actions
Knowledge	Strengthening the management of climate, hydrology and oceanography knowledge and their potential impacts	• Strengthening the capacity of generation and divulgation of hydrological, meteorological and oceanographic information for decision making • Collecting CC proof and developing complementary analysis based on CC scenarios • Complementing future modelling of CC phenomena • Studying potential impacts, vulnerability and risk in the face of CC and climate variability • Strengthening knowledge about CCA measures
	Education, formation, communication and sensitization of the public	• Developing strategies of popularization, divulgation and appropriation of information and knowledge • Promoting the integration of contents and processes of capacitation and awareness rising into formal and informal education • Promoting the use of communication media for divulgation of knowledge about impacts and adaptation options to CC • Promoting a capacitation, education and popularization process with territorial entities and decision makers
	Strengthening of institutional capacities for CCA	• Strengthening of the public and private institutional environment for CCA • Improving the capacities of regional CC nodes for implementation, follow-up and evaluation of CCA • Strengthening of collaboration, research and innovation in CCA issues
Planning	Incorporation of climate change and variability in national planning instruments	• Incorporating CCA lineaments and actions in instruments of environmental and territorial law • Incorporating CCA lineaments and actions in instruments of local, regional and national development planning • Incorporating CCA lineaments and actions in instruments of sectorial planning
	Development of resilient investment projects	• Fixing sectorial CCA goals that guide public and private investment projects
Development transformation	Management of CC impacts on biodiversity and ecosystem service offer	• Strengthening the functionality of water supply and regulation services of ecosystems through environmental and hydrological management • Integrating soil degradation management actions with directed towards CCA • Using of marine, coastal, island and ocean zones as resilience pillar
	Agriculture and livestock production and food security adapted to CC	• Integrating rural development and responsive capacity to CC • Integrating adaptation as criterion to sustainable use of renewable natural resources

	Prospective risk reduction in basic infrastructure	• CC resilient and competitive infrastructure, transportation and mobility • Strengthening reliability and access to energy in CC scenarios
	Green growth of human environment	• Health • System of resilient cities

Guide to climate change adaptation based on ecosystems in Colombia (AbE)

The guide to climate change adaptation based on ecosystems (AbE) established by the PNACC as articulation action for the implementation of the National Climate Change Policy (PNCC) is based on the principle of biodiversity and ecosystem service use as climate change adaptation strategy. The guide summarizes the principles and processes that aim at the maximizing of the role of socio-ecosystems in climate risk reduction and resilience increase in the face of climate change and variability. It stresses the role of Colombia´s different ecosystems and their services that are directly linked to climate through water and temperature regulation and soil retention, and thus contribute to food security or risk prevention linked to erosive processes and inundations. (Álvarez Grueso *et al.*, 2018)

Some examples of ecosystem-based climate change adaptation measures and their benefits can be seen in **Table 8**.

Table 8: Ecosystem-based climate change adaptation measures and their benefits modified after Álvarez Grueso et al. (2018).

Ecosystem-based climate change adaptation measures and their benefits	
Adaptation measures	**Benefits**
Restoration, reforestation, regeneration	• biodiversity protection and increase • long-term ecosystem services provision • interruption of direct precipitation impact on the soil • water capture • lower thermal sensation
Restoration of wetland ecosystems	• increase of responsive capacity to inundations
Restoration of springs and riparian buffer zones	• erosion reduction • biodiversity protection • water regulation • reduction of water stress
Live fences	• wind breakers: reduction of wind erosion processes • lower thermal sensation • alternative food source for livestock • landscape improvement
Rainwater harvest and use	• reduction of pressure on surface and groundwater sources
Agroforestry systems	• upkeeping of genetic diversity • reduced soil compaction • reduced greenhouse gas emission
Silvopastoral systems	• increased well-being of animals • increased quality of animal products
Bioengineering constructions	• reduction of erosion, landslides and surface failures • integration into the landscape • natural regeneration processes

Regional Integral Climate Change Plan for the Capital Region of Bogotá-Cundinamarca (PRICC)

The Regional Integral Climate Change Plan for the Capital Region of Bogotá-Cundinamarca PRICC (2012) is a pilot model pushed by the United Nations in order to strengthen the capacity of local governments to create resilient territories that are capable of dealing with the challenges of climate change. The PRICC concentrates on vulnerability reduction, the improvement of life quality, the prevention of losses and the increase of revenue. Some of its goals are the definition of strategic action lines and adaptation and mitigation project portfolios in the face of climate change and variability. In this process 20 project profiles for priority sectors and areas were developed. The sectors of energy, transportation, livestock, mining, agriculture and waste were defined as priority sectors and the projects were elaborated in line with other priorities like the reduction of greenhouse gas emissions. (IDEAM *et al.*, 2012)

Based on the priority sectors 114 adaptation measures were elaborated for the topics of

1. Integrated hydrological resources management (25 measures)
2. Integrated soil resources management (3 measures)
3. Integrated biodiversity management and ecosystem services (11 measures)
4. Human settlements (33 measures)
5. Sustainable production and consumption (12 measures)
6. Financing of mitigation and adaptation - public policy (9 measures)
7. Education, training, public access to information and public knowledge (21 measures)

The priorization of adaptation measures on that list is based on the needs in climate change topics elaborated in a vulnerability study by Conservación Internacional (CI) and on the suggestions stemming from workshops by the IDEAM considering social, economic, environmental and institutional priorization axis. Priorization criteria were elaborated for all of those four priorization axis.

Social criteria:

- Improvement of public health conditions
- Reduction of impacts on infrastructure and housing
- Strengthening of food security
- Improvement of access to water

Environmental criteria:

- Protection of riparian buffer zones
- Protection of hydrologic recharge areas

Economic criteria:

- Conservation of strategic ecosystems
- Effect on GDP
- Reduction of economic losses

Institutional strengthening:

- Organisation of territorial governance
- Propelling the responsive capacity of regional or territorial entities in the face of events Produced by climate change

Based on the above-mentioned priority sectors and priorization criteria the following adaptation measures were elaborated.

Hydrological resources:

- Implementation of reservoir lake systems for hydraulic storage and regulation

- Implementation of water reservoirs
- Implementation of actions to avoid erosion and sedimentation in water body areas
- River renaturation in order to prevent inundation
- Adaptation of fluvial drainage networks
- Protection of inundation areas
- Restoration of inundation areas
- Integrated restoration of water bodies
- Design and implementation of sustainable urban drainage systems
- Program of efficient water use
- Water recycling – use of grey water
- Rainwater management
- Retention and storage of rainwater

Biodiversity and ecosystem services:

- Creation of conservation corridors and new areas that foster assisted migration, Preservation of microclimates and runoff regulation
- Technology changes and improvements in land use, silvicultural activities, promotion of sustainable forest use and reforestation
- Improvement of soil stability

Risk management:

- Mobile water provision plan
- Implementation of inundation prevention and attention plans
- Strengthening of early warning systems for agro-meteorological extremes and inundations
- Implementation of drought plans
- Hydraulic inundation walls: unidirectional structure to prevent urban flooding
- Resettlement of housing in danger zones and land purchases
- Agricultural insurances

Territorial law:

- Implementation of measures to appropriate soil use

Sustainable production and consumption:

- Green markets and businesses
- Product sowing and variety
- Crop protection against frost
- Crop protection in dry seasons
- Construction of irrigation districts
- Contour ploughing

Based on the above-mentioned adaptation measures, priority sectors and priorization criteria, 12 adaptation project profiles were elaborated in **Table 9**.

Table 9: Adaptation project profiles based on priority sectors and prioritization criteria of the PRICC modified after IDEAM et al., (2012).

Project	Objective	Adaptation measures
1. Conservation of strategic ecosystems	Encourage a recovery, ecologic restoration, and conservation project	• conservation, restoration, preservation • erosion and sedimentation prevention

for water supply vulnerable to CC	for a zone of sub-Andean humid forest or a dry forest in the West of the department	in areas of water bodies • conservation corridors • restoration of degraded ecosystems
2. Implementation of model for an environmental service bank	Adaptation and implementation of the BanCO2 model to allow the conservation of most vulnerable ecosystems through direct participation of rural communities	• restoration of degraded ecosystems • environmental responsibility
3. Strengthening of productive chains (for potato and sugar cane)	Establishment of a technical cooperation program that allows for the strengthening of the productive chain of the panela sugar cane (in Caparrapí, Guaduas, La Palma, Villeta and Útica) in order to promote rural development, natural resources and biodiversity management, and conservation of sensitive ecosystems	• product sawing and variety • crop protection against frost • crop protection against dry seasons • incorporation of biodiversity conservation systems in productive systems • sustainable production and consumption
4. Design and construction of an irrigation district in the Tequendama region	Supplying the Tequendama region with an irrigation district	• construction of irrigation districts • modernization of irrigation techniques
5. Maintenance and amelioration of water bodies and streams for water regulation and reduction of hydric stress	Establishing a water body maintenance and amelioration program through dredging, renaturation and flood zone protection	• river renaturation • protection of flood areas
6. Construction of sustainable buildings	Promotion of new technologies for the development of sustainable construction initiatives that allow for the regulation of temperature and for the drainage of rainwater in urban centres	• construction materials and waste management for sustainable construction • infrastructure with eco-materials • green covers (e.g. facades, roofs, window boxes, urban forests, hanging gardens, green roads) • blue rooftops for excess water management
7. Stabilization of slopes through bioengineering work	Design and implementation of projects for slope stabilisation through bioengineering activities in Silvania, Facatativá, Subachoque, Quipile, Viani, Villeta, Zipaquirá	• erosion and sedimentation prevention in areas of water bodies • soil strengthening through appropriate sowing and renaturation of plant cover
8. Strengthening program for climate event early warning systems	Generate public-privat alliances for the strengthening of early warning systems and the regional coordination in risk management and CCA topics	• strengthening of early warning system for agrometeorological extreme events and inundations
9. Alternative use of protected land due to risks	Realization of a study to establish possible soil use for risk areas	• land use control
10. Promotion of risk transference schemes	Promotion of alternatives for hydrological resources use and reuse in regions most affected by reductions in water availability (e.g. Mosquera,	• agricultural insurances • agricultural incentives • economic and financial tools

	Soacha, Pasca, Supatá, Guachetá, Fúquene, Tausa, Facatativá, Subachoque, Cáqueza and Fómeque) through grey and rainwater use in urban areas	
11. Follow-up and evaluation of mitigation and adaptation projects	Establishment and identification of tools and schemes that allow for climate change risk reduction in productive sectors	• continuous up-dating of needs and strategies
12. Promotion of alternative water use and reuse in Bogotá's residential area	Establishment of dissemination and follow-up mechanisms to CCA measures	• water saving, efficient use, and distribution • reduction of consumption • water recycling and grey water use • rainwater management: collection, storage and distribution

4-year Action Plan Cundinamarca (PAC)

The 4-year Action Plan of Cundinamarca (PAC) 2016-2019 is the CAR's planning instrument directed at the institutional commitment that serves as guide for climate change adaptation actions in the jurisdiction of the CAR. It follows the criteria and principles of environmental management elaborated in the National Development Plan 2014-2018 and the Bicentennial Vision of Colombia, and is aimed at the achievement of the goals and objectives suggested by the Regional Environmental Management Plan (PGAR). (CAR, 2016)

The PAC 2016-2019 plants 22 projects with respective goals and objectives, for which 111 indicators were developed (see **Table 10**).

Table 10: Projects with their goals, objectives and indicators from "harmonization of the PAC 2016-2019 and the PGAR 2012-2023" modified after CAR (2016).

Strategies	Programs	Projects
Social innovation and regional identity towards environmental sustainability	Environmental Culture	1. Knowledge management and environmental innovation 2. Culture for environmental protection
	Regional leadership in the SINA	3. Support for the construction of national, regional and municipal policies, norms and tools for the environmental management
	Incidence of territorial models	4. Identification of the state or natural resources
Social fabric for joint environmental responsibility	Regulation and governance	5. Service culture to strengthen environmental management 6. Environmental authority in the CAR territory 7. Evaluation control and surveillance of the use, management, exploitation and mobilisation of natural resources 8. Integrated Unit of Environmental Governability UIGA 9. Management for institutional strengthening and development 10. Administrational infrastructure and documental management
	Inter-institutional and social interaction spaces	11. Clean production and green businesses 12. Spaces for civil participation and negotiation of environmental management 13. Soil and water conservation for environmental sustainability

Protection and sustainable use of natural elements with territorial expression	Watershed approach	14. Management and regulation of hydrological catchments 15. Infrastructure for environmental management 16. Hydrologic regulation and hydraulic adaptation
	Environmental determinants	17. Conservation and protection of the principal ecological structure (EEP) 18. Planning, agreement and follow-up of the environmental component in the territorial law
	Mainstreaming of risk management and climate change	19. Climate change and risk knowledge 20. Risk reduction and mitigation, and disaster assistance 21. Integrated program of municipal eco-sustainability with focus on alternative energy
	Megaproject Bogotá river	22. Hydraulic adaptation and environmental recovery of the Bogotá river and other actions of integrated catchment remediation

Of the three strategies the "Protection and sustainable use of natural elements with territorial expression" is given the most weight with 60 %, while "Social innovation and regional identity towards environmental sustainability" and "Social fabric for joint environmental responsibility" are weighed 20 % each. Of the nine programs the "Watershed approach" and the "Bogotá river megaproject" are given the most weight, while the "Regional leadership in the SINA" is given the least weight. (CAR, 2016)

To all of the above-mentioned projects there are specific objectives (see **Table 11**) to be achieved and evaluated by 2019:

Table 11: Projects and their objectives based on the 4-year Action Plan of Cundinamarca (PAC) modified after CAR (2016).

Projects	**Objectives**
1. Knowledge management and environmental innovation	• Position and strengthen knowledge management system and environmental innovation
2. Culture for environmental protection	• Implement strategic plan of culture about water • Implement strengthening plan for waste management culture: Ciclo Re Ciclo • Implement formation process for increasing adaptive capacity in the face of CC and risk prevention • Implementation of educational communication plan • Implementation of prioritized actions for strengthening of territorial plans of environmental education
3. Support for the construction of national, regional and municipal policies, norms and tools for the environmental management	• Formulate prioritized suggestions to strengthen and harmonize policies, norms and tools for environmental management of the SINA
4. Identification of the state or natural resources	• Realize 20 campaigns annually about monitoring of catchments of 2nd order with the calculation of water quality index (ICA) and define riparian buffer zones of 96 priority streams • Monitor, diagnose and model 2 priority aquifers • Determine water demand and offer in 4 priority catchments • Operate and maintain monitoring nets and implement an environmental technological monitoring system • Implement priority actions for 6 fauna or flora species with conservation management plans, and elaborate management plan for 4 flora or fauna species or ecosystems • Monitor and diagnose soil resources in 4 areas of 2nd order catchments • Monitor, model and annual follow-up of air quality in 7 priority zones

	• Maintain, implement and update environmental and geographical information system of the CAR and report information • Setting up of environmental research centre (CIA) • Setting up or validation of 20 techniques of environmental matrices (water, air and soil) for the maintenance of accreditation of the CIA and broadening of its services • Realize environmental economic assessment in priority zone of a protected area
5. Service culture to strengthen environmental management	• Implement the institutional assistance and service plan • Implement the strengthening plan for the environmental documentation centre of the CAR
6. Environmental authority in the CAR territory	• Solve 7000 files opened up to 2015 that are still in process • Solve all environmental authorizations in the established time frames • Attend all environmental complaints and violations filed since 2016 • Realize follow-up to 9000 environmental permits, concessions and authorizations and/or passed programs of efficient use and saving of water (PUEAA)
7. Evaluation control and surveillance of the use, management, exploitation and mobilisation of natural resources	• Realize annual control of wastewater activities in 7 2nd order catchments • Follow-up of approved basic sanitary and discharge management plans • 1000 actions of control and surveillance of use, exploitation and commercialization of plant resources • Evaluation and environmental surveillance of mining activities with 1750 actions • Elaborate and develop a plan for prevention, control, surveillance and management of invasive and predatory fauna • Accomplish priority activities of the hazardous waste management plan • Annual follow-up to the solid waste management plan • Evaluate and follow-up of plans to offensive odour impact reduction • 16 follow-ups to the environmental management plan of the Muña reservoir or of the industries in its influence area
8. Integrated Unit of Environmental Governability UIGA	• Realize 40 operations to high impact activities that include the use, management or mobilization of natural resources, and strengthen permanent surveillance in the territory
9. Management for institutional strengthening and development Administrational infrastructure and documental management	• Implement priority actions of the strategical plan about information and communication technologies • Implement priority actions of the online government strategy • Follow-up, up-dating and improvement of the integrated public management system • Implement the strategy of institutional positioning • Strengthen institutional management through subscription and execution of 20 interinstitutional cooperation tools
10. Administrational infrastructure and documental management	• Manage the documentary organization of 24 archives of central and regional dependencies like the assessment of the central historical archive • Build an administrational headquarter of the corporation • Maintain and equip 10 administrational seats to the entity
11. Clean production and green businesses	• Promote environmental participatory self-management processes for transformation towards sustainable production systems in 200 businesses • Implement the regional program for green businesses • Promote or follow-up 24 sustainable chains in the frame of environmental self-management
12. Spaces for civil participation and negotiation of	• Intervene in all socio-environmental conflicts prioritized in the scope of the CAR's environmental observatory

environmental management	• Implement priority formation processes to strengthen the environmental management capacity of communal and social organizations • Implement 300 projects of social undertaking for environmental conservation (ESCA) • Implement the ancestral ethnic agenda with indigenous communities
13. Soil and water conservation for environmental sustainability	• Intervention of 3500ha in erosive areas, with biomechanical and bioengineering constructions, and conservational agricultural and livestock labour • Provide technical assistance to 4000 peasant families about conservation techniques in agriculture and livestock farming • Implement dissemination strategy of soil and water conservation principles for environmental sustainability • Implement educational strategy for the promotion of the tree as generator of environmental services (Cultura del Árbol)
14. Management and regulation of hydrological catchments	• Formulate and up-date POMCAs in 5 catchments • Implement priority actions of POMCAS • Formulate and adopt regulation plan of hydrological resources in a water body in the CAR territory • Formulate the general forestry regulation plan for the CAR territory • Realize the regulation of 40 water bodies
15. Infrastructure for environmental management	• Administrate, operate and maintain the infrastructure of parks • Accomplish annual objectives of priority projects for infrastructure and basic sanitation development • Accomplish annual objectives of priority projects for environmental management infrastructure
16. Hydrologic regulation and hydraulic adaptation	• Realize administration, operation and maintenance processes of infrastructure in the 3 reservoirs, the 2 hydraulic systems for environmental management and flood control, and the machinery bank of the CAR • Accomplish annual objective of priority projects in hydrological infrastructure development • Accomplish annual objective of priority projects in hydraulic adaptation and maintenance
17. Conservation and protection of the principal ecological structure (EEP)	• Re-delimitation and re-categorization of 5 protected areas • Declaration process of 3 new protected areas • Delimitation and characterization of 190 strategical ecosystems (wetlands and páramos) • Formulation and up-dating of 8 environmental management plans of protected areas and strategical ecosystems • Implement 10 % of the action defined in the priority environmental management plans of protected areas and strategic ecosystems • Intervene 4000ha with conservation actions, reforestation, recovery, restoration or rehabilitation
18. Planning, agreement and follow-up of the environmental component in the territorial law	• Implement priority actions in the urban environmental management program • Follow-up of 50 municipalities advised in the environmental management system for municipalities, and advise 30 new municipalities • Support the updating of 30 municipalities • Advise and assist all municipalities in the incorporation of the environmental determinants in the process of revision and adjustment of the territorial law plans (POT)
19. Climate change and risk knowledge	• Identify, spatialize and monitor annually critical risk points in the 105 municipalities of the CAR • Design studies for risk knowledge in 10 catchments

	• Implement the priority measures for climate variability and change impact reduction • Advise all territorial entities in climate change and risk management knowledge
20. Risk reduction and mitigation, and disaster assistance	• Implement annual objective in risk reduction • Support disaster assistance activities in all emergency priority points
21. Integrated program of municipal eco-sustainability with focus on alternative energy	• Formulate and implement the integrated program for alternative energies and sustainable environmental management in a priority municipality
22. Hydraulic adaptation and environmental recovery of the Bogotá river and other actions of integrated catchment remediation	• Reach at least 50 % of the execution of ampliation and optimization of the Salitre wastewater treatment plant • Execute the hydraulic adaptation of the Bogotá river • Execute integrated sanitary actions • Hydraulic adaptation and environmental recovery of the Bogotá river in priority sections with technical assistance studies and availability of the necessary properties to implement the intervention • Reduce flood risk and improve water quality • Create multifunctional areas alongside the Bogotá river

Integrated National Adaptation Project (INAP)

The Integrated National Adaptation Project (INAP) 2006-2011, technically supported by IDEAM and coordinated by Conservation International Colombia (CIC) was the first strict climate change adaptation project in Colombia (The World Bank, 2012). The objective of the INAP is to define and implement specific pilot adaptation measures and policy options to meet projected impacts of climate change. Its suggestions focus on the implementation of ecosystem-based adaptation measures in the area of high mountain ecosystems, insular areas, and human health concerns related to the expansion of areas linker to malaria and dengue. (The World Bank, 2006) One of the main impacts of the INAP was the creating of a new framework for adaptation to climate change in the Colombian government, the elaboration of national and sectorial policies like the national hydrological policy and the regional health plans, and the empowering and strengthening of institutions. (The World Bank, 2012) The INAP consists of four components:

A. Production of climate, climate variability and climate change information for support in decision making
B. Design and implementation of an adaptation program to guarantee the maintenance of environmental services in the Chingaza massif.
C. Design and implementation of an adaptation program for insular areas in the Colombian Caribbean
D. Response to the increased exposition to tropical vector diseases (malaria and dengue) due to climate change,

of which especially A and B are of importance to the department of Cundinamarca. (MADS *et al.*, 2011)

In the scope of component A. Climate information production for decision making, four activities were performed in order to

- improve the technical and scientific capacity,
- produce climate change information,
- generate climate change scenarios to support the implementation of CCA measures,

- and complement and strengthen the climate change data network.

Some achievements in these sectors were the up-dating and acquisition of new technologic equipment for data compilation, processing and analysis, the modelling of future climate projections, the improvement of weather forecasts all over the country and the complementation and strengthening of the weather station network for climate change monitoring. (MADS *et al.*, 2011)

In the scope of component B. Adaptation program for the maintenance of environmental services in the Chingaza massif, the following four adaptation measures were implemented:

- Directing the climate change information in the planning and management of the Chingaza massif
- Reducing adverse impacts of hydrological regulation in the Bogotá river catchment
- Developing land use planning models that incorporate climate change impacts
- Improving the productive agroecosystems in the catchment

Some achievements in these sectors were information analysis and modelling of water and carbon cycles in high mountain systems in order to simulate the expected evolution of páramo and high mountain ecosystems in different climate scenarios. Eight automatic measuring stations were put up beside others in the Chingaza massif and pilot research work was elaborated. (MADS *et al.*, 2011)

In order to reduce negative impacts in the Río Blanco catchment, ecological restoration actions were implemented under the aspect of local and social participation, including pedagogical meetings for decision making and identification of traditional knowledge. Examples are vegetation covers of riparian buffer zones and life fences both consisting of native plant species. An experimental centre for germination and propagation of high Andean species was built. In order to improve productive agroecosystems in the Río Blanco catchment of the Chingaza massif agroforestry systems were promoted. Through the elaboration of a study, productive systems were characterized and mapped, and environmental, socio-cultural and economic vulnerabilities were identified. Alternative practices were elaborated, and areas of special importance were defined. The reduction of chemical fertilizer, the planting of live fences, the protection of water sources, the installation of drip irrigation systems, and slope conservation beside others are some of the achieved actions. Community trainings about the implementation of sustainable livestock, agriculture and agroforestry systems, about appropriate technologies, improvement of pastures and animal genetics, processing of dairy products, corporate management and basic sanitation were held. Also, the implementation of a silvopastoral system, three agroforestry systems, and more live fences and water source protections were planned up to 2050.

For the inclusion of climate change impacts into land use planning the municipalities of La Calera and Choachí were accompanied and technically assisted in their adjustment of territorial law schemes. Training activities and information interchanges were organized, and advances were made in the definition of Adapted Ecological Territorial Structure (EETA) as a network of spaces and corridors for the maintenance of biodiversity and ecosystem services. Its central axis is the maintenance of hydrological resources and thus the protection of the páramo system, the high mountain wetlands, the aquifer recharge zones and the main drainage network. Additionally, the municipalities of the pilot area were supported in the elaboration of risk management plans and adaptive life plans were elaborated in several sectors of La Calera and Choachí. A territorial vulnerability analysis was worked out and climate change topics were included in the primary and secondary school curriculum. (MADS *et al.*, 2011)

While components C and D are important on a national scale, they don´t specifically consider the area of Cundinamarca, in case of component C because there are no insular regions in the central region of the country and in the case of component D because vector diseases were not especially considered for the area of Cundinamarca. However it is worth to mention that the INAP helped to incorporate climate change elements in health planning, programs and policies and to build a frame to understand the role of climate in the health sector. (MADS *et al.*, 2011)

Table 12 summarizes the main goals, objectives and strategies of the above-mentioned climate change adaptation plans and projects.

Table 12: The main goals, objectives and strategies of the mentioned climate change adaptation plans and projects in Colombia and Cundinamarca.

Plan/project	Goals	Objectives	Strategies
TACC, 2016	• environmental sustainability • sustainable growth and territorial planning • disaster risk management • integration of CC into territorial development planning	• reduction of negative impacts of CC • facing of ozone layer reduction • solid waste and organic pollutant management • conservation, restoration and sustainable use of strategic ecosystems • rational and efficient energy use	• elaboration of a PRICC • training of institution and civil society • awareness rising • identification and prioritization of CCA measures
Nat. strategy for CC education, formation and sensitization, 2010	• establishment of guidelines for the implementation of programs and projects of CC education, formation and sensitization	• information access • public awareness • training • education • research • participation	• promotion of public access to CC and CCA information • awareness raising and fostering behavioural changes • development of capacities, skills and scientific competences to face CC issues • inclusion of CC into education • knowledge generation about social, economic and environmental aspects of CC • promotion of public participation in planning, execution, monitoring and evaluation of CC programs and projects
PNACC, 2012	• prioritization of adaptation actions for long-term sustainability and competitiveness	• reduction of climate change and variability risks and impacts • reduction of vulnerability (of settlements, ecosystems and productive sectors) • increase of social, economic and ecosystem responsive capacity to climate hazards	• planned CCA: identification, prioritization, implementation, evaluation and follow-up • incorporation of climate risk and CC management in planning documents • local, territorial and participatory actions • awareness raising • information generation • land use planning
PNACC,	• guidance to	• CC knowledge	• strengthening of knowledge

2016	decision making and knowledge management • reduction of losses or expected damages	management • incorporation of CCA in sectorial and territorial development planning • sustainable, competitive and equitable development • green growth	generation and management • CC education, communication, training and awareness raising • strengthening of institutional capacities for CCA • incorporation of CC in national planning instruments • management of CC impacts on biodiversity & ecosystem services • adaptation of agriculture, livestock farming and food security to CC • prospective risk reduction in basic infrastructure
Guide to CC AbE in Colombia, 2018	• articulation of the implementation of the PNCC • maximization of the role of socio-ecosystems in climate risk reduction and resilience increase	• biodiversity and ecosystem service use as CCA strategy • biodiversity and ecosystem service protection and increase	• restoration, reforestation, regeneration (e.g. wetland ecosystems, springs, riparian buffer zones, live fences) • rainwater harvest and use • agroforestry and silvopastoril systems • bioengineering constructions
PRICC, 2012	• strengthening the capacity of local governments to create CC resilient territories • vulnerability reduction • improvement of life quality • loss prevention & revenue increases	• definition of strategic action lines and CCA project portfolios for the sectors of energy, transportation, livestock, agriculture, mining and waste	• hydrological resource management • soil resource management • biodiversity management and ecosystem services • sustainable production and consumption • financing of mitigation and adaptation – public policy • education, training, public access to information
PAC, 2016-2019	• achievement of the goals and objectives suggested by the PGAR	• protection and sustainable use of natural elements with territorial expression • social innovation and regional identity towards environmental sustainability • social fabric for joint environmental responsibility	• environmental culture and knowledge management • strengthening of regional leadership with policies, norms and tools for environmental management • regulation and governance with evaluation control & surveillance of the use of natural sources • inter-institutional and social interaction spaces for civil participation • management and regulation of hydrological catchments • mainstreaming of risk management and CC
INAP, 2006-2011	• definition and implementation of specific pilot adaptation measures and policy options to	• creating a framework for CCA in the Colombian government • elaboration of national and sectorial politics for CCA	• improvement of technical and scientific capacity • production of CC information and generation of CC scenarios • strengthening of the CC data network

	meet projected CC impacts • focus on ecosystem-based adaptation measures in high mountain ecosystems, insular areas, and human health related to vector diseases	• production of climate, climate variability and climate change information for support in decision making • design and implementation of an adaptation program to guarantee the maintenance of environmental services in the Chingaza massif	• directing CC information in the planning and management of the Chingaza massif • reduction of adverse impacts of hydrological regulation in the Bogotá river catchment (through ecological restoration, social participation, pedagogical meetings, live fences) • development of land use planning models that incorporate CC impacts (risk management plans) • improvement of productive agroecosystems (agroforestry systems, alternative practices, community trainings for sustainable livestock, agriculture and agroforestry systems)

4.1.5 Categorization and qualitative analysis of the plans and projects

In order to analyse the general tendencies of climate change adaptation plans and projects in Colombia and more specifically Cundinamarca, they are categorized according to different criteria based on categories established by McDowell *et al.* (2018). The categories include the motivation for adaptation, the initiative of adaptation, the nature of adaptation, the methodology of adaptation, the knowledge basis of the adaptation, the involved sectors in the adaptation, the leading actor of the adaptation, the vulnerable groups addressed in the adaptation and the spatial scale of the adaptation. A complete table including the categories suggested by McDowell *et al.* (2018) can be found in **Annex 4**. The most relevant and differing categories are elaborated in **Table 13** for the plans and projects presented in the last part of the preceding subchapter.

Table 13: Analysis of the climate change adaptation suggested and executed by the different plans and projects presented in chapter 4.1.

	Motivation and initiative of CCA	**Nature of CCA**	**Sectors addressed**	**Leading actor**	**Spatial scale**
TACC, 2016 (plan)	climatic and non-climatic stressors anticipatory	regulatory	sustainable development, hazard risk management	intergovernmental organizations (UNDP), academic institutions (IDEAM)	national
National strategy for CC education, formation and sensitization, 2010 (plan)	climatic and non-climatic stressors anticipatory and reactionary	educative, research/ knowledge based	environmental conservation	academic institutions (IDEAM)	national
PNACC, 2012 (plan)	climatic stressors anticipatory	regulatory, research-based, educative	sustainable development, hazard risk management,	national institutions (DNP, MADS, UNGRD)	national
PNACC, 2016 (plan)	climatic stressors anticipatory	research based, regulatory, educative	sustainable development	national institutions (DNP, MADS, IDEAM, UNGRD)	national
AbE, 2018	climatic and	regulatory,	sustainable	national	local, community

(guide)	non-climatic stressors anticipatory	behavioural	development, ecosystem conservation	institutions (MADS)	level
PRICC, 2012 (plan)	climatic and non-climatic stressors anticipatory and reactionary	behavioural, research based, educative, implementation of technologies	sustainable development, environmental conservation, hydrological resources, agriculture and livestock farming, hazard risk management	national (MADS, DNP, parques), regional (Alcaldia de Bogotá, Gobernacion de Cundinamarca, CAR, Corpoguavio) and academic (IDEAM, IAH) institutions	regional
PAC, 2016-2019 (plan)	climatic and non-climatic stressors anticipatory and reactionary	regulatory, knowledge based, behavioural	agriculture, hydrological resources, hazard risk management, environmental conservation	regional institutions (CAR)	regional and local
INAP, 2006-2011 (project)	climatic stressors anticipatory	behavioural, educative, research based	agriculture, forestry, hydrological resources, hazard risk management, environmental conservation	academic (IDEAM) and national (CIC) institutions	regional and local

Many of the CCA plans and actions suggested and implemented are motivated not only by climatic stressors but by non-climatic stressors. The mentioned non-climatic stressors are mainly linked to ecosystem and biodiversity degradation, the contamination and loss of natural resources, and the need for sustainable economic development. Deforestation, soil degradation, water contamination and food insecurity are the non-climatic problems that are most mentioned to be of concern and to motivate adaptation actions. Temperature increases, water scarcity, droughts and extreme precipitation events are the climatic stressors that most motivate adaptation actions.

Most of the adaptation plans and projects are not just reactionary but rather anticipatory initiatives. Meaning that they anticipate potential future stressors (especially in the case for climatic stressors) and prepare for them instead of just coping with situations they are already presented with. In the case of non-climatic stressors like environmental degradation they are strongly reactionary.

The plans and projects include adaptation actions of regulatory, behavioural, educative and research-based nature mainly. Most of them suggest regulations in territorial and land use planning as well as the establishment of protected areas destined for conservation and restoration. The improvement of productive systems in agriculture and livestock farming through alternative practices, agroforestry, silvopastoral systems, rainwater harvest and irrigation is the most promoted behavioural action. Educative actions include the incorporation of climate change into the education system, training of the civil society, awareness raising and the public participation in the design and implementation of pilot projects and adaptation actions. Research-based adaptation is mainly present in hazard and disaster risk management.

All of the plans and projects pursue a participatory methodology including the civil society and local communities.

The sectors most addressed are hazard risk management, environmental conservation, agriculture and forestry.

The big majority of the considered CCA plans and projects engage with the physical science basis of climate change and consider the local literature about climate change and variability impacts, climate vulnerability and social dimensions like socio-economic, socio-ecologic and political factors.
For all considered CCA plans and projects international, national, regional and/or academic institutions are the leading actors. Most involved actors are national institutions like the MADS, the DNP, the UNGRD, regional institutions like the CAR, academic institutions like the IDEAM and international institutions like the UNDP and CI.
On a spatial scale, most plans and projects suggest adaptation actions of regulatory and educational nature on a national level, but especially research-based and behavioural actions on a regional and local level.
There are no vulnerable groups addressed specifically. The CCA plans and actions suggested and implemented are based on territorial vulnerability, but do not specifically address highly vulnerable groups like the poor, elderly, minorities or women.

McDowell et al. (2018) distinguish between adaptation action and adaptation research, where adaptation action refers to individual or collective responses to climatic stimuli as tangible efforts to address climate-related changes. Adaptation research on the other hand uses formalized methods to evaluate adaptation actions and options and generates insights that deepen understanding of existing adaptation actions and future adaptation possibilities.
While adaptation action and its planning are well diffused in Colombia´s politics and planning, adaptation research is almost inexistent.
One example is the disaster risk management performance index that was developed by Carreño, Cardona and Barbat (2007) and applied for the case of Colombia and Bogotá. However, this index is not currently used for CCA evaluation in Colombia.
The guide to the formulation and monitoring of the action plans of the CARs and of sustainable development 2007-2011 by MADS (2009) proposes mechanisms for follow-up and evaluation that are based on management monitoring, performance evaluation indices, and social control. A monitoring matrix for management and advance of physical and financial targets can be found in **Annex 5**. However, the guide does not provide specifications on how the indices are to be calculated.
CAR (2016) suggests the setting of quantifiable targets and the use of achievement indicators (e.g. number of actions or interventions, percentage to which an activity was carried out).
The performance evaluation is then based on physical and financial efficacy and on management capacity. However, while this allows to evaluate an institution, it does not contribute to the evaluation of specific CCA measures.
In the evaluation of the PRICC, Otter and Escovar (2014) state that the reviewing of project reports and management documents revealed that no systematic and periodic monitoring had been made to report the project advances. They find that documents mainly reported advances in the implementations of activities in a descriptive way, and only marginally reported advances in the expected results.

4.2 Registry of regional adaptation measures

This sub-chapter addresses the regional adaptation measures in Colombia and specifically the analysis of adaptation measures and projects in Cundinamarca. It presents a consolidation of all the regional climate change adaptation measures taken by the Regional Autonomous Corporation of Cundinamarca (CAR). That registry is analysed in a simple quantitative way.

4.2.1 Quantitative analysis of CCA measures by the CAR

In order to quantitatively analyse climate change adaptation in Cundinamarca, a consolidation of CCA measures taken by the CAR is presented here. According to the CAR´s CCA contracts of 2014, 2015, 2016, 2017 and 2018, the measures that were taken during this period are isolation of areas of ecological importance, live fences, connectivity creation between forest relicts through ecological restoration, bio-engineering constructions, agroforestry systems and silvopastoral systems (CAR, 2019a).

A total of 89 punctual adaptation actions were taken by the CAR in the years of 2014-2018. 26 of them were taken in forest connectivity, 25 in isolation, 14 in agroforestry systems, 11 in live fences, 9 in silvopastoral systems and 4 in bio-engineering constructions (see **Figure 24**). Beside these measures, workshops to strengthen CC knowledge were organized in all the municipalities that count with the implementation of the mentioned CCA measures. **Figure 25** shows the municipalities where CCA measures were carried out and their location in Cundinamarca.

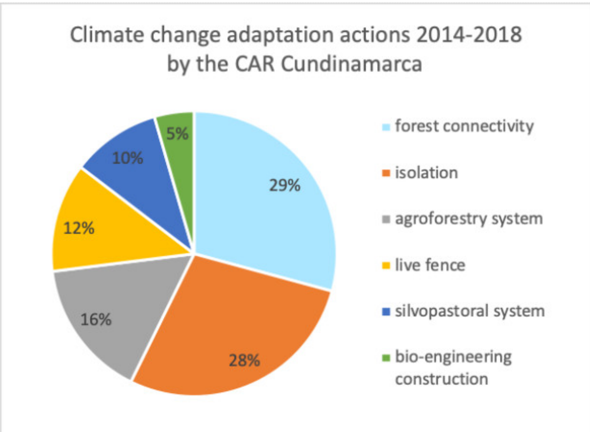


__Figure 24__: Percentage of the numbers of climate change adaptation measures taken in the six categories the CAR concentrates on. Source: Own figure based on data from CAR, 2019a

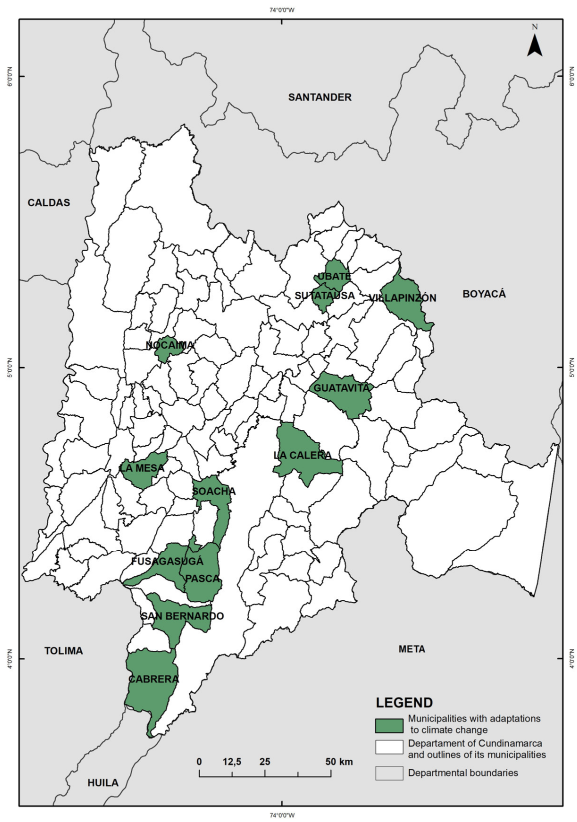


__Figure 25__: The department of Cundinamarca with all the municipalities in which climate change adaptation measures were implemented by the CAR. Source: ArcGis based on data from CAR, 2019a

All of the climate change adaptation measures are ecosystem-based, meaning that they aim at the ensuring of the environmental functioning and the combination of productive systems with natural ecosystems in order to benefit from the services provided by the natural ecosystems.

Ecological restoration is the recovery of the ecological characteristics of the affected ecosystems and aims at the recovery of their ecological functions like water regulation, carbon capture and soil protection. In order to connect ecosystems, to conserve ecosystem services, to provide terrestrial and aquatic habitats and to contribute to a diverse fauna and flora, the vegetation cover is increased using native plant species. (CAR, 2019c) The isolation of areas of ecological importance aims at their protection from any kind of anthropic pressure and is carried out with help of wooden posts and barbed wire. (CAR, 2019c) Live fences are used for the delimitation and protection of water sources in order to reduce the fragility of the hydrological system. They also improve soil stability and serve as wind barriers for the protection of plantations. (CAR, 2019d) In agroforestry systems forest trees and cultivation crops are alternated sequentially in order to reduce the crops´ vulnerability to climate change. Crops are less exposed to the direct impact of intense precipitation events, extreme heat, or wind, and the trees also help reduce soil erosion. (CAR, 2017a) Silvopastoral systems combine livestock farming and silviculture creating benefits for the soil and the animals. The trees serve as alternative food source, when pasturing grass becomes scarce, they provide shade to the livestock, act as live fence and may be used for wood production. (CAR, 2017a) An example of bio-engineering constructions is the implementation of dikes and terraces for sediment retention. Both can be used in areas with steep slopes to inhibit erosion, mass movements and soil loss caused by soil instability. (CAR, 2019c)

10.88 km of isolation actions were taken along streams and around water sources. They are located in San Bernardo (4.65 km), in Villapinzón (2.22 km), in Pasca (2.18 km), in Villa de San Diego de Ubaté (1.56 km) and in Sutatausa (0.24 km). The connectivity between forest relicts was restored over a total area of 304 ha in Villapinzón (171.9 ha), Cabrera (114.59 ha), La Calera (6 ha), Soacha (3.5 ha), Fusagasugá (3.5 ha), San Bernardo (2.5 ha), Villa de San Diego de Ubaté (1.02 ha), La Mesa (0.87 ha) and Sutatausa (0.02 ha). Silvopastoral systems were implemented on 8.5 ha. This action was undertaken in Pasca (4.5 ha), Villa de San Diego de Ubaté (1.89 ha), Villapinzón (1.1 ha) and San Bernardo (1 ha). A total of 7.24 ha of live fences was set up in San Bernardo (4.24 ha), in Pasca (2.6 ha) and in Fusagasugá (0.4 ha). Agroforestry systems were implemented on 5.44 ha in Pasca (2 ha), Villa de San Diego de Ubaté (1.74 ha), San Bernardo (1.17 ha) and La Mesa (0.53 ha). Four bio-engineering constructions were set up, two of them in La Calera and one of them each in Guatavita and Nocaima. (See **Figure 26**)

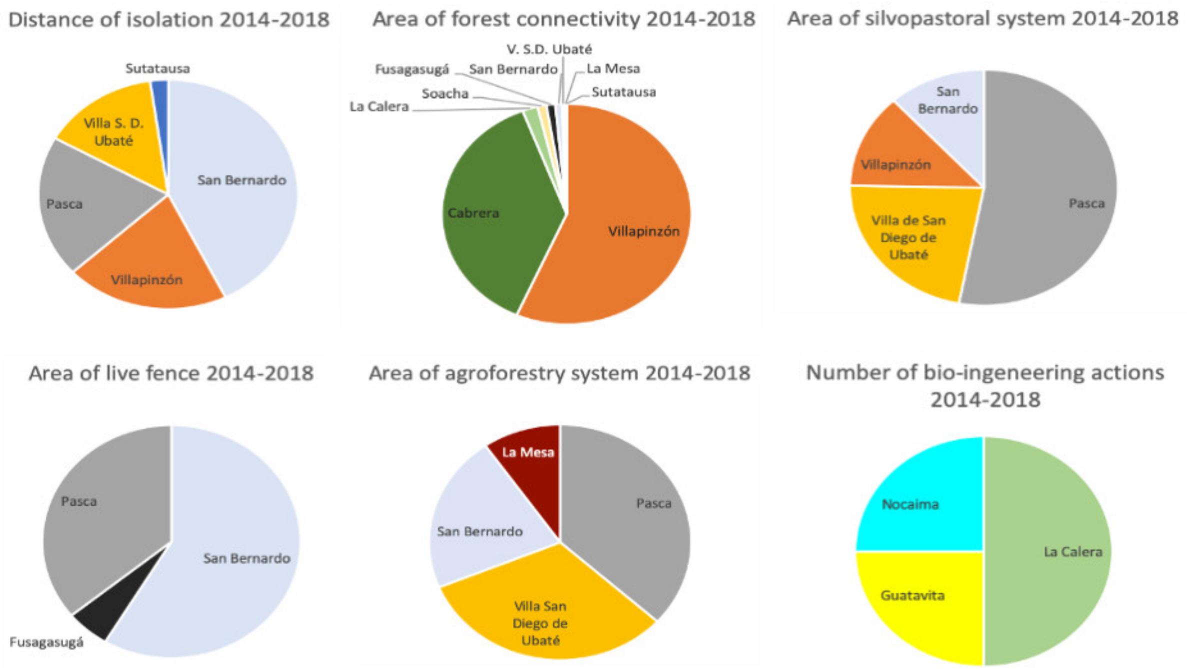


Figure 26: Visualization of the distribution of climate change adaptation measures implemented by the CAR in different municipalities during the period of 2014-2018. Source: Own figure based on data from CAR (2019a)

It is important to be aware that in this work only adaptation measures initiated and lead by the CAR were considered. As climate change adaptation is often promoted and conducted by other private or public institutions (e.g. SETIS, gobernación, conservación internacional, junta comunal etc.) or initiated by local communities or individuals and not formally supervised, this register is not complete.

4.2.2 Discussion

Climate change adaptation in South and Central America is mainly ecosystem-based including the protection of important areas, conservation agreements and community management. (IPCC, 2014) According to IDEAM, UNDP, MADS, DNP and Cancillería (2017) the biggest part of climate change adaptation measures in Colombia are taken in the environmental sector with 71.4 % in hydrological resources and 21.5 % in biodiversity and forestry governance actions. The remaining part is located in the sectors of transportation, urban development and others. This tendency can also be confirmed for the department of Cundinamarca. All of the actions listed in the CAR´s consolidation of CCA measures are to some extent aimed at the protection or regulation of hydrological resources or the assurance of ecosystem functioning and biodiversity promotion.

The objectives most addressed in the national climate change adaptation discourse are risk management, land use planning and vulnerability reduction. Many of the adaptation measures suggested by the plans and projects in the first section of this sub-chapter do not seem to be elaborated specifically as an adaptation to climate change only, but they rather appear to be a response to environmental challenges. The same can be observed for the adaptation measures listed by the CAR. Many of the adaptation actions for example aim at the protection of hydrological sources and riparian buffer zones from contamination and pressure caused by the agriculture and livestock as well as the domestic sector.

While adaptation action and its planning are well diffused in Colombia´s politics and planning, adaptation research in the country is weak. In Colombia as well as in the department of Cundinamarca the information about the effect of CCA actions on the addressed situation is very limited. There is a lack in research that generates insights and deepens the understanding about the success and limitations of existing adaptation actions. This will hinder the efficient planning of effective adaptation in the future. McDowell and Koppes (2017) emphasize that beside adaptation research playing a supporting role in adaptation planning, the success of adaptation also depends on other factors as for example the decision-making context and the availability of resources.

4.3 Analysis and evaluation of local implementation and follow-up of adaptation measures

After landslides and strong winds during the La Niña phenomenon of 2010 and 2011, communities took reactionary adaptation measures that pushed the municipal administration and the environmental authorities towards CCA planning and vulnerability evaluations. (CAR, 2017d) Over the past five years the CAR was active in several municipalities working with different environmental offices on many projects. Some of the more recent implementations in CCA were made in Villapinzón, La Mesa, Villa de San Diego de Ubaté, Pasca, San Bernardo, Soacha, Beltrán, Jerusalén and Supatá. In Villapinzón monitoring plots were set up to evaluate the structure, biodiversity and carbon uptake of the páramo ecosystem. The project aims at the knowledge up-dating about the impacts of climate change on the páramo ecosystem services and at the training of students in the matter. In most of the other municipalities projects include ecologic restoration of ecosystems with native species of the local reference ecosystem, the isolation of areas of ecological importance like water sources, the protection of riparian buffer zones and other areas of interest with live fences, the connectivity creation between forest relicts, bio-engineering constructions, agroforestry systems and silvopastoral systems (CAR, 2019a). They aim at ecologic connectivity, the protection of hydrological resources, hydrological regulation, soil stability, the securing of ecosystem services and the generation of microclimatic conditions in the face of environmental degradation and climate change. For all of the municipalities the suggested CCA measures are based on local vulnerability analyses and the expected climate changes under RCP 6.0 for the period of 2011-2040. They are elaborated with the help of members of the local population in organizational and educational workshops, integrating local knowledge and the concerns brought forward by the inhabitants of the respective municipalities. These talks and workshops aim at the sensitization about climate change and the necessity of adaptation. In several municipalities there were also billboards placed with information about climate change and climate change adaptation (see **Figure 27**).

***Figure 27**: Billboards with information about climate change and climate change adaptation in Vereda Juan XXIII in Pasca with D. Escobar and A. S. Garzón. (left) and in the Neuta wetland in Soacha (centre and right). Picture source: Laura Niggli*

4.3.1 Case studies

In this chapter some of the CCA projects in the municipalities of Pasca, Soacha and Jerusalén (see **Figure 28**) are described in more detail. In an attempt to gain an insight and understanding of these CCA measures, the process and implications of their implementation, the reception of the local communities and the achievements and difficulties in their preservation, excursions were organized to accompany the CAR on their field work. Monitoring activities, educational and knowledge sharing workshops, and maintenance activities were analysed observing the work and interaction of several employees of the CAR and the environmental office in charge. The conversation with local community members, political and administrative leaders, contractors in charge of the maintenance and members of the CAR and the executive environmental office contributed to the understanding of the

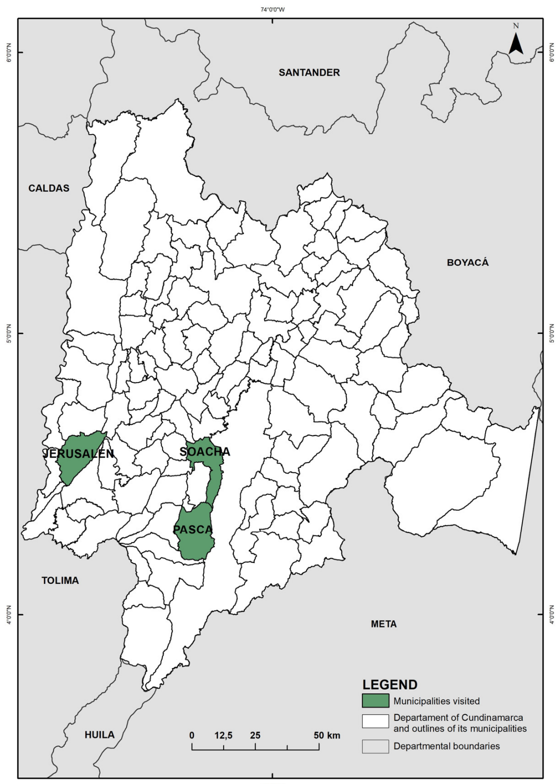


***Figure 28**: The municipalities in Cundinamarca that were visited in the scope of this work. Source: ArcGis*

context in which CCA measures are embedded. The evaluations made in the following section after the respective description of the CCA projects are based on the conversations and experiences made on these field trips.

Pasca

Part of Pasca is in the transition zone of the ecologic corridor of the Sumapaz páramo and the high Andean forest. This area is of great importance due to its diversity in flora and fauna and its provision of ecosystem services and at the same time is highly vulnerable to possible climate change impacts. Despite anthropic activities, in the Juan XXIII Vereda a high percentage of the native high Andean forest vegetation is still conserved. This can be explained by the low population density in the region due to displacements by the armed conflict in the past. (CAR, 2019b)
In the municipality of Pasca climate change adaptation measures were taken in the form of educational workshops for the municipality and of actions on several properties starting in 2017. (CAR, 2017b) Ecologic restoration, the setting up of live fences and the implementation of silvopastoral systems were carried out. (CAR, 2017a)

The following boxes contain information about some CCA measures carried out in the municipality of Pasca. They are based on information reports written by the CAR (2017a, 2017b, 2017c, 2019d).

Box 1.1: CCA measures taken by the CAR in the municipality of Pasca				
Project: Educational presentations and workshops **Objective:** Strengthening of knowledge about climate change and variability Sensitization about CCA based on the páramo ecosystem and the Andean forest				
Site	**Date**	**Measure**	**Activities**	**Observation**
Municipality of Pasca	2017	Popularization event	Workshops on 5 different dates	-
	2018	Educational talks	Popularization of the maintenance activities to the mayor´s office	-

Box 1.2 a: CCA measures taken by the CAR in the municipality of Pasca: Vereda Juan XXIII - Filadelfia				
Context: Forestry reserve fragmentated due to agriculture and livestock farming **Project:** Ecologic restoration and live fence **Objective:** Restoration of vegetation coverage and connection of forest relicts				
Site	**Date**	**Measure**	**Activities**	**Observation**
Vereda Juan XXIII Property Filadelfia	2017	Ecologic recovery on 2 ha Live fence on 1 ha	Planting of 2909 seedlings	-
	21.04.2017	Maintenance	Clean-up Fertilization Replacement	Mortality rate: 7 % Weed and grass grows quick. Regular maintenance is necessary.
	20.06.2017	Maintenance	Clean-up Fertilization Replacement	Mortality rate: 8 % Weed and grass grows quick. Regular maintenance is necessary.

	15.02.2019	Maintenance	Clean-up Fertilization Replacement	Mortality rate: 42.25 % Presence of rodents limits plant growth and grasses asphyxiate planted species.

Box 1.2 b: Evaluation of the CCA measures taken by the CAR in the municipality of Pasca: Juan XXIII

Evaluation based on a field trip on 02.12.2019:

The property was formerly bought by the CAR in order to protect and restore the forest it was originally covered with. While in 2017 the property was completely empty and covered only with pastures, in the present there is growing forest vegetation on a large area (see **Figure 29**). The mortality rate was very low in the beginning, but after there was no maintenance for more than one year it went up strongly. Some of the seedlings were tilted or snapped, and/or covered in pasture. Also a few of the already further grown trees were tilted as they lack a support or overgrown by parasitic plant species. However, generally the trees and bushes are strong and far grown. Another follow-up maintenance is advisable for part of the ecologic restoration. However, the contract between the CAR and the executing environmental office does not include another follow-up. An informal agreement is reached to carry out another maintenance activity in the Vereda Juan XXIII but to cut one implied in another CCA contract with the same environmental office. The agreement and the diversion of the maintenance activity are not mentioned in the technical report about the CCA measures taken in Pasca. This may lead to the loss of relevant information fundamental for the success of similar projects in the future.

Figure 29*: Vereda Juan XXIII, Pasca, in 2017 (top left) and in Dec. 2019 (top right and bottom right). The unloading and organizing of plant seedlings in Vereda Juan XXIII, Pasca, in Dec. 2019 (bottom left). Picture sources: CAR, 2019b (top left), Laura Niggli (top right, bottom left and bottom right)*

Box 1.3 a: CCA measures taken by the CAR in the municipality of Pasca: Vereda El Retiro

Context: Farmland exposed to constant passage of livestock
Unprotected stream draining into tributaries of the Sumapaz river

Project: Live fence, silvopastoral system and isolation of hydrological source

Objective: Protection of the stream La Trampa
Implementation of productive system that can cope with projected CC
Vegetation cover with plant species compatible with the reference ecosystem

Site	Date	Measure	Activities	Observation
Vereda El Retiro Property El Retiro	20.06.2017	3 live fences on a total of 1.32 ha	Planting of 992, 360 and 300 seedlings for 3 live fences	-
	2017	Maintenance	Clean-up Fertilization Replacement	Low mortality rate: 1.35 % Quick growth of grass. It is advisable to have maintenance in short time periods until the trees are big enough to outreach the grass.
	18.07.2017	816 m isolation of stream La Trampa	Installation of posts and barbed wire	-
	20.07.2017	Silvopastoral system on 4.5 ha	Planting of 1200 seedlings to divide the pastureland and for pruning of the livestock	-
	15.02.2019	Maintenance	Clean-up Fertilization Replacement of 650 seedlings	Mortality rate: 53 %
	21.08.2019	Educational workshop	Workshop about CC and sowing day	Participation of institutional sectors and inhabitants of the municipality of Pasca

Box 1.3 b: Evaluation of the CCA measures taken by the CAR in the municipality of Pasca: El Retiro

Evaluation based on a field trip on 02.12.2019:

The posts and electric fence previously installed to keep out livestock and prevent the destruction of seedlings for the silvopastoral system disappeared. Cows and horses had been allowed on the pasture and many of the seedlings and small trees had been treaded down. (see **Figure 30**) Talking to the local people in charge of the planting and maintenance actions we figured out the damage must have happened when they were away for a couple of weeks. The person in charge of the farmland said the municipality had rented it out as pastureland, while the mayor asserts it was not rented out. Nobody knew anything of the whereabouts of the posts and electric fence, but several local inhabitants affirmed that as these materials are expensive, they were most probably taken. The farmer living on the land stated that generally the farmers who use community land for pasturing bring their own fence and dismantle it once the move on to another pasture. The mayor was friendly and welcoming but couldn't help us anymore as the elections were due in less than a month. There was a general lack of clarity about who is in charge and who is responsible. It seemed like no one feels responsible and that there is no appropriation of the adaptation measure by the local community. There is a strong tendency of short-term thinking.

***Figure 30**: Planted tree seedlings in Vereda El Retiro in June 2017 (left) and in Dec. 2019 (right). Picture source: CAR, 2017a (left), Laura Niggli (right)*

The lack of clarity about who is in charge of a CCA project, may lead to the diffusion of responsibility. Also, a lack of interest, information and involvement of the community usually hinders the appropriation of a project, as its value and benefits are not internalised. Short-term thinking and stronger weighting of personal interests due to their financial and social situation leads people to take decisions harmful to projects aimed at the benefit of the broad community.

Changes and adaptations due to logistic and financial limits are often not mentioned in the final reports. This leads to the loss of information relevant for the execution and success of similar projects. As the CCA activities led by the CAR are meant to figure as educational pilot projects, the information they are based on, serves as indicative model for future projects. Gaps in the compiled information may thus lead to mis-recommendations for future CCA measures.

Soacha

The Neuta wetland is a natural water body that acts as a regulating system for surface runoff in its influence area, as a CO_2 sink, and a source for biodiversity. It is prone to being flooded during rainy season or high flow volumes. Uncontrolled urban spreading led to ecosystem fragmentation and domestic wastewater drainage into the wetland contaminates the water source. As the wetland was not fenced, the zone was accessible to transportation and was often traversed by cars. It was also used as landfill by some of the local inhabitants. (CAR, 2019b)

The aim of the CCA measures in the Neuta wetland is to preserve and recover its natural vegetation, soils and the associated fauna. The goal is to preserve and restore the conditions of the wetland where they have been altered by human activity. The restoration project was executed with the participation of the local community. (CAR, 2019b) The actions initiated by the CAR were broadened by the local association “friends of the Neuta wetland” and a small chagra (traditional countryside garden) was established for educational practices and awareness rising. At the group´s initiative the seedlings in the garden centre are grown following alternative practices like biological pest control, associations with herbs and flowers etc. (Yesid from SETIS, personal communication, 06.12.2019)

Social tensions have been high during the implementation of the measures. Vegetation material has been stolen and seedlings have been destroyed in some areas. A total of 5600 seedlings were planted. (CAR, 2019b)

The following boxes contain information about the CCA measures carried out in the context of the Neuta wetland in Soacha. They are based on information reports written by CAR (2019b, 2019c, 2019d).

Box 2a: CCA measures taken by the CAR in the municipality of Soacha: Neuta wetland

Context: Strategic wetland reduced and contaminated due to anthropic pressure

Project: Ecologic restoration

Objective: Restoration of vegetation cover to ensure hydrological regulation and to generate habitats for biodiversity as well as a green space in the urban context of Bogotá

Site	Date	Measure	Activities	Observation
Humedal Neuta	15.07.2017	Ecologic restoration on 1.4ha	Planting of 2012 seedlings in the area of Lagos de Malibu	Some community members participated in the implementation through “tree adoption” days
	17.08.2017	Ecologic restoration on 1.2ha	Planting of 2148 seedlings in the area of Parque Campestre	Some community members participated in the implementation through “tree adoption” days
	19.08.2017	Ecologic restoration on 0.9ha	Planting of 1440 seedlings in the area of Ducales I	Some community members participated in the implementation through “tree adoption” days
	2017	Educational billboards	Mounting of 6 billboards about CC, biodiversity, hydrological regulation etc.	-
	From 2017	Maintenance	Weed control, plant replacement, fertilization, irrigation and phytosanitary control is recommended every 2 months for 2 years	Plant maintenance, waste collection etc. is all based on voluntary work.
	15.02.2019	Maintenance	Clean-up Fertilization Replacement of 1300 seedlings	High mortality rate of 69 % due to little precipitation, strong winds, clayey soils and quick growth of grass. It is advisable to have maintenance in short time periods until the trees are big enough to outreach the grass.
	13.05.2019	Project presentation	Mainstreaming of the project to the municipality of Soacha and educational workday	Participation of institutions, the mayor, and some local ethnic communities
	17.08.2019	Educational workshop	Explicative walking tour through the	People from the “friends of the wetland Neuta” association

			wetland and symbolic planting of seedlings	acted as guides

Figure 31: Planted seedlings in Parque Campestre, Neuta wetland in 2017 (top left) and in Dec. 2019 (top right) and in Lagos de Malibu, Neuta wetland in 2017 (bottom left) and Dec. 2019 (bottom right). Picture sources: CAR, 2019b (left), Laura Niggli (right)

Box 2b: Evaluation of the CCA measures taken by the CAR in the municipality of Soacha: Humedal Neuta

Evaluation based on a field trip on 06.12.2019:

A large amount of the seedlings died as the municipality did not irrigate them in very dry periods. Despite the high mortality rate, the vegetation in the wetland is a lot more abundant than in 2017 (see **Figure 31**). The area is fenced with only two official access points that grant public access during opening hours between 8 am and 4 pm. The entry is restricted for dogs and cyclists or any other means of transport. However, the fence is cut in several places and people enter outside the opening hours and with their dogs. The area is misused by the inhabitants of adjacent buildings and the further neighbourhood to smoke Marihuana, walk dogs off-leash and ride bikes. The wetland is regarded as empty space with no special purpose and the general, public opinion is that the area is dangerous as it is not broadly frequented. People generally think it would be more profitable to use it as residential area. On the day of the field trip we even encountered a motorcyclist trying to traverse the wetland area as a shortcut (see **Figure 32**, right). The irrigation system for seedlings and trees is compromised in countless locations as off-leash playing dogs chew and destroy the hoses (see **Figure 32**, left). A number of eucalyptus trees in this zone further deprive the area of soil humidity. Interestingly, these non-native and water-intensive trees were planted more than two decades ago through a popular action by the community. As this autonomous adaptation project was not guided by an official entity, it does not follow the strategy of restoration of vulnerable ecosystems with native species promoted by Colombia´s national and regional governments. Regardless, the now tall grown trees may help to adequate the area for other trees and bushes of native and reference ecosystem specific species.

Figure 32: Torn water hose (left) and motorcyclist (right) in Lagos de Malibu, Neuta wetland in Dec. 2019. Picture source: Laura Niggli

As the waste disposal system is inefficient and unreliable in many Colombian neighbourhoods, people used to bring their household waste to what they think of as an empty area - the Neuta wetland. The fencing of the wetland led to the prevention of its use as garbage dump. Small pieces of trash, however, are still deposited there by the local population. Due to ignorance, difficulty or higher costs, domestic wastewater pipes are often connected to rainwater drains instead of to the sewage system tube, that is generally below the rainwater pipe in housing constructions. As the rainwater pipe drains into the Neuta wetland, wastewater ends up in the ecosystem too. (Yesid from SETIS, personal communication, 06.12.2019)
Situations like these ones illustrate how the social, political and economic reality of Colombians can prevent them from effectively supporting CCA measures.

Jerusalén

The municipality of Jerusalén is in the altitudinal zonation of tropical dry forest, an ecosystem highly vulnerable to climate change and the most threatened of the Colombian ecosystems. (CAR, 2019d) The land is mainly used for agriculture, and due to over-exploitation, the area suffers from erosion and organic soil loss. Tree vegetation is sparse due to the transition from livestock farming to agriculture and due to recent climate change impacts. (CAR, 2019c)
The aim of the CCA measures in Jerusalén is to restore some of the natural vegetation of its ecosystem and to connect forest relicts in the area. The measures include the implementation of silvopastoral and agroforestry systems in order to cope with expected climatic changes and to increase productivity, and the isolation of water reservoirs in order to ensure the water provision in dry periods. (CAR, 2019c)

The following boxes contain information about the CCA measures carried out in Jerusalén. They are based on information reports written by CAR (2019c, 2019e) and CAR and Cedro Andino (2019a, 2019c).

Box 3a: CCA measures taken by the CAR in the municipality of Jerusalén

Context: Fragmentation of tropical dry forest, productive land exposed to climate change

Project: Ecologic restoration, live fences, silvopastoral and agroforestry system

Objective: Restoration of vegetation coverage and connection of forest relicts
Implementation of productive systems that can cope with CC

Site	Date	Measure	Activities	Observation

Jerusalén	16.01.2019	Mainstreaming of the project	Talk about the need of CCA in Jerusalén	The mayor, the CAR, an environmental office and the secretary of economic and environmental development were present.
	05.04.2019	Ecologic restoration (0.52 ha), live fences (1.32 km), agroforestry systems (2.47 ha) and a silvopastoral system (2.4 ha)	Implementation of a total of 2650 seedlings and setting up of barbed wires	Live fence was implemented around a local water reservoir beside others.
	15.04.2019	Educational workshop	Knowledge exchange and presentation of the CCA measures	-
	27.04.2019	Educational workshop	Knowledge exchange and sensitization about CC	-
	09.07.2019	Educational workshop	Talk about ecologic restoration, live fences and restructuration of productive systems	Municipal social leaders were present.
	2019	Maintenance	Clean-up Fertilization Replacement of 795 seedlings	Mortality rate: 33 % mainly due to strong dry period and high temperatures, in some cases due to wildfires

Box 3b: Evaluation of the CCA measures taken by the CAR in the municipality of Jerusalén

Evaluation based on a field trip on 27.04.2019:

As the CAR arrived in the late morning/close to midday to the workshop, several farmers with tight time schedules had already left. In the conversation with the local community it became clear that the farmers´ interests are almost entirely guided by market incentives. The local agriculture is mainly based on corn, as it is a crop that is relatively resistant and keeps for about 6 months. However, the farmers complain that the prices are often very low as the market dictates them. The cultivation of more resistant and less pesticide-intensive local corn species, suggested as CCA measure is lamented to be difficult as the local traditional corn is harder than the imported one and is often rejected by buyers. Agroforestry systems and the association with other species like mango or pumpkin are suggested as an alternative backup if the corn is lost due to climatic events. (See **Figure 33**) However, the farmers interject that as the harvest of these crops is concentrated on a short period of time, the market gets temporally swamped and prices drop. And as they don´t keep very long they are often lost or sold at prices that don´t cover the producing cost. The farmers are more interested in adaptation measures related to the value chain and their power on the market than in adaptation to CC.

Some areas apt for ecologic restoration were not selected, because they are known to be illegally used for corn cultivation. The CAR states it is probable that the farmers would destroy seedlings to get back to corn cultivation. The CAR seems not to be very well-regarded by the local population. Even when seen in the village, the mayor did not welcome the representatives of the CAR and was not present at the workshop. Several people directly concerned by the CCA measures - for instance the ones who own water reservoirs that are to be protected by live fences - did not show up at the workshop.

***Figure 33**: Tree seedlings for an agroforestry system (top), barbed wire for isolation and tree seedlings for a live fence around a water reservoir (bottom left), and educational and knowledge exchange workshop in Jerusalén in April 2019 (bottom right). Picture sources: CAR and Cedro Andino, 2019a (top left and right, bottom left), Laura Niggli (bottom right)*

Even though the monoculture of corn has many disadvantages like the decline in soil fertility, local farmers often prefer to not cultivate or associate with other species as they will have difficulties to get them bought at a profitable price on the market. The promotion of CCA measures is difficult when the local community is not financially stable, and the priority of the farmers is survival long before environmental protection or adaptation to potential future problems.

4.3.2 Discussion

Difficulties and tensions often arise when the CCA measures do not take into account baseline social problematics. The social, economic and political context may influence CCA measures in an indirect way and handicap the understanding, acceptation, appropriation and support of projects. This can be evidenced in all the cases presented above.

As seen in Jerusalén, the willingness to commit to CCA measures goes hand in hand with the economic opportunities they afford. The farmers´ dependency on the market and the prices that big intermediaries dictate causes them to always consider the financial profitability before the environmental benefits of a CCA project.

In the case of Pasca the problems the CAR faces in the implementation and preservation of CCA projects are the lack of appropriation, responsibility, involvement and interest of members of the local community. The short-term mentality that leads to the theft of material and the destruction of common goods is mainly based on the prioritization of the own financial stability and can be led back to the generally weak economic situation most small-scale farmers in Colombia live in. The same can be said about the internal adjustments that are made between the CAR and the environmental office. As financial resources especially in the environmental sector are extremely limited, projects are closely bound to contracts formerly established and official relocation of resources is complicated. Hence, unofficial agreements are the norm and information loss is common.

For the case of Soacha some of the main problems are the contamination of the wetland with sewage water and garbage or its misuse as a park to freely walk dogs or to ride bikes. All of these problems are originally caused by the situation the people live in, their livelihood and their social and financial difficulties. Wastewater is often discharged into the Neuta wetland because the connection of the sanitary system to the rainwater pipe is more economic. As the garbage disposal system is inefficient, people use the area as landfill in order to displace the waste from their own houses, yards and streets to a place it affects them less. And people ride bikes and walk their dogs in the zone because green spaces especially in marginal areas of Bogotá are sparse and many people have nowhere else to go. In this case the protection of the wetland is in conflict with the financial stability and the recreational possibilities of the adjacent population.

Situations like these ones illustrate how the social, political and economic reality of Colombians can prevent them from effectively supporting CCA measures.

5 Discussion

This chapter aims at the merge and connection of the topics approached in the preceding chapters 3 and 4. It firstly discusses the link and the coherence between the projected climate change impacts and the climate change adaptation strategies suggested by the national and regional governments. Secondly it examines the coherence between the mentioned strategies and the regional adaptation measures. And thirdly it discusses the coherence between the regional adaptation measures and their practical implementation and follow-up. It analyses the strengths and achievements as well as the difficulties and gaps of climate change adaptation in Cundinamarca.

5.1 The expected climate change impacts linked to national and regional CCA strategies

In the assessment of climate change impacts on the hydrological resources of the Bogotá river catchment it was found that it can be expected that for a big range of projections in the hydrological resource system there will be sufficient water supply for certain periods of the year, but water shortages for other periods of the year. Respecting the simplicity of the approach and the uncertainties arising from the data and the underlying assumptions, the regulation and intra-annual as well as intra-regional redistribution of water can be assumed to become fundamental to cope with climatic changes in the future.

Several of the main concerns and suggested CCA measures and strategies of the most important considered national and regional planning documents are related to or may influence the future situation of hydrological resources. 7 out of 11 evaluated documents strongly focus on sustainable use of natural resources and 3 out of 11 directly mention the efficient use and saving of water as important CCA measures. 7 out of 11 documents suggest environmental and climate change education and sensitization as an important CCA measure. Awareness and knowledge diffusion are important to avoid or cope with a potential future situation of temporal or local water shortages or bad water distribution. 5 out of 11 documents suggest the implementation of CCA in politics and planning, which is also to be regarded fundamental in order to cope with and adapt to potential temporal or local water scarcity. 3 out of 11 documents mention the importance of the reduction of contamination (e.g. of hydrological systems). This is important especially because the capacity of the water treatment plants is more limited than the storage volume of the water regulation system in the Bogotá river catchment. Vulnerability analysis and reduction are CCA measures suggested by 8 out of 11 documents, which too benefits the adaptation to the projected impacts on the hydrological resources in Cundinamarca.

Also the evaluated CCA plans and projects mention topics related to or influencing the hydrological resources in their main goals, objectives and strategies. 4 out of 8 plans and projects mention hydrological resource management as one of their main strategies. The PAC specifically suggests management and regulation of hydrological catchments and the INAP proposes the reduction of adverse impacts of hydrological regulation in the Bogotá river catchments through measures like ecological restoration. The conservation, restoration and sustainable use of strategic ecosystems is suggested by 6 out of 8 plans and projects to guarantee their provision of ecosystem services. This is important as hydrological regulation is a fundamental ecosystem service provided by many of the natural ecosystems in Cundinamarca. 5 out of 8 plans and projects focus strongly on sustainable growth and territorial planning, which too, plays an important role in the future availability of hydrological resources. And 6 out of 8 plans and projects concentrate on awareness rising and fostering behavioural changes beside others, which will be essential for any kind of adaptation to

changes in the hydrological system.
In total, adaptations to the projections drawn for the hydrological resources in the Bogotá river catchment seem to be well represented in both, the general and specific documents evaluated as well as in the national and regional plans and projects

According to the results from the assessment of climate change impacts on the agroclimatic potential based on crop-specific climate corridors, the projected higher temperatures may be expected to have no direct negative effects, or to even be beneficial for the cultivation of the considered crops. The precipitation projections on the contrary indicate that precipitations will be excessive for the cultivation of all crops in most scenarios in at least some months of the year. The tendency of the wet season peaks as well as the dry period peaks to exacerbate and of the annual precipitation to become even less equally distributed can be assumed to be disadvantageous and the cultivation of all crops can be expected to become limited in at least some months of the year. In addition to that, crops like coffee may become more affected by diseases and pests that proliferate thanks to the changing climate. This cause the need to adjust the cultivation calendar or to move or change crops in some areas.
Several of the main concerns and suggested CCA measures and strategies of the most important considered national and regional planning documents are related to or may influence the future situation of agriculture. 7 out of 11 documents suggest territorial and regional planning as CCA measures. Land use planning is essential for sustainable agricultural production. 6 out of 11 documents suggest measures in productive sectors, and several documents mention local production and consumption, modernization of irrigation technologies, soil stability and erosion reduction for CCA. Vulnerability analysis and reduction are CCA measures suggested by 8 out of 11 documents. And education, sensitization, participation and/or inclusion of communities in the planning of CCA are suggested as measures by 9 out of 11 documents in total. This benefits the future situation of agriculture as people in the rural context and especially engaged in the agriculture sector are often especially vulnerable to CC and the CCA measures are generally more effective when local communities are included.
In the evaluated CCA plans and projects 4 out of 8 suggest adaptations for agriculture, livestock farming and food security in their main objectives and strategies, including specific examples like agroforestry and silvopastoral systems. The PRICC specifically suggests soil resource management and the PNACC 2012 mentions the productive sectors in its objective of vulnerability reduction. 4 out of 8 plans and projects focus on territorial and land use planning, both instruments essential to the agricultural sector. And 6 out of 8 plans and projects include awareness rising to foster behavioural changes, with the PRICC specifically suggesting sustainable production and consumption in its strategies. However, no specific strategies or measures are suggested to adapt to the potential increase in the proliferation of pests and diseases in cultivated crops like coffee.
On the one hand adaptations to the projections elaborated for the direct impact of CC on the agroclimatic potential in Cundinamarca appear to be well represented in both, the general and specific political documents as well as in the national and regional CCA plans and projects evaluated. On the other hand, CCA measures addressing the indirect impact of CC on the agroclimatic potential through the increase of pests and diseases for example, seem not to be included in the planning documents or the national and regional CCA plans and projects.

The qualitative analysis of the CCA plans and projects shows that many of the CCA plans and actions suggested and implemented are motivated not only by climatic stressors but by non-climatic stressors. This makes sense considering that in both the impact assessments on the hydrological system and the agroclimatic potential, climatic changes turned out to be only part of the problem. The increase in water demand, the contamination of water sources and streams, and the destruction of water-regulating ecosystems are all non-climatic stressors mentioned to be a threat to the water resources and the hydrological system in Cundinamarca. The same can be said about the threats to the agricultural system of Cundinamarca. Beside the expected limitations due to the changes in the precipitation pattern, soil erosion, low fertility, the exploitation of soils with no aptitude for intensive agricultural systems as well as plant diseases and pests can further limit agricultural yield. The tendency of adaptation measures to be based on non-climatic stressors can thus also be directly deduced from the problem-causing factors in the assessed situations of hydrological resources and agricultural production.

The fact that the most immediate problems are often not purely related to climate change also explains that there are both anticipatory and reactionary CCA plans and projects. The reactionary adaptation measures are mainly based on non-climatic stressors like environmental degradation caused by the productive sectors. However, the example of the potential future increase in the proliferation of pests and diseases that affect the coffee cultivation shows that CCA should not only focus on reactionary measures based on non-climatic stressors.

All of the plans and projects pursue participatory methodology including the civil society and local communities. The necessity of this can also be seen in the assessment of the hydrological resources and the agroclimatic potential. As hydrological resources can be assumed to become temporally and/or locally scarce in the future due to climatic and non-climatic factors, it is essential to include the civil society most vulnerable and most affected by this in the planning of adaptation measures. The same is true for the agriculture sector. As changes and adaptations in the productive systems will locally be necessary, the participation of local farmers is fundamental to the success of adaptation measures.

For all considered CCA plans and projects international, national, regional and/or academic institutions are the leading actors. This seems natural for research based and regulatory CCA measures, but not absolutely necessary for educational and behavioural CCA measures. Formal leadership of governmental or academic institutions makes sense for the regulation and adaptation of hydrological resources over a whole catchment, as changes in the upper catchment may have strong repercussions on areas in the lower catchment. However, for the adaptation of productive systems it might be beneficial to not only base project leadership on institutions like the MADS, CAR, IDEAM and similar, but also on smaller local associations that are closer to the community concerning the understanding of local priorities and values.

According to Hallegatte (2009), one of the main difficulties in the planning of climate change adaptation is the uncertainty in climate change projections. This is especially important as non-scientific institutions and decision-makers often aren´t aware of these uncertainties and of the fact that they cannot unquestionably rely on climate change projections. A possibility to adapt to future climate without the need of certain climate change projections is the focus on robust adaptation measures, meaning measures that are adapted to the full range of possible climate changes instead of only one. (Hallegatte, 2009)

Examples of such adaptation measures by Hallegatte (2009) are:

- no-regret strategies (bring a benefit even if there is no climate change)
- reversible strategies (are adjusted/stopped flexibly in response to new information)
- safety margin strategies (extra capacity implemented in the phase of design)
- soft strategies (institutional and financial tools, e.g. recovery plans, early warning

systems, insurance schemes)
- and strategies that reduce decision-making time horizons (investments with short lifetime, e.g. cheap houses in flood risk areas)

The importance of uncertainty in climate change projection in Colombia is evident in the comparison of the country´s 2nd and 3rd national communications on climate change. While for example the 2nd national communication published in 2010 projects decreases in precipitation for Cundinamarca by the end of the 21st century, the more recent 3rd national communication projects an increase of 10-30 % in large part of Cundinamarca by the same time. Differences can also be evidenced in the projection of the average temperature in Colombia, that was found to increase by 2.4°C in the 2nd and by no more than 2°C in the 3rd national communication for the middle of the 21st century. (see **Table 1**)
It is also to be mentioned that uncertainties in the climate change modelling for Colombia arise in many projections due to the climatic extreme events in 2010 and 2011 caused by an exceptionally strong La Niña phenomenon. Several publications have been found to wrongly exhibit tendencies of increasing precipitations due to a bias in the precipitation modelling caused by the mentioned La Niña (D. Pabón, personal communication, 17.10.2019).
This leads to the conclusion that the need for robust climate change adaptation measures exists for Colombia too. It stands out that almost all of the CCA measures suggested by the national and regional plans and projects are no-regret strategies. This can be explained by the fact that Colombia follows an ecosystem-based approach to CC and that many of the measures are motivated by non-climatic stressors. Measures like ecosystem conservation and restoration, sustainable use of natural resources and environmental education and awareness raising provide benefits even in the absence of climate change. The general reduction of vulnerability as well as specific measures like the harvest and use of rainwater, alternative productive systems, the rational and efficient use of energy and solid waste and organic pollutant management are not only advantageous in certain future climate projections, but already under the present climate and in the current social, economic and political context. Some suggested measures like land use planning and the rational and efficient energy use are not only no-regret strategies, but they are also reversible, meaning that if the available information about the future changes, they can be adjusted or stopped almost immediately. The creation of a framework for CCA in the Colombian government, the integration of CCA in political planning and the promotion of CC research are soft strategies, that do not require structural high-investment operations. And some of the measures like the prospective risk reduction in basic infrastructure suggested in the PNACC 2016 are safety margin strategies, characterized by the condition that when building new infrastructure (e.g. bridges or wastewater treatment plants) the cost of some additional capacity for safety is a lot lower than the adaptation of already existing infrastructure. The only non-robust CCA strategy mentioned in the national and regional general and CCA-specific planning documents is the resettlement of inhabitants from high risk zones, suggested by the recent POMCA of the Bogotá river.

In conclusion it can be said that the national and regional CCA strategies and guidelines as well as the national and regional CCA plans and projects are generally robust and apt for the changes in climate that are projected and presented in this work. However, it is important to stress that anticipatory CCA measures especially to indirect climate change impacts like the proliferation of pests and diseases affecting agricultural crops should not be disregarded.

5.2 The national and regional CCA strategies linked to the regional CCA measures

The CCA measures suggested for the different municipalities by the CAR are based on the

vulnerability analysis for the respective municipalities in first instance and on the results from workshops and knowledge exchanges with the local communities in a second instance. The analysis of climate change vulnerability is based on the average of the climate change projections made by IDEAM *et al.* (2015) for RCP 4.5 and RCP 8.5 and for the period of 2011-2040. (CAR and Universidad Nacional de Colombia, 2018) Hence, for the elaboration of the CCA measures by the CAR, changes in the climate are only considered for the near future up to 2040 and not up to the end of the 21st century.
As analysed in the assessment of the climate change impacts on hydrological resources and the agroclimatic potential, there can be seen distinct differences between the projections made for the near future and those made for the end of the 21st century. For example, while the projections of the hydrological balance in the Bogotá river catchment in the near future for some RCPs are higher than currently, they are significantly lower than currently towards the end of the century. The same distinctive difference can be seen for the second period of RCP 8.5 in the projections for the agroclimatic potential. If we assume that the changes towards the end of the century are different from the ones expected for the near future, it is questionable, if adaptations to projected short-term changes (2011-2040) are sustainable. Regardless, as most of the adaptations are no-regret measures, they can be assumed to have benefits and/or no disadvantages in following periods.
Most of the CCA measures lead by the CAR are ecologic restorations, followed by alternative productive systems. They are all accompanied with educational workshops. The adaptations in hydrological resources focus on hydrological regulation, protection of water sources and the reduction of pollution of hydrological resources. Measures concerning soil resources like alternative productive systems focus on the increase of organic matter and the retention capacity of water and nutrients in the soil, the management of pests and diseases, the generation of micro-climatic conditions, carbon capture, and food security. The educational measures focus on the mainstreaming of concepts, the acknowledgement of the importance of territorial and land use planning, and the awareness raising in the topic of the protection of hydrological sources. (CAR and Cedro Andino, 2019b)
As found in chapter 4.1, the main concerns mentioned most by Colombia´s general and climate change specific planning documents are sustainable and resilient development, hazard risk management, sustainable use of natural resources and biodiversity and ecosystem protection. The CCA measures most suggested (additional to the main concerns) are CC and CCA research and information, vulnerability analysis and reduction, territorial and regional planning, communal participation, communication and sensitization, CC and CCA information management, hazard risk information generation and management, sectorial planning, strengthening of institutionality, improvement of financing and investment, measures in productive sectors, implementation of CCA in politics and planning and maintenance of forest coverage.
The focus on sustainable and resilient development and especially on sustainable use of natural resources and biodiversity and ecosystem protection is followed by the CAR. The measures suggested by the CAR are strongly ecosystem-based and aim at the maintaining of ecosystem services provided by hydrological resources and soil resources beside others. Risk management is not directly addressed by the CAR´s CCA measures as the National System for Disaster Risk Management (SNGRD) is in charge of adaptations aimed at the reduction of hazard risk.
With vulnerability analysis and reduction being the basic approach to elaborating CCA measures of the CAR, it follows one of the most suggested measures by Colombia´s general and climate change specific planning documents. The measures implemented by the CAR also

concur with communal participation, communication and sensitization, measures in productive sectors and maintenance of forest coverage. Other CCA measures suggested by the national and regional planning documents like CC, CCA and hazard risk research and information, territorial, regional and sectorial planning, and implementation of CCA in politics and planning are not directly addressed by the CAR, as other institutions (e.g. IDEAM, MADS, SNGRD, DNP etc.) are in charge of these processes. The strengthening of institutionality and the improvement of financing and investment too, are not directly addressed by the CAR, despite their relevance for the CAR´s effectivity and efficiency.

Just like for the national and regional CCA strategies, the robustness of the regional CCA measures led by the CAR is very high. As the measures implemented by the CAR are ecosystem based and aim at the reduction of vulnerability, they follow no-regret strategies and provide benefits independent from the future changes in climate.

It can be concluded that the regional CCA measures led by the CAR are consistent with the national and regional CCA strategies and guidelines and the national and regional CCA plans and projects.

5.3 The regional CCA measures led by the CAR and their practical implementation and follow-up

Analysing the link between adaptation measures led by the CAR and the result of their implementation in practical cases on a local scale several problems become evident. The successes are often fewer than expected and the objectives aimed at by the strategies of the CAR are only reached partially. These discrepancies can be mainly attributed to three problems that are regularly encountered:

1. The social context is not taken into account sufficiently.
2. There is no continuity in the follow-up.
3. There is a significant gap in CCA evaluation and research.

These three issues as well as some additional difficulties in climate change adaptation are analysed in the following four subchapters.

5.3.1 Problem: Social context

As found in the analysis and evaluation of local implementation and follow-up of adaptation measures in chapter 4.3, there were difficulties in the implementation and preservation of CCA measures in all analysed projects. While the actions suggested by the CAR seem to be relatively simple and straightforward, the implementation often is complicated and problematic due to underlying social contexts and economic tendencies.

While in educational workshops and project presentations many of the local inhabitants come to understand the need of climate change adaptation and to approve of the idea of participating in it, their broader social context may lead to them adopting a double-minded attitude in the process of the execution and preservation of the measures.

In some cases, this leads to people directly opposing CCA measures, and in others it just prevents them from feeling commitment, responsibility and appropriation.

In the case of the Neuta wetland in Soacha for instance, people directly disregard the access restrictions as they deprive them of a space that is of use to them. The same tendency is true for other situations. For example, the recovery of ecosystems through reforestation or limitation of access to people and livestock, is rarely warmly welcomed as farmers rely on the areas for livestock farming and cultivation as well as on firewood for rural heating and cooking. The fencing of water sources, ponds and streams often meets resistance, as the restriction of the direct access of cows and horses to the water resources causes more work for the cattle

owners, and as farmers want to take advantage of all of their land and expand their cultivated fields to as close as possible to the water.
In the case of Vereda El Retiro in Pasca, while the idea of silvopastoral systems and live fences may have been supported, the implementation of them was not a primary priority to all of the inhabitants. The people´s long-term or short-term thinking and the priorities that shape their actions depend on the social context and the financial position they are in. The disregarding of the access limitation for livestock and even the theft of the electric wire that led to the destruction of common goods was thus not caused by the people´s direct opposition to the CCA measure, but by the prioritization of their own financial stability. The same is valid for the case of Soacha and Jerusalén. The contamination of the Neuta wetland through the discharge of sewage water and garbage is not just due to the fundamental unwillingness of the people to respect the CCA project, but to the limitations of the social context they live in. The engagement of the local population in suggested CCA measures is directly linked with the economic opportunities those measures provide and with the resources they still have at their disposal after performing the activities they pursue for their survival and welfare. In this light anticipatory climate change adaptation becomes a luxury to people that live in economic instability. And this means that the successful implementation and preservation of a CCA project is limited by the economic and financial weakness of the local population.
In order to enable effective and efficient climate change adaptation it is thus fundamental to take into account the social, cultural, economic, financial and political context in which a project is embedded.

5.3.2 Problem: Continuity

An issue that becomes evident in all cases in the different municipalities is the importance of monitoring and maintenance of implemented CCA measures. For all measures that include the planting of bush and tree species the seedling mortality rates go up significantly if there are no regular maintenances carried out. In order to ensure efficient maintenances, the projects have to be monitored. Even though the CAR includes follow-up and monitoring periods in its plans, they appear to be rather short and never exceed 4 years.
There is a slight tendency towards punctual interventions rather than an integrated improvement of the general situation, both in the CCA measures suggested by the CAR as well as in the national and regional plans and projects. For instance, the CAR promotes punctual ecosystem restoration and forest connectivity, but there are no clear strategies implemented about how to battle deforestation in Cundinamarca. Another example is the PAC 2016-2019 that suggests the extension of wastewater treatment plants in the Bogotá river catchment instead of targeting at the prevention of wastewater drainage into the river.
The tendency towards punctual CCA measures and the lack of monitoring and follow-up actions point at one big challenge found in the evaluation of climate change adaptation in Colombia: the lack of continuity. CCA projects in Colombia are generally carried out in a limited timeframe, mostly related to the duration of government periods. This leads to projects being initiated and implemented during the 4 years term of office of the national presidency or the shifted period of 4 years term of office of the municipal government and being abandoned after the government period ends. As changes in the government come with rotations in the sectorial and regional administration and planning and in all state institutions, planning priorities often change, and former projects get restructured or dismissed while new ones are launched. This only allows for punctual measures and limits the assured time for monitoring, follow-up and maintenance activities to 4 years at most. Changes in municipal governments slow down the implementation of CCA measures by the CAR, as normally administrational workshops and project presentations have to be repeated and the engagement and

commitment of the local government have to be newly gained. When local governors are not regularly kept updated about the implemented measures, the projects are generally forgotten and lost.
The lack in continuity is further exacerbated by insufficient financial stability of environmental-related institutions like the CAR and the IDEAM. As CCA measures are bound to specific annual contracts and those contracts are bound to the financial resources granted during a governmental period, there is little flexibility for the dealing with problems that newly emerge and there is no capacity for planning beyond the regular 4 years. Generally, financial resources run short at the end of the government period as well as at the end of the year, and as money cannot be moved from one year to another year, it is oftentimes wrongly allocated. An example to this is that in the IDEAM climate change research related field work can often not be carried out in December due to financial and logistic shortages (J. L. Ceballos, personal communication, 29.11.2019). And the effects of this were also observed in the case of Vereda Juan XXIII in Pasca in the internal adjustments that were made between the CAR and the environmental office in order to enable an effective maintenance of the implemented ecologic restoration, that led to the loss of information essential for CCA research and evaluation. Continuity is also limited by the strongly varying national resource allocation. Thus, single branches of departments or even complete departments cannot count with long-term funding. For example, the annual budget the CAR had at its disposal between 2016 and 2020 showed variations of up to 34 %. (Consejo Directivo República de Colombia, 2015, 2016, 2017, 2018, 2019) The approved share of the national budget spent on the environment and sustainable development sector was 0.3 % and 0.33 % for the years of 2019 and 2020. (Ministerio de Hacienda y Crédito Público, 2018, 2019)
Due to the low priority of the environmental sector in the political planning of Colombia, many projects rely on foreign resources released by programs like the UNDP, The World Bank, GEF or CI. Examples are the Regional Integral Climate Change Plan for the Capital region of Bogotá – Cundinamarca (PRICC) that was supported by the UNDP, and the National Adaptation Pilot Project (INAP) that was partly financed by The World Bank, the GEF, and CI. However, as resources by international corporations are usually project-based and time-limited, permanent or long-term funding is not enabled either. As the INAP, started in 2006, was finalized in 2011, no further follow-up and monitoring measures were carried out for example in La Calera, where several implementations had been made. The CAR started CCA projects in La Calera again in 2016 (CAR and Consorcio Obras Ambientales, 2016; CAR, 2017e) and found that many of the formerly initiated projects had been abandoned. Live fences had extremely high mortality rates and a garden centre that had been set up for the students of the local school was found empty. A project for the production of yoghurt in a school that had been developed to improve the economic independence and development, had been abandoned with the equipment stored and unused. (M. E. Baez, personal communication, 23.11.2019)
The missing continuity due to administrational and financial instabilities causes higher expenses in financial and human resources as it leads to measures having to be repeated. This slows down the expected effect of a certain CCA measure, and it is significantly less efficient than setting up effective monitoring and maintenance systems and routines in the first place.

5.3.3 Problem: Evaluation and research

According to McDowell et al. (2018) the formal evaluation of climate change adaptation and its implications is extremely limited and unsuccessful adaptation actions are rarely mentioned. This is also found to be true for Colombia and more specifically Cundinamarca. From the 11 planning documents analysed in this work, only two, namely the Regional Development Plan 2016-2020 and the CONPES 3700 of 2011, strongly suggest the follow-up and evaluation of

CCA projects. Of the 8 national and regional CCA plans and projects again only two, namely the national strategy for CC education, formation and sensitization and the PNACC 2012, include CCA follow-up and evaluation in their main strategies.
For Cundinamarca it is found that for example in the PRICC no evaluations were made of the effect of implemented measures, and advances were only monitored for the implementation of CCA measures (Otter and Escovar, 2014). CAR (2016) suggests the setting of quantifiable targets and the use of achievement indicators to evaluate the performance of an institution. The CAR's performance index was evaluated as an average 70.5 % for the years between 2006 and 2010 (MADS, 2016b). However, none of this contributes to the evaluation and research of CCA measures.
While in several reports about CCA measures by the CAR (e.g. CAR, 2016, 2017c; CAR and Cedro Andino, 2018, 2019b) the importance of follow-up and evaluation actions to CCA projects is asserted, their scope is limited to the advice of periodical monitoring by the local communities. Of the 19 reports about the implementation, follow-up and maintenance of CCA measures by the CAR considered in this work, only one contains a systematic evaluation of the implemented measures. This Contract 1697 of 2017 about San Bernardo contains a section about the evaluation and verification of the project results, assessing the project advance and the final product. CAR and Cedro Andino (2018) use indicators to evaluate the community´s perception of the benefits and weaknesses of the implemented CCA measures. They evaluate the efficacy and efficiency of all of the implemented CCA measures with indices proposed for measures in hydrological resources, in soil resources, and in CC knowledge strengthening.
The goal of the hydrology related CCA measures is the reduction of vulnerability through the strategical integration of the conservation of water sources, which is assessed through non-structured interviews. Local inhabitants evaluate the decrease of floods in wet periods, the decrease of water shortage in dry periods, the water availability and the prevention of the contamination of water sources as high, medium or low. The goal of soil related CCA measures is the reduction of vulnerability through the increase of forest cover with native species through restoration processes and through the improvement of cultural soil use practices. Local inhabitants evaluate the decrease of climate impacts especially in dry and rainy seasons, the increase of the resistance capacity of productive systems to climate variability and the increase of adaptive capacity of the local communities as high, medium or low. The goal of knowledge related CCA measures is the reduction of vulnerability through the internalizing of CC concepts and the motivation and training of community members. Local inhabitants evaluate their ability to differentiate between the concepts of climate variability and climate change as high, medium or low. While "high" means that the contribution of the CCA project to vulnerability reduction is significant, "medium" means it is moderate and "low" means the project does not contribute to vulnerability reduction and measures are to be taken urgently. With this method CAR and Cedro Andino (2018) found that in San Bernardo according to 100 % of the interviewed people all of the implemented measures reduce vulnerability significantly and they came to the conclusion that the effectivity of the implemented CCA measures is between 50-100 %. (CAR and Cedro Andino, 2018)
It is worth noting that this approach is very simple, and the rough estimation of 50-100 % vulnerability reduction is based on the purely qualitative assessment of some members of the local community. Also, there is no detailed assessment of what the successful and the less successful parts were and why.
In general, it was found that for the national and regional context the importance of CCA evaluation is not sufficiently recognized and strategies for CCA evaluation are sparse. Accordingly, on a local scale in Cundinamarca detailed evaluations of CCA measures

implemented by the CAR or other institutions are inexistent. Hence, there is a lack in research that generates insights and deepens the understanding about the success and limitations of existing adaptation actions. This can be expected to hinder the efficient planning of effective adaptation in the future.

5.3.4 Additional problems and difficulties

As seen in the case of the Neuta wetland in Soacha, another problem may be the lack of communication with, contact points to or presence of official entities that support and guide CCA projects. In the case of the vegetation restoration that was carried out in a popular action by the local community, the selection of non-native and water-demanding species did not lead to the kind of adaptation that is intended by Colombia´s national and regional governments. Due to ignorance such unguided autonomous CCA measures may cause maladaptation.

Since in this work only CCA measures guided by the CAR are considered, the complementarity of projects and the interinstitutional cooperation are not addressed. However, UNDP and IDEAM (2010a) state that one of the major challenges in the face of climate change is the improvement of interinstitutional coordination and DNP (2011a) affirms that CCA projects are often not complementary and that they are carried out by a variety of different actors that often do not coordinate actions between each other. According to DNP (2011a) the generated climate and climate change information is often poorly communicated to the decision makers of the appropriate productive sectors and territories and the CAR (2016) asserts that the main vulnerability in the CAR territory is due to a lack of adequate information for decision making on all levels.

Additionally, it is interesting to mention that the CCA measures led by the CAR are generally rather reactionary and strongly concentrate on experienced non-climatic stressors. Even if they provide benefits also in the case of climate change, it is important not to neglect anticipatory adaptation to climatic stressors. For example, the anticipatory adaptation to potentially great losses in the cultivation of certain crops is essential for the agriculture sector. A neglect of anticipatory adaptation to climatic stressors may often not be visible at a current time but can be expected to lead to great difficulties in the future.

5.4 Suggestions

As established, the successful implementation and preservation of CCA measures depends on the local community´s sense of responsibility and the appropriation of a project. The engagement and commitment to the project are defined by the priorities of the inhabitants and thus directly linked with the social, cultural, economic, financial and political context they live in and they are limited by. In order to avoid unnecessary damage, losses and excessive work and to enable effective and efficient climate change adaptation it is advisable to analyse this context in detail and to prioritize measures that strengthen the local communities in their social, economic, financial, and political context.

It is also important to try to include all members of the concerned communities to increase acceptance, appropriation and commitment and to avoid maladaptation caused by autonomous, unguided projects. To enable the participation of the biggest possible number of community members, educational workshops, presentations and knowledge exchanges should be timed in a way that they favour the time schedule of the local community rather than the one of the environmental authorities.

The monitoring and maintenance of CCA projects is fundamental to ensure their sustainability. It is advisable to allocate sufficient resources in monitoring and maintenance in proportion to the implementation of CCA measures in order to avoid costs of having to implement a measure twice. In order to ensure the sustainability of a project between the activities by the CAR and even after the finalization of the contract and in absence of the CAR, it is important to have a clear division of responsibilities and assignment of activities in the local community. Therefore, projects should include local associations throughout their whole process of research, design, implementation and follow-up. The participation of local associations and interest groups can be expected to be more successful than the participation of single members of the community who participate on a voluntary basis, as the participation of individuals is more probable to suddenly end due to personal changes in priorities or unavailability. If there is no local association that can be incorporated, it is important to generate commitment in and social control among the participating individuals and to create a group dynamic and structure that allows for the distribution of responsibilities and assignment of clear tasks. It may also be of use to not finalize projects but leave them in process over a longer time period. During the first years after the implementation the remunerated official part-time but long-term employment of a community member in monitoring, maintenance and updating may help to avoid that projects are abandoned and forgotten shortly after their implementation through changes in the local government and other factors.

In the case of foreign funding of Colombian CCA projects, it is important to come up with a financially feasible follow-up strategy already in the phase of the design to avoid the sudden abandonment of the project after the formal finalization. It may be favourable to base subsequent CCA measures on formerly implemented projects to benefit from already existing infrastructure and human capital and to avoid the abandonment of former projects.

Climate change adaptation evaluation and research are important for the efficient planning of effective adaptation in the future. However, there is a lack in research that generates insights and deepens the understanding about the success and limitations of existing adaptation actions. It is strongly recommendable to concentrate more resources on the formal CCA research and to elaborate and implement a CCA evaluation system in order to systematically analyse implemented CCA measures.

One possible scheme for CCA evaluation is provided by an approach of McDowell and Koppes (2017). They mention five criteria for successful CCA planning and elaborate three principles for CCA research. The criteria for successful CCA planning are effectiveness, efficiency, equitability, legitimacy and sustainability and they evaluate if the adaptation achieves its goals, if its benefits outweigh the cost of its implementation, if its consequences benefit the most vulnerable, if it is underpinned by an inclusive decision-making process, and if it is attentive to social and ecological needs in the present and into the future. The principles for CCA research are the paying attention to site-specific conditions, to the human dimensions of the change, and to the socio-ecological dynamics. (McDowell and Koppes, 2017)

As a conclusion to the evaluation of the PRICC by Otter and Escovar (2014), they point out the importance to include and plan a clear and precise monitoring and evaluation system with specific indicators to measure targets, products, results and effects already in the stage of the design of the CCA project.

After all, it is also important to not lose too much focus on the adaptation to actual climate change. While an ecosystem-based approach of CCA is commendable, CCA should not tend to merely react to general environment related stressors. The concentration on environment related CCA strategies based on the current needs and problems of the local communities should not lead to the neglection of CC research-based adaptations. It is recommendable to further engage with a potential change in the cultivation of certain crops, even though there may not yet be the need to do so.

6 Conclusion

Aiming at the analysis of the different organizational levels of climate change adaptation in Colombia, and more specifically in the central department of Cundinamarca, this work intended to contribute to the rather sparse CCA research and evaluation in Colombia. It was guided by four main research questions:

1. Is there a coherent link between the expected climate change impacts in the department of Cundinamarca based on scientific data, and the strategies and guidelines to CCA proposed by the national and regional governments?
2. Is there a coherent link between the strategies and guidelines to CCA proposed by the national and regional governments, and the registered CCA measures in the department of Cundinamarca?
3. Is there a coherent link between the registered CCA measures in the department of Cundinamarca and the practical implementation of CCA based on local case studies?
4. What are the strengths and weaknesses, achievements and difficulties of the CCA strategies implemented in the department of Cundinamarca?

Projected climate change can be expected to have impacts on both the hydrological resources as well as the agroclimatic potential in Cundinamarca. As the Bogotá river catchment is strongly regulated by several water reservoirs storing water originating within as well as outside of the borders of Cundinamarca, it is relatively resilient to projected changes in the supply and demand of hydrological resources. Regardless, critical situations could arise from the projected change in the annual precipitation distribution and the relatively low capacity of the water treatment, release and transportation system. Paired with potentially large increases in demand and evapotranspiration changes that are difficult to project, this makes it probable that adaptations have to be made to deal with temporal and local inaccessibility of hydrological resources, even if the annual water balance for the total Bogotá river catchment is positive for all projections. The cultivation of potatoes, sugar cane, coffee and corn can be expected to be less directly limited by temperature than by the changes in the annual precipitation pattern under projected future climate. Periods of water scarcity and excess may lead to the reduction of the annual period apt for cultivation and thus adaptations to the sowing, growth and harvest schedules may have to be made. Beside the direct impact of climate change on the agroclimatic potential, it is also important to consider its potential indirect effects like the increase in pests and diseases or soil erosion.

Thanks to its relatively long history in CCA, Colombia has a variety of political planning documents that include and address CC and CCA as well as an abundance of plans and projects that elaborate CCA goals and objectives and suggest different CCA strategies and measures. As the adaptation to climate change in Colombia is mainly ecosystem based, many CCA actions are motivated not only by climatic stressors but by non-climatic stressors related to ecosystem and biodiversity degradation amongst others. While the adaptation measures to non-climatic stressors are strongly reactionary, the measures to projected climatic stressors are mainly anticipatory, which allows the detailed planning of strategies and actions. The CCA measures regionally most implemented by the CAR like ecosystem restoration, the protection of hydrological resources, the improvement of productive systems in agriculture and livestock farming and educational actions for awareness rising, follow the national and regional CCA strategies focusing on environmental conservation, agriculture and forestry beside others. And as promoted by the national government they follow a participatory approach trying to include the civil society and local communities. It can thus be concluded that the regional CCA measures led by the CAR are consistent with the national and regional CCA strategies and guidelines and the national and regional CCA plans and projects.

As most of the CCA strategies and guidelines suggested by the national and regional governments as well as of the CCA projects and measures implemented in Cundinamarca by the CAR are no-regret strategies, they are generally robust and apt for the uncertain changes in climate and their impacts that are projected and presented in this work.

While adaptation action and its planning are consistent and well diffused through Colombia´s politics and planning, adaptation research is almost inexistent and the evaluation of CCA measures is limited to project advances and performance evaluation. In addition to this, CCA projects often lack systematic and periodic monitoring and follow-up actions that ensure the sustainability of the implemented measures. CCA evaluation and research, however, are important to enable a deeper understanding of the functioning of CCA, to guarantee the successful implementation of CCA measures and to avoid repeated mistakes, negative side-effects and maladaptation.

In the practical implementation of local CCA measures by the CAR difficulties are caused mainly by this gap in CCA evaluation and research, by a lack of continuity in the follow-up of CCA projects and by shortcomings in the consideration of the social context of the local communities. Based on this, recommendations for successful CCA can be made for these three main areas.

It is necessary to elaborate and implement a CCA evaluation system for example like the one provided by McDowell and Koppes (2017) in order to systematically analyse implemented CCA measures. And it is essential to include and plan a clear and precise monitoring and evaluation system with specific indicators already in the stage of the design of the CCA project.

The success in the implementation and preservation of a CCA measure depends on the engagement and commitment of the local inhabitants, which is driven by the people´s sense of responsibility and their appropriation of the project on the one hand, and by their economic and financial possibilities on the other hand. In order to successfully implement and preserve a CCA measure it is fundamental to take into account the social, cultural, economic, financial and political context the local community lives in and is pushed and limited by. It is thus strongly recommendable to sufficiently analyse this context and to adjust planned CCA projects to the findings so as to empower the local communities in their social, cultural, economic, financial and political context and to strengthen and enlarge their possibilities to engage and commit. To enable the participation of the community for the creation of commitment, it is of use to organize meetings according to the habits and availability of the community members.

The inclusion of local associations in the research, design, implementation and follow-up of a CCA project is also important to create continuity and, in this manner, ensure the sustainability of the implemented CCA measures. Mainly caused by a lack of financial resources and frequent rotations in the national, regional and local governments as well as in the institutions´ work force, the discontinuity is strongly linked to deficient communication, information loss and the diffusion of responsibility. It is thus recommendable to include structured local groups in which responsibilities are divided clearly and explicit tasks are assigned to create social control and to enable the persistency of the project. In this way, experiences can be shared, information can be transmitted, and knowledge can be generated. So, not only does feasible follow-up strategy led by the local community ensure the continuity of the project, but also it may set the groundwork for following measures that can be based on already existing infrastructure, social structures and human capital.

For future work in CCA in Cundinamarca and Colombia there is a strong need of specific CCA research that includes CCA evaluation as well as the social, cultural, financial, economic and political context of CCA. And future project leaders should engage more deeply in the continuity of their projects.

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Annex

Annex 1

Historical and projected monthly mean temperature (°C) and precipitation (mm) with standard deviation (STDV) for the periods 2040-2059 (p. 1) and 2080-2099 (p. 2) and the reference period of 1981-2005 for the RCPs 4.5 and 8.5 in the department of Cundinamarca. Differences between the projections and the reference period are given in absolute values for the temperature (Diff.) and in percentage for the precipitation (% diff.). The amplitude (Amp.) is the difference between the wettest and the driest month of the year.

Monthly mean temperature in °C for the department of Cundinamarca based on CCSM4 projections									
Month	Historical	RCP 4.5				RCP 8.5			
	1981-2005	p. 1	Diff.	p.2	Diff.	p. 1	Diff.	p. 2	Diff.
Jan	20.17	21.53	1.36	21.99	1.82	22.18	2.01	24.24	4.07
Feb	20.53	22.04	1.52	22.56	2.03	22.78	2.25	25.06	4.53
Mar	20.72	22.04	1.32	22.63	1.92	22.75	2.03	25.23	4.52
Apr	20.37	21.60	1.24	22.24	1.87	22.22	1.85	24.56	4.20
May	20.12	21.39	1.27	21.83	1.71	21.94	1.82	24.01	3.89
Jun	19.68	21.01	1.33	21.43	1.75	21.57	1.89	23.56	3.88
Jul	19.50	20.83	1.33	21.27	1.77	21.33	1.82	23.32	3.82
Aug	19.98	21.30	1.32	21.81	1.84	21.91	1.93	24.05	4.07
Sep	20.22	21.54	1.32	22.04	1.82	22.16	1.94	24.26	4.04
Oct	20.04	21.38	1.35	21.77	1.74	21.98	1.94	24.10	4.07
Nov	20.05	21.30	1.25	21.74	1.70	21.89	1.84	23.84	3.80
Dec	20.08	21.30	1.22	21.76	1.68	21.84	1.77	23.96	3.88
Annual mean	**20.12**	**21.44**	**1.32**	**21.92**	**1.80**	**22.04**	**1.92**	**24.18**	**4.06**
Amp.	1.21	1.21		1.36		1.42		1.92	
STDV	0.33	0.36	0.08	0.40	0.10	0.42	0.13	0.55	0.25

Monthly mean temperature in °C for the department of Cundinamarca based on MPI-ESM-MR projections									
Month	Historical	RCP 4.5				RCP 8.5			
	1981-2005	p. 1	Diff.	p.2	Diff.	p. 1	Diff.	p. 2	Diff.
Jan	20.25	21.95	1.71	22.62	2.38	22.71	2.47	25.71	5.47
Feb	20.62	22.45	1.82	23.31	2.69	23.35	2.73	26.41	5.79
Mar	20.67	22.68	2.00	23.40	2.73	23.66	2.99	26.43	5.76
Apr	20.32	22.26	1.94	23.01	2.69	23.02	2.70	25.85	5.53
May	20.07	21.84	1.77	22.37	2.30	22.62	2.55	24.95	4.88
Jun	19.63	21.31	1.68	21.66	2.03	21.97	2.35	24.28	4.65
Jul	19.52	21.02	1.51	21.57	2.05	21.70	2.18	24.26	4.74
Aug	19.99	21.63	1.64	22.10	2.11	22.51	2.52	25.23	5.24
Sep	20.22	22.11	1.89	22.67	2.45	23.17	2.95	25.88	5.66
Oct	20.08	22.30	2.23	22.55	2.48	22.79	2.71	25.30	5.22
Nov	20.08	21.70	1.62	22.15	2.07	22.34	2.26	24.62	4.54
Dec	20.17	21.83	1.67	22.11	1.95	22.47	2.30	25.00	4.83
Annual mean	**20.13**	**21.92**	**1.79**	**22.46**	**2.33**	**22.69**	**2.56**	**25.33**	**5.19**
Amp.	1.16	1.66		1.84		1.96		2.18	
STDV	0.34	0.47	0.20	0.59	0.28	0.56	0.26	0.75	0.45

Monthly mean precipitation in mm for the department of Cundinamarca based on CCSM4 projections									
Month	Historical	RCP 4.5				RCP 8.5			
	1981-2005	p. 1	% diff.	p.2	% diff.	p. 1	% diff.	p. 2	% diff.
Jan	66	71	+7	72	+9	79	+19	62	-7
Feb	83	102	+23	90	+8	102	+23	79	-5
Mar	149	124	-17	139	-7	156	+4	138	-8
Apr	225	260	+16	238	+6	228	+2	216	-4
May	253	280	+11	292	+16	266	+5	300	+19
Jun	235	275	+17	287	+22	263	+12	310	+32
Jul	204	264	+30	273	+34	249	+22	275	+35
Aug	168	172	+2	205	+23	181	+8	170	+2
Sep	198	202	+2	186	-6	204	+3	180	-9
Oct	238	288	+21	299	+26	245	+3	233	-2
Nov	225	247	+10	187	-17	241	+7	196	-13
Dec	110	101	-8	104	-6	77	-30	105	-4
Annual sum	**2154**	**2385**	**+11**	**2372**	**+10**	**2290**	**+6**	**2265**	**+5**
Amp.	187	217	+16	227	+21	190	+2	248	+33
STDV	64	81		82		71		83	

Monthly mean precipitation in mm for the department of Cundinamarca based on MPI-ESM-MR projections									
Month	Historical	RCP 4.5				RCP 8.5			
	1981-2005	p. 1	% diff.	p.2	% diff.	p. 1	% diff.	p. 2	% diff.
Jan	58	76	+32	74	+29	50	-14	46	-20
Feb	85	110	+29	83	-2	93	+10	81	-4
Mar	171	165	-4	152	-11	154	-10	161	-6
Apr	223	231	+3	222	-1	243	+9	266	+19
May	267	288	+8	310	+16	261	-2	357	+34
Jun	218	214	-2	242	+11	236	+8	297	+36
Jul	202	225	+12	247	+23	205	+1	216	+7
Aug	157	136	-13	176	+12	152	-3	154	-2
Sep	171	174	+1	178	+4	155	-10	163	-5
Oct	241	264	+9	275	+14	303	+26	311	+29
Nov	191	238	+25	248	+30	238	+25	332	+74
Dec	132	128	-3	141	+7	152	+16	109	-17
Annual sum	**2116**	**2248**	**+6**	**2349**	**+11**	**2241**	**+6**	**2494**	**+18**
Amp.	209	212	+1	236	+13	254	+21	311	+49
STDV	62	66		74		74		104	

Annex 2

Monthly values for the minimum (Min. T), maximum (Max. T) and mean temperatures (Mean T), the mean temperature change relative to the reference period 1981-2005 (Δ mean T) as well as the sunshine duration and the relative humidity (RH) that were used to calculate the potential evapotranspiration (ETo) in the Bogotá river catchment for all RCPs and periods 1 (2040-2059) and 2 (2080-2099) for the two models CCSM4 and MPI-ESM-MR using the ETo calculator provided by the Food and Agriculture Organization of the United Nations (FAO).

Bogotá river catchment for the historical reference period							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.4	26.9	17.05	+1.36	5.5	78.5	2.4
February	6.9	27.7	17.38	+1.52	5.1	78.5	2.8
March	7.5	26.8	17.22	+1.32	4.0	80.7	3
April	8.8	26.2	17.15	+1.25	3.5	82.6	3.1
May	9.0	26.0	17.17	+1.29	3.5	82.4	3.3
June	8.7	25.9	17.03	+1.35	3.8	80.7	3.5
July	8.1	25.7	16.79	+1.33	4.1	79.6	3.5
August	8.0	26.1	17.01	+1.35	4.3	78.5	3.5
September	7.5	26.5	17.06	+1.34	4.2	78.5	3.2
October	7.8	26.6	17.04	+1.37	4.2	80.7	2.7
November	7.8	25.7	16.87	+1.26	4.2	82.6	2.2
December	7.0	26.3	16.88	+1.26	4.6	81.6	2.1

Bogotá river catchment for CCSM4 RCP 4.5 period 1							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.4	26.9	17.05	+1.36	5.5	78.5	2.4
February	6.9	27.7	17.38	+1.52	5.1	78.5	2.8
March	7.5	26.8	17.22	+1.32	4.0	80.7	3
April	8.8	26.2	17.15	+1.25	3.5	82.6	3.1
May	9.0	26.0	17.17	+1.29	3.5	82.4	3.3
June	8.7	25.9	17.03	+1.35	3.8	80.7	3.5
July	8.1	25.7	16.79	+1.33	4.1	79.6	3.5
August	8.0	26.1	17.01	+1.35	4.3	78.5	3.5
September	7.5	26.5	17.06	+1.34	4.2	78.5	3.2
October	7.8	26.6	17.04	+1.37	4.2	80.7	2.7
November	7.8	25.7	16.87	+1.26	4.2	82.6	2.2
December	7.0	26.3	16.88	+1.26	4.6	81.6	2.1

Bogotá river catchment for MPI-ESM-MR RCP 4.5 period 1							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.5	27.9	17.38	+1.69	5.5	78.5	2.5
February	7.1	28.5	17.64	+1.78	5.1	78.5	2.9
March	7.8	28.7	17.84	+1.94	4.0	80.7	3.2
April	9.1	28.0	17.77	+1.86	3.5	82.6	3.3
May	9.2	27.4	17.64	+1.75	3.5	82.4	3.4
June	8.9	26.9	17.38	+1.70	3.8	80.7	3.6
July	8.2	26.2	16.95	+1.50	4.1	79.6	3.6
August	8.1	27.0	17.30	+1.64	4.3	78.5	3.5
September	7.8	28.3	17.63	+1.92	4.2	78.5	3.3
October	8.2	29.3	17.94	+2.27	4.2	80.7	2.9
November	8.0	26.7	17.21	+1.60	4.2	82.6	2.3
December	7.2	27.5	17.28	+1.66	4.6	81.6	2.2

Bogotá river catchment for CCSM4 RCP 4.5 period 2							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.6	28.4	17.53	+1.84	5.5	78.5	2.5
February	7.2	29.3	17.92	+2.06	5.1	78.5	3
March	7.8	28.6	17.82	+1.92	4.0	80.7	3.1
April	9.1	28.0	17.75	+1.85	3.5	82.6	3.3
May	9.2	27.3	17.61	+1.72	3.5	82.4	3.4
June	8.9	27.1	17.44	+1.76	3.8	80.7	3.6
July	8.3	27.1	17.25	+1.79	4.1	79.6	3.6
August	8.2	27.7	17.53	+1.87	4.3	78.5	3.6
September	7.8	28.1	17.57	+1.85	4.2	78.5	3.3
October	8.0	27.7	17.43	+1.76	4.2	80.7	2.8
November	8.0	27.1	17.34	+1.73	4.2	82.6	2.3
December	7.3	27.7	17.35	+1.73	4.6	81.6	2.2

Bogotá river catchment for MPI-ESM-MR RCP 4.5 period 2							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.9	30.0	18.05	+2.36	5.5	78.5	2.7
February	7.5	31.1	18.53	+2.67	5.1	78.5	3.2
March	8.2	30.9	18.58	+2.68	4.0	80.7	3.4
April	9.5	30.3	18.52	+2.62	3.5	82.6	3.5
May	9.5	29.0	18.16	+2.27	3.5	82.4	3.6
June	9.0	28.0	17.72	+2.04	3.8	80.7	3.7
July	8.4	27.8	17.49	+2.03	4.1	79.6	3.7
August	8.3	28.3	17.74	+2.08	4.3	78.5	3.7
September	8.1	29.9	18.18	+2.46	4.2	78.5	3.5
October	8.3	29.9	18.16	+2.48	4.2	80.7	3
November	8.2	28.0	17.66	+2.05	4.2	82.6	2.4
December	7.3	28.2	17.53	+1.91	4.6	81.6	2.3

Bogotá river catchment for CCSM4 RCP 8.5 period 1							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.7	28.9	17.71	+2.02	5.5	78.5	2.6
February	7.3	30.1	18.17	+2.31	5.1	78.5	3.1
March	7.9	29.1	17.97	+2.07	4.0	80.7	3.2
April	9.1	28.0	17.76	+1.86	3.5	82.6	3.3
May	9.3	27.7	17.73	+1.84	3.5	82.4	3.5
June	9.0	27.6	17.59	+1.91	3.8	80.7	3.6
July	8.3	27.1	17.28	+1.82	4.1	79.6	3.6
August	8.3	27.9	17.61	+1.95	4.3	78.5	3.6
September	7.9	28.4	17.69	+1.97	4.2	78.5	3.3
October	8.1	28.4	17.64	+1.97	4.2	80.7	2.9
November	8.1	27.4	17.46	+1.85	4.2	82.6	2.3
December	7.3	27.9	17.43	+1.81	4.6	81.6	2.2

Bogotá river catchment for MPI-ESM-MR RCP 8.5 period 1							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	6.9	30.3	18.17	+2.48	5.5	78.5	2.7
February	7.5	31.3	18.58	+2.72	5.1	78.5	3.2
March	8.3	31.8	18.86	+2.96	4.0	80.7	3.5
April	9.5	30.4	18.55	+2.65	3.5	82.6	3.5
May	9.6	29.8	18.42	+2.54	3.5	82.4	3.7
June	9.2	28.9	18.04	+2.35	3.8	80.7	3.8
July	8.5	28.2	17.63	+2.18	4.1	79.6	3.7
August	8.5	29.6	18.17	+2.51	4.3	78.5	3.8
September	8.4	31.5	18.70	+2.98	4.2	78.5	3.7
October	8.5	30.5	18.37	+2.70	4.2	80.7	3
November	8.3	28.6	17.84	+2.23	4.2	82.6	2.4
December	7.5	29.3	17.88	+2.26	4.6	81.6	2.3

Bogotá river catchment for CCSM4 RCP 8.5 period 2							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	7.7	35.2	19.79	+4.10	5.5	78.5	3.2
February	8.5	36.9	20.45	+4.59	5.1	78.5	3.8
March	9.1	36.4	20.41	+4.51	4.0	80.7	3.9
April	10.2	34.9	20.06	+4.16	3.5	82.6	4
May	10.3	33.9	19.79	+3.90	3.5	82.4	4.1
June	10.0	33.6	19.59	+3.91	3.8	80.7	4.2
July	9.3	33.2	19.29	+3.83	4.1	79.6	4.3
August	9.3	34.4	19.76	+4.10	4.3	78.5	4.3
September	8.9	34.8	19.81	+4.09	4.2	78.5	4
October	9.2	34.8	19.79	+4.12	4.2	80.7	3.5
November	9.1	33.4	19.43	+3.82	4.2	82.6	2.8
December	8.3	34.3	19.55	+3.93	4.6	81.6	2.8

Bogotá river catchment for MPI-ESM-MR RCP 8.5 period 2							
Month	**Min. T**	**Max. T**	**Mean T**	**Δ mean T**	**Duration of sunshine**	**RH**	**ETo**
	[°C]	[°C]	[°C]	[°C]	[h/d]	[%]	
January	8.4	39.3	21.16	+5.47	5.5	78.5	3.7
February	9.0	40.4	21.62	+5.76	5.1	78.5	4.2
March	9.7	39.8	21.55	+5.65	4.0	80.7	4.3
April	10.9	38.6	21.28	+5.38	3.5	82.6	4.4
May	10.8	36.6	20.69	+4.80	3.5	82.4	4.4
June	10.3	35.8	20.34	+4.66	3.8	80.7	4.5
July	9.8	35.8	20.18	+4.72	4.1	79.6	4.6
August	9.9	37.7	20.88	+5.23	4.3	78.5	4.7
September	9.7	39.5	21.38	+5.66	4.2	78.5	4.6
October	9.7	38.0	20.86	+5.19	4.2	80.7	3.8
November	9.4	35.4	20.11	+4.49	4.2	82.6	3
December	8.8	36.8	20.37	+4.75	4.6	81.6	3.1

Annex 3

Monthly and annual values for the hydrological balance in the total Bogotá river catchment calculated according to data from CCSM4 and MPI-ESM-MR for RCPs 4.5 and 8.5 and for periods 1 (2040-2059) and 2 (2080-2099). Variables: precipitation (P), water transferred to the catchment (Tr), extracted groundwater (GW), infiltrated water (Inf.) evaporation (Evap.), evapotranspiration (ETR), water returned to the catchment (Rt), and total demand.

Total Bogotá river catchment for CCSM4 RCP 4.5 period 1										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	201.90	26.78	0.38	25.48	4.72	179.58	109.31	185.98	-57.38
Feb	28	299.71	24.19	0.35	23.02	4.30	208.36	75.92	131.77	32.72
Mar	31	306.69	26.78	0.38	25.48	4.56	271.25	65.85	116.99	-18.58
Apr	30	581.84	25.92	0.37	24.66	3.99	286.92	38.83	73.70	257.69
May	31	532.13	26.78	0.38	25.48	4.37	281.20	33.35	65.41	216.19
Jun	30	373.10	25.92	0.37	24.66	3.76	212.81	61.01	108.91	110.26
Jul	31	390.29	26.78	0.38	25.48	4.13	189.80	78.46	137.02	139.49
Aug	31	280.82	26.78	0.38	25.48	4.36	197.44	86.51	149.79	17.43
Sep	30	307.29	25.92	0.37	24.66	4.13	240.02	62.79	111.73	15.83
Oct	31	616.47	26.78	0.38	25.48	4.34	290.94	39.37	74.96	287.28
Nov	30	497.79	25.92	0.37	24.66	4.09	289.67	35.78	68.87	172.58
Dec	31	241.89	26.78	0.38	25.48	4.45	220.26	71.13	125.38	-35.38
Annual		**4629.93**	**315.36**	**4.52**	**300.05**	**51.20**	**2868.23**	**758.30**	**1350.50**	**1138.14**

Total Bogotá river catchment for MPI-ESM-MR RCP 4.5 period 1										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	229.60	26.78	0.38	25.48	4.72	187.06	109.31	185.98	-37.17
Feb	28	316.51	24.19	0.35	23.02	4.30	215.80	75.92	131.77	42.07
Mar	31	351.18	26.78	0.38	25.48	4.56	289.33	65.85	116.99	7.83
Apr	30	506.81	25.92	0.37	24.66	3.99	305.43	38.83	73.70	164.15
May	31	499.72	26.78	0.38	25.48	4.37	289.72	33.35	65.41	175.26
Jun	30	297.94	25.92	0.37	24.66	3.76	218.89	61.01	108.91	29.02
Jul	31	317.44	26.78	0.38	25.48	4.13	195.22	78.46	137.02	61.22
Aug	31	231.92	26.78	0.38	25.48	4.36	197.44	86.51	149.79	-31.47
Sep	30	305.55	25.92	0.37	24.66	4.13	247.52	62.79	111.73	6.58
Oct	31	532.66	26.78	0.38	25.48	4.34	312.50	39.37	74.96	181.91
Nov	30	548.21	25.92	0.37	24.66	4.09	302.83	35.78	68.87	209.83
Dec	31	254.86	26.78	0.38	25.48	4.45	230.74	71.13	125.38	-32.90
Annual		**4392.38**	**315.36**	**4.52**	**300.05**	**51.20**	**2992.48**	**758.30**	**1350.50**	**776.33**

Total Bogotá river catchment for CCSM4 RCP 4.5 period 2										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	199.98	26.78	0.38	25.48	4.72	187.06	109.31	187.57	-68.38
Feb	28	265.23	24.19	0.35	23.02	4.30	223.25	75.92	133.21	-18.08
Mar	31	347.27	26.78	0.38	25.48	4.56	280.29	65.85	118.58	11.37
Apr	30	535.15	25.92	0.37	24.66	3.99	305.43	38.83	75.24	190.95
May	31	549.92	26.78	0.38	25.48	4.37	289.72	33.35	67.00	223.87
Jun	30	391.49	25.92	0.37	24.66	3.76	218.89	61.01	110.45	121.03
Jul	31	406.51	26.78	0.38	25.48	4.13	195.22	78.46	138.61	148.70
Aug	31	333.85	26.78	0.38	25.48	4.36	203.08	86.51	151.38	63.23
Sep	30	284.70	25.92	0.37	24.66	4.13	247.52	62.79	113.27	-15.81
Oct	31	657.51	26.78	0.38	25.48	4.34	301.72	39.37	76.55	315.95
Nov	30	375.40	25.92	0.37	24.66	4.09	302.83	35.78	70.41	35.48
Dec	31	246.40	26.78	0.38	25.48	4.45	230.74	71.13	126.97	-42.95
Annual		**4593.40**	**315.36**	**4.52**	**300.05**	**51.20**	**2985.74**	**758.30**	**1369.23**	**965.36**

Total Bogotá river catchment for MPI-ESM-MR RCP 4.5 period 2										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	234.34	26.78	0.38	25.48	4.72	202.02	109.31	187.57	-48.98
Feb	28	235.22	24.19	0.35	23.02	4.30	238.13	75.92	133.21	-62.97
Mar	31	331.24	26.78	0.38	25.48	4.56	307.42	65.85	118.58	-31.78
Apr	30	490.37	25.92	0.37	24.66	3.99	323.94	38.83	75.24	127.66
May	31	537.35	26.78	0.38	25.48	4.37	306.76	33.35	67.00	194.26
Jun	30	338.90	25.92	0.37	24.66	3.76	224.97	61.01	110.45	62.36
Jul	31	355.41	26.78	0.38	25.48	4.13	200.65	78.46	138.61	92.17
Aug	31	303.37	26.78	0.38	25.48	4.36	208.72	86.51	151.38	27.10
Sep	30	304.35	25.92	0.37	24.66	4.13	262.52	62.79	113.27	-11.15
Oct	31	553.94	26.78	0.38	25.48	4.34	323.27	39.37	76.55	190.82
Nov	30	575.00	25.92	0.37	24.66	4.09	316.00	35.78	70.41	221.92
Dec	31	283.01	26.78	0.38	25.48	4.45	241.23	71.13	126.97	-16.83
Annual		**4542.50**	**315.36**	**4.52**	**300.05**	**51.20**	**3155.62**	**758.30**	**1369.23**	**744.58**

Total Bogotá river catchment for MPI-ESM-MR RCP 4.5 period 2										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	234.34	26.78	0.38	25.48	4.72	202.02	109.31	187.57	-48.98
Feb	28	235.22	24.19	0.35	23.02	4.30	238.13	75.92	133.21	-62.97
Mar	31	331.24	26.78	0.38	25.48	4.56	307.42	65.85	118.58	-31.78
Apr	30	490.37	25.92	0.37	24.66	3.99	323.94	38.83	75.24	127.66
May	31	537.35	26.78	0.38	25.48	4.37	306.76	33.35	67.00	194.26
Jun	30	338.90	25.92	0.37	24.66	3.76	224.97	61.01	110.45	62.36
Jul	31	355.41	26.78	0.38	25.48	4.13	200.65	78.46	138.61	92.17
Aug	31	303.37	26.78	0.38	25.48	4.36	208.72	86.51	151.38	27.10
Sep	30	304.35	25.92	0.37	24.66	4.13	262.52	62.79	113.27	-11.15
Oct	31	553.94	26.78	0.38	25.48	4.34	323.27	39.37	76.55	190.82
Nov	30	575.00	25.92	0.37	24.66	4.09	316.00	35.78	70.41	221.92
Dec	31	283.01	26.78	0.38	25.48	4.45	241.23	71.13	126.97	-16.83
Annual		**4542.50**	**315.36**	**4.52**	**300.05**	**51.20**	**3155.62**	**758.30**	**1369.23**	**744.58**

Total Bogotá river catchment for MPI-ESM-MR RCP 8.5 period 1										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	152.57	26.78	0.38	25.48	4.72	202.02	109.31	185.98	-129.16
Feb	28	272.30	24.19	0.35	23.02	4.30	238.13	75.92	131.77	-24.46
Mar	31	323.79	26.78	0.38	25.48	4.56	316.46	65.85	116.99	-46.69
Apr	30	539.42	25.92	0.37	24.66	3.99	323.94	38.83	73.70	178.25
May	31	455.51	26.78	0.38	25.48	4.37	315.28	33.35	65.41	105.49
Jun	30	333.98	25.92	0.37	24.66	3.76	231.05	61.01	108.91	52.90
Jul	31	286.64	26.78	0.38	25.48	4.13	200.65	78.46	137.02	25.00
Aug	31	254.86	26.78	0.38	25.48	4.36	214.36	86.51	149.79	-25.45
Sep	30	264.67	25.92	0.37	24.66	4.13	277.52	62.79	111.73	-64.30
Oct	31	606.50	26.78	0.38	25.48	4.34	323.27	39.37	74.96	244.98
Nov	30	552.34	25.92	0.37	24.66	4.09	316.00	35.78	68.87	200.79
Dec	31	305.19	26.78	0.38	25.48	4.45	241.23	71.13	125.38	6.94
Annual		**4347.76**	**315.36**	**4.52**	**300.05**	**51.20**	**3199.90**	**758.30**	**1350.50**	**524.29**

Total Bogotá river catchment for CCSM4 RCP 8.5 period 2										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	177.87	26.78	0.38	25.48	4.72	239.43	109.31	187.57	-142.86
Feb	28	232.53	24.19	0.35	23.02	4.30	282.78	75.92	133.21	-110.31
Mar	31	352.58	26.78	0.38	25.48	4.56	352.62	65.85	118.58	-55.65
Apr	30	490.30	25.92	0.37	24.66	3.99	370.22	38.83	75.24	81.31
May	31	588.80	26.78	0.38	25.48	4.37	349.37	33.35	67.00	203.10
Jun	30	438.99	25.92	0.37	24.66	3.76	255.37	61.01	110.45	132.05
Jul	31	419.15	26.78	0.38	25.48	4.13	233.19	78.46	138.61	123.38
Aug	31	283.66	26.78	0.38	25.48	4.36	242.56	86.51	151.38	-26.45
Sep	30	287.75	25.92	0.37	24.66	4.13	300.02	62.79	113.27	-65.26
Oct	31	533.31	26.78	0.38	25.48	4.34	377.15	39.37	76.55	116.32
Nov	30	399.77	25.92	0.37	24.66	4.09	368.67	35.78	70.41	-5.98
Dec	31	259.25	26.78	0.38	25.48	4.45	293.67	71.13	126.97	-93.03
Annual		**4463.96**	**315.36**	**4.52**	**300.05**	**51.20**	**3665.05**	**758.30**	**1369.23**	**156.62**

Total Bogotá river catchment for MPI-ESM-MR RCP 8.5 period 2										
Month	**Days**	**P**	**Tr**	**GW**	**Inf.**	**Evap.**	**ETR**	**Rt**	**Demand**	**Balance**
	No.	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]	[Mm3]
Jan	31	141.03	26.78	0.38	25.48	4.72	276.84	109.31	187.57	-217.12
Feb	28	234.36	24.19	0.35	23.02	4.30	312.54	75.92	133.21	-138.25
Mar	31	346.05	26.78	0.38	25.48	4.56	388.79	65.85	118.58	-98.35
Apr	30	591.55	25.92	0.37	24.66	3.99	407.24	38.83	75.24	145.54
May	31	618.34	26.78	0.38	25.48	4.37	374.93	33.35	67.00	207.08
Jun	30	426.58	25.92	0.37	24.66	3.76	273.61	61.01	110.45	101.40
Jul	31	311.30	26.78	0.38	25.48	4.13	249.45	78.46	138.61	-0.74
Aug	31	259.89	26.78	0.38	25.48	4.36	265.13	86.51	151.38	-72.79
Sep	30	275.58	25.92	0.37	24.66	4.13	345.02	62.79	113.27	-122.43
Oct	31	616.04	26.78	0.38	25.48	4.34	409.48	39.37	76.55	166.72
Nov	30	763.01	25.92	0.37	24.66	4.09	395.00	35.78	70.41	330.92
Dec	31	219.26	26.78	0.38	25.48	4.45	325.14	71.13	126.97	-164.49
Annual		**4802.99**	**315.36**	**4.52**	**300.05**	**51.20**	**4023.18**	**758.30**	**1369.23**	**137.51**

Annex 4

Categorization for climate change adaptation actions modified after McDowell *et al.* (2018).

Motivation	Initiative	Nature	Methodology	Knowledge basis	Involved sectors	Leading actor	Vulnerable groups	Spatial scale
- climatic stressors (e.g. experienced or anticipated changes in climatic events or climate-induced changes in the cycle of natural resources) - non-climatic stressors (e.g. non-climatic processes of environmental change like soil erosion, deforestation or water contamination, food insecurity, economic opportunities like last change tourism, population pressures of resource development	- reactionary (coping activities) - anticipatory (preparative activities)	- behavioural (e.g. changes in the structure and nature of farming, migration etc.) - regulatory (e.g. creation or revision of regulations) - research/knowledge based - educative - implementation of technologies - modification of infrastructure	- autonomous (i.e. no guidance from formal adaptation strategy) - community-based - participatory (involving non-academic stakeholders in research design or assessment) - modelling projections of biophysical changes - textual projections of biophysical changes - modelling projections of social change - spatial and temporal analogues - longitudinal study design - comparative approaches, cross-scale analyses	- engages substantively with the physical science basis of CC - relies on basic information and assumptions about the nature of CC - engages substantively with the social dimensions - informal, descriptive examination of relationships	- agriculture - hydrological resources - hazard risk management - forestry - tourism - environmental conservation	- community members - intergovernmental organisations - national governments - national institutions - regional institutions - academic institutions - NGOs	- economically disadvantaged - indigenous - women - youth - elderly - migrants - sick and weak	- small scale (e.g. household, community) - medium scale (e.g. region) - large scale (e.g. nation) - single region - single community - multiple communities - multiple regions - multiple mountain ranges - etc.

Annex 5

Monitoring matrix for management and advance of physical and financial targets of the action plan, based on MADS (2009).

CORPORACIÓN AUTÓNOMA REGIONAL.........................

VIGENCIA EVALUADA (AÑO): ______________________ PERIODO EVALUADO (SEMESTRE): ______________

(1) PROGRAMAS - PROYECTOS DEL PLAN 2007-2011 (inserte filas cuando sea necesario)	COMPORTAMIENTO META FISICA										META FINANCIERA						(17) OBSERVACIONES
	(2) UNIDAD DE MEDIDA	(3) META FISICA ANUAL (Según unidad de medida)	(4) AVANCE DE LA META FISICA (Según unidad de medida y Periodo Evaluado)	(5) PORCENTAJE DE AVANCE FISICO % (Periodo Evaluado) ((4/3)*100)	(5-A) DESCRIPCIÓN DEL AVANCE (Se puede describir en texto lo que se desea aclarar del avance númerico respectivo)	(6) PORCENTAJE DE AVANCE PROCESO DE GESTION DE LA META FISICA (aplica unicamente para el informe del primer semestre)	(7) META FISICA PERIODO PLAN (Según unidad de medida)	(8) ACUMULADO DE LA META FISICA (Según unidad de medida)	(9) PORCENTAJE DE AVANCE FISICO ACUMULADO % ((8/7)*100)	(10) PONDERACIONES DE PROGRAMAS Y PROYECTOS (OPCIONAL DE ACUERDO AL PLAN)	(11) META FINANCIERA ANUAL ($)	(12) AVANCE DE LA META FINANCIERA (Recursos comprometidos periodo Evaluado) ($)	(13) PORCENTAJE DEL AVANCE FINANCIERO % (Periodo Evaluado) ((12/11)*100)	(14) META FINANCIERA PERIODO DEL PLAN ($)	(15) ACUMULADO DE LA META FINANCIERA $	(16) PORCENTAJE DE AVANCE FINANCIERO ACUMULADO % ((15/14)*100)	
PROGRAMA No 1																	
Proyecto No 1.1.																	
Actividad No 1.1.1																	
Actividad No 1.1.n																	
....																	
Proyecto No 1.2.																	
Actividad No 1.2.1																	
Actividad No 1.2.n																	
....																	
Proyecto No 1.n.																	
Actividad No 1.3.1																	
Actividad No 1.3.n																	
....																	
PROGRAMA No N																	
Proyecto No N.1.																	
Actividad No N.1.1																	
Actividad No N.1.n																	
....																	
Proyecto No N.2.																	
Actividad No N.2.1																	
Actividad No N.2.n																	
....																	
Proyecto No N.n.																	
Actividad No N.n.1																	
Actividad No N.n.n																	
....																	
(18) TOTAL METAS FISICAS Y																	

*El total de las metas fisicas y financieras sera el resultado de una sumatoria, promedios aritmetico o ponderados segun el caso y solo se aplica para las columnas relacionadas con porcentajes de avance y metas financieras.

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Zürich, 31. January 2019 Laura Niggli