Climate risk analysis for adaptation planning in Cameroon's agricultural sector

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Nele Gloy[1], Priscilla Kephe[1], Lennart Jansen[2], Sebastian Ostberg[1], Juliane Kaufmann[3], Lina Staubach[3], Mesmin Tchindjang[4], Paula Romanovska[1], Regina Vetter[5], Julia Tomalka[1], Timothée Kagonbé[6], Muriel Anaba[7], Isabella Zouh[7], Joseph A. Amougou[7], Carla Cronauer[1] and Christoph Gornott [1,2]

1: Potsdam Institute for Climate Impact Research (PIK), 2: University of Kassel, 3: Humboldt Forum for Food and Agriculture (HFFA) Research GmbH, 4: University of Yaoundé I, 5: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 6: Ministry of Environment, Nature Protection and Sustainable Development (MINEPDED), 7: National Observatory on Climate Change (ONACC)

A report prepared as part of the AGRICA project by the Potsdam Institute for Climate Impact Research (PIK) together with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), in cooperation with the Ministry of Environment, Nature Protection and Sustainable Development (MINEPDED), the National Observatory on Climate Change (ONACC), a local consultant from the University of Yaoundé I, the HFFA Research GmbH and stakeholders from local and national governmental institutions, civil society, academia, the private sector, practitioners and development partners in Cameroon and beyond.

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Authors' contributions
Nele Gloy and Christoph Gornott coordinated and edited the overall study, ensuring alignment between the different analysis steps and distilling key results and the conclusion. Christoph Gornott, Lisa Murken and Nele Gloy designed the study approach with valuable input from stakeholders. Nele Gloy, Timothée Kagonbé and Mesmin Tchindjang coordinated the stakeholder engagement process. Paula Romanovska performed the climate analysis in Chapter 1. Isabella Zouh and Muriel Anaba supervised by Joseph A. Amougou, together with Priscilla Kephe, conducted the land cover change assessment in Chapter 2. Sebastian Ostberg analysed climate impacts on potential pasture productivity for Chapter 3. Regina Vetter contributed to Chapter 4. Lennart Jansen with inputs from Abel Chemura analysed climate impacts on maize yields and the risk mitigation potential of improved seeds using crop models in Chapter 5 and contributed to Chapter 5 and 6. Priscilla Kephe analysed climate impacts on cassava yields and the risk mitigation potential of ISFM using crop models in chapter 5. Nele Gloy with inputs from Abel Chemura conducted the crop and agroforestry suitability analysis for chapter 5, 6 and 7. Juliane Kaufmann And Lina Staubach together with Steffen Noleppa conducted the farm-level cost-benefit analyses in Chapters 5–7. Julia Tomalka contributed to Chapter 3, designed the gender approach for chapter 4, and contributed the gender sections in Chapter 5–7. Mesmin Tchindjang and Carla Cronauer contributed to Chapter 1. All authors contributed to the Annex on methods and Chapter 8 on uncertainties.

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Abstract

Cameroon has a high socio-economic dependency on agriculture, a sector which is strongly influenced by weather-related factors and increasingly challenged by the impacts of climate change. Currently, only limited information on climate risks and its impacts is available for the agricultural sector in the country. Therefore, this study aims to provide a comprehensive climate risk analysis including a thorough evaluation of three potential adaptation strategies that can guide local decision makers on adaptation planning and implementation in Cameroon. The impact assessment consists of several steps including climate projections based on two emissions scenarios (SSP3-RCP7.0 and SSP1-RCP2.6), assessing land cover changes, modelling and comparing future suitability and yield of three widely used crops (maize, cassava and cocoa) and an assessment of grassland productivity under future climate conditions. Further the study outlines gender-related challenges and opportunities in national adaptation planning. Based on the projected climate change impacts on agricultural production, three different adaptation strategies ((1) Improved varieties, (2) Integrated soil fertility management (ISFM) and (3) Agroforestry), that were suggested and selected by different national stakeholders, were analysed regarding their potential to risk mitigation, (cost-) effectiveness and suitability for local conditions. The analyses have been further complemented by expert- and literature-based assessments, semi-structured key informant interviews and two stakeholder workshops.

The results show, that by 2050 mean annual temperature is projected to increase by 1.1 °C under the low emissions scenario and 1.5 °C under the high emissions scenario compared to 2004. Some uncertainty exists for annual precipitation projections, the model ensemble projects an increase in precipitation, which is stronger under the high emissions scenario while also projecting an increase in precipitation intensity. Projected impacts of climate change on agricultural yields vary between regions and show partly opposing trends. Maize yields will decrease in the Sudano-Sahelian Zone by up to 84 % by 2090 under SSP3-RCP7.0 and over 30 % of yield losses for cassava are projected for AEZ I and II by the end of the century under the SSP3-RCP7.0 scenario. Significant positive cassava yield effects are projected in the (Guinean) High Savannah Zone, High Plateau (Western Highlands), and humid Mono- and Bimodal (Rain)forest Zones, respectively, under SSP1-RCP2.6. Crop models show that the areas suitable for maize and cocoa will decrease in Cameroon, especially under SSP3-RCP7.0, while the suitability for cassava will remain relatively stable. Regarding the livestock sector, it seems very likely that the grazing potential will decrease under both climate change scenarios with higher decreases under SSP1-RCP2.6 than under SSP3-RCP7.0.

All three adaptation strategies were found to be economically beneficial, to have a high potential for risk mitigation and to entail different co-benefits. Particularly, ISFM can be highly recommended resulting in very positive effects for smallholder farmers, and the environment. Improving seeds has a high potential to improve livelihoods, but this adaptation strategy is also support-intensive. Lastly, agroforestry has a potential to reduce the impact of climate risks on cocoa production, but future climatic suitability needs to be considered. The findings of this study can help to inform national and local adaptation and agricultural development planning and investments in order to strengthen the resilience of the agricultural sector and especially of smallholder farmers against a changing climate in Cameroon.

KEYWORDS

climate change adaptation

climate impacts

climate risk

agriculture

maize

cacao

cassava

livestock

Cameroon

biophysical modelling

cost-benefit analysis

gender

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Foreword

Since the ratification of the United Nations Framework Convention on Climate Change in 1994, Cameroon has always made efforts to meet its commitments to the international community. The initial National Communication of 2001 enabled the country to embark on a vast program to improve the environment and the living conditions of the populations as well as adaptation to climate change. With the Paris Agreements in 2015 and the promulgation of the White Paper on the Adaptation of African Agriculture in Marrakech in Morocco in 2016, each country on the African continent on the basis of the NDCs and NAPs tries to promote adaptation policies and effective mitigation.

In Cameroon, a vulnerability assessment was conducted in 2013. It supported the drafting of the Second National Communication (2015) and the PNACC (2015). Another vulnerability assessment followed in 2020 to enable the preparation of the third communication and the Biennial Update Report (BUR). These studies have identified the main climatic hazards to which populations and ecosystems are exposed while assessing the vulnerabilities of populations and economic sectors in Cameroon. Among these sectors, in particular, agriculture has been identified as the most vulnerable sector in which appropriate strategies must be put in place.

The Ministry of the Environment, Nature Protection and Sustainable Development (MINEPDED) is constantly working for a paradigm shift and to encourage projects for adaptation and mitigation. Thus, the agricultural sector has benefited from several strategy documents, in particular the Rural Sector Development Strategy (2006), the National Agricultural Investment Plan of Cameroon 2014–2020 (2014); the Cameroon Agricultural Risk Assessment (2017) from PARM and the Cameroon Climate Resilient Agricultural Investment Plan-PNIAIC (2020). In 2018, ONACC carried out an Economic Assessment of the impact of climate change on the yields of food crops in the Centre, East, Far North and South West regions of Cameroon.

All these documents show the importance of the agricultural sector in Cameroon which contributes 17 % of the GDP in 2021 and employs about 60 % of the active population. This sector is very exposed to climatic risks which, in turn, can inhibit economic and social development. Farmers and stockbreeders are confronted with many dangers resulting from climatic vagaries such as drought, heat pockets and floods which attack plants, destroy crops and animals, cause famines and food insecurity, not to mention the consequent fluctuations in prices of crops, inputs and outputs.

Despite the initiatives taken, strategies and management measures put in place for about a decade, we note that their effectiveness is still slow to produce the expected results despite the will of the government and bilateral partners.

This study complements the previous ones and sheds new light on them with the projection on the influence of climate change on small producers and on agriculture in general by 2100 with maize, cassava, cocoa and to a lesser extent cotton and pasture. The major objective pursued by the study is: Analysis of climate risks in agricultural production and the potential for appropriate adaptation planning to support resilient land use planning and support the implementation of CDN, NAPCC and SND30. From this objective arise two major questions: What will be the impact of climate change on the production and suitability of selected crops and grazing? What are the appropriate adaptation strategies to mitigate these impacts and contribute to resilient land use planning?

The study was carried out from 2022 to 2023 as part of the AGRICA project implemented by Potsdam Institute for Climate Impact Research (PIK) and GIZ, which has already carried out since 2018, similar climate risk profile studies and climate risk analysis in 15 African countries. This has benefited from the free expertise of the PIK team supported by ONACC and a national consultant with the supervision of MINEPDED and the technical and financial support of the German Federal Ministry for Economic Cooperation and Development (BMZ) and GIZ. The methodology of the study considers: (1) climate data: (EWEMBI, CHIRPS, CRU), local weather data and climate projection data (ISIMIP), (2) satellite remote sensing data, (3) different types of models (EcoCrop, APSIM, LPJmL) and (4) cost-benefit analysis as well as social (evaluation of co-benefits, interviews with key informants) analyses. This methodology had been discussed and validated during the launch of the project in May 2022. A preliminary version of the results was presented and validated during the workshop issued on March 29, 2023 in Yaoundé. This workshop, which brought together representatives of the main stakeholders in the environment sector in Cameroon (public administrations, professional organizations, private companies, financial institutions, technical and financial partners, academic and research institutions, NGOs and civil society, etc.) made it possible to comment and enrich the document.

Scientifically, this study is the first carried out in Cameroon in this area and as such devotes an essential document for adaptation and mitigation with strategies and action proposals for better management of agricultural climate risks and our rain-fed agriculture in the distant future. It is thus made essential for decision-making in the agricultural sector in Cameroon.

HELE Pierre
Minister of the Environment, Protection of Nature and Sustainable Development

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List of abbreviations

AEZ	Agroecological zones
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRA	Alliance for the Green Revolution in Africa
APSIM	Agricultural Production System Simulator
ASI	Anthesis-Silking Interval
asl	above sea level
BCR	Benefit-Cost Ratio
BMZ	German Federal Ministry for Economic Cooperation and Development
C3S	Copernicus Climate Change Service
CBA	Cost-Benefit Analysis
CFA	Communauté Financière Africaine (African Financial Community)
CGIAR	Consultative Group on International Agricultural Research
CHC	Cameroon Highland Composite
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CILSS	Permanent Interstates Committee for Drought Control in the Sahel
CIMMYT	Centre for Maize and Wheat Improvement
CIS	Climate Information Services
CMD	Cassava Mosaic Disease
CMIP	Coupled Model Intercomparison Project
CMS	Cameroon Maize Selection
CRA	Climate Risk Analysis
CSM	Crop System Model
CV	Coefficient of Variation
CWR	Crop Water Requirement
DD	Degree Days
DTMA	Drought-Tolerant Maize for Africa
ECS	Equilibrium Climate Sensitivity
ERA5	Fifth generation ECMWF atmospheric reanalysis of the global climate
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning Systems Network
GCM	Global Climate Model
GDHY	Global Dataset of Historical Yield
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLC	Global Land Cover
GrCO2	Global CO2 emissions
GRDC	Global Runoff Data Centre
GS	Growing season
HWSD	Harmonised World Soil Database
IAM	Integrated Assessment Models
ICV	Improved Crop Varieties
IFATI	Institute in Agriculture and Innovative Technologies
IITA	International Institute of Tropical Agriculture
IMV	Improved Maize Variety
IPCC	Intergovernmental Panel on Climate Change
IRAD	Institute of Agricultural Research for Development
IRR	Internal Rate of Return
ISFM	Integrated Soil Fertility Management
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
ISRIC	International Soil Reference and Information Centre
ITCZ	Intertropical Convergence Zone
LPJmL	Lund-Potsdam-Jena with managed Land
MAE	Mean Absolute Error
MINADER	Ministry of Agriculture and Rural Development
MINEFOP	Ministry of Employment and Vocational Training
MINEPAT	Ministry of Economy, Planning and Land Planning
MINEPDED	Ministry of Environment, Protection of Nature and Sustainable Development
MINEPIA	Ministry of Livestock, Fisheries and Animal Industries
MMEM	Multi-Model Median
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organisation
NPV	Net Present Value
ONACC	National Observatory on Climate Change
OOS	Out-Of-Sample
OPV	Open-Pollinated Variety
pBias	percent Bias
PIK	Potsdam Institute for Climate Impact Research
PNDRT	National Program for Roots and Tubers Development
PNDSA	National Agricultural Seed Development Plan
PNIA	National Agriculture Investment Plan
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
SDGs	Sustainable Development Goals
SOM	Soil Organic Matter
SSA	sub-Saharan Africa
SSP	Shared Socioeconomic Pathways
SWIM	Soil and Water Integrated Model
TLU	Tropical Livestock Unit
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for Internal Development
USD	United States Dollar
WEMA	Water-Efficient Maize for Africa
WMO	World Meteorological Organization

Introduction

While many countries increasingly recognise the importance of adapting to a world of changing climate, there is often a lack of guidance on how to operationalise adaptation goals. As part of their international commitments, such as under the Paris Agreement, countries seek to develop and implement adaptation policies and investment plans, for instance as part of their Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs). The agricultural sector is particularly vulnerable to climate change, due to its high dependency on climatic factors. Extreme events and slow-onset hazards, such as floods, droughts or extreme temperatures, increasingly threaten agricultural production and thereby pose a serious threat to agricultural livelihoods with cascading impacts on food and nutrition security.

Adaptation decisions often take place at the sub-national level, where decision-makers have to cope with a lack of locally specific data on current and projected climate risks and their impacts, as well as on costs and benefits of suitable adaptation strategies. To address this issue, fine-grained climate risk analyses and assessments can serve as a foundation for risk-informed and economically sound investment decisions at the local level. A better understanding of projected climate impacts on agricultural production, associated climate risks and possible benefits of adaptation measures both at national and province level is important to guide, incentivise and accelerate public and private-sector investments for climate-resilient agricultural development.

This study provides an in-depth analysis of climate risks for selected crops (maize, cassava and cocoa) and livestock systems in Cameroon, together with recommendations and an accompanying assessment of the feasibility, costs and benefits of three selected adaptation strategies. Cameroon was selected for this study due to the country's high socio-economic dependency on the agricultural sector, which is highly exposed and vulnerable to climate change. In their NAP, Cameroon is pointing out the need for adaptation planning to cope with climate change related risks. Therefore, the study seeks to provide the base for risk-informed and economically sound adaptation decisions for the agricultural sector in Cameroon by addressing the following questions:

- How will climatic conditions change in the next decades?
- How has land cover changed and how are these changes linked to agricultural production?
- How will the climatic changes influence smallholder agricultural production in Cameroon?
- What are suitable adaptation options to address these risks?
- What are gender-related challenges in adaptation planning in Cameroon?

The findings are meant to support national and local policy makers, development actors, the private sector and farmers to inform long-term resilient land use planning, adaptation planning and investment. In addition to this in-depth scientific report, we also provide a summary for policy makers offering a condensed overview of those findings with a particular focus on its relevance for policy making.

Study area

Located in Central Africa, the Republic of Cameroon stretches from the Gulf of Guinea to Lake Chad, between 2°–13° North and 8° 30'–16° 10' East (République du Cameroun, 2015). Covering an area of approximately 475,000 km², Cameroon is bordered by Nigeria to the northwest, by Chad to the north, by the Central African Republic to the east, by Congo, Gabon and Equatorial Guinea to the south (Figure 1). To the west, it has an opening of approximately 400 km of coastline on the Atlantic Ocean (MINEPDED, 2021). Countries in sub-Saharan Africa are highly exposed to climate change due to their geographical location in the intertropical zone. Cameroon is no exception in this regard, especially those parts of the country which are located in the Sahel region and, therefore, particularly affected by desertification; or in coastal areas, which are threatened by rising sea levels. Hence, climate change presents a major challenge for Cameroonians as their economic and social well-being is highly dependent on the sustainability of key sectors (République du Cameroun, 2015).

Cameroon regularly faces climatic hazards including floods, droughts and soil erosion. Thus, climatic hazards have a greater impact on the Sudano-Sahelian agroecological zone (AEZ) with regard to extreme droughts and floods and the coastal AEZ with regard to floods. The impacts of climate change are multifaceted and vary not only from one AEZ to another, but also from one economic sector to another. The changing of weather patterns, in particular droughts and floods, should not, however, be underestimated. Biophysical risks and post-harvest losses on crop production are the two major risks of the agricultural sector in Cameroon. The frequency of these risks is very high (every year, even several times a year) and the severity of losses in the event of extreme events (accumulation of diseases and pest attacks in particular) is very high. Price volatility constitutes a second major risk factor, affecting producers each year.

Cameroon's total population was estimated at 26.5 million in 2021 (World Bank, 2020), with varying population densities in the ten administrative regions, ranging from 7 to 200 inhabitants/sq (average density of 56 inhts/sq). According to projections, the expected population in Cameroon for 2050 is 50 million, while for 2100, it is approximately 90 million people (UN data, 2022). The Cameroonian economy is dominated by the primary sector in which agriculture, livestock and fishing employ more than 70 % of the working population and represent 16.9 % of GDP in 2021 (Worldbank, 2023, 2021). Major cultivated food crops are millet, sorghum, cassava and maize, which are predominantly rain-fed and grown by small-scale peasant farmers (Epule, 2021; FAO, 2021). Furthermore, Cameroon is the fourth largest producer of cocoa in the world (according to the latest cocoa season) and also grows coffee, lumber and cotton (FAO, 2004; ICCO, 2023).

Figure 1: Topographical Map of Cameroon with administrative borders.

Agricultural activities in the country are highly sensitive to temperature increases, heat waves, and droughts, making it the most vulnerable sector to the effects of climate change (République du Cameroun, 2015). According to the Cadre Harmonisé (2021) analysis from October to December 2021, around 2.4 million people (9 % of the total population) were estimated to be severely food insecure. This can be explained by various factors, like the impacts of Boko Haram incursions in Far North Region, price increases of basic staple commodities, COVID-19-related economic shocks, which disrupted trade flows and agricultural practices, and climatic hazards (FAO, 2021; IPC, 2021). The development of climate-resilient agriculture and the improvement of farmers' adaptive capacities are therefore especially important.

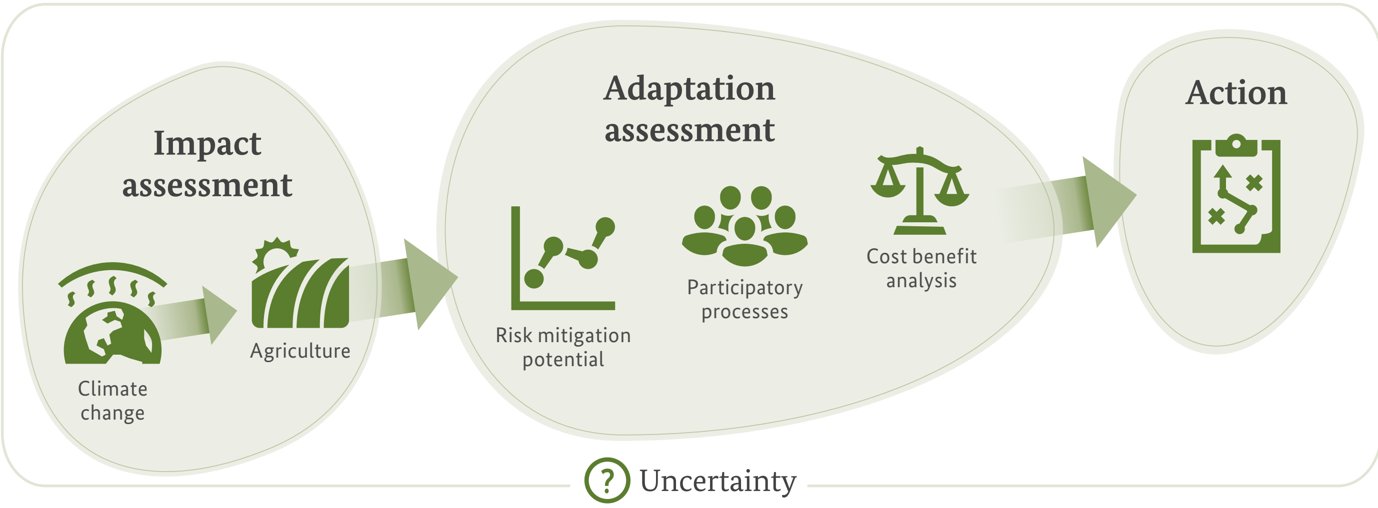

Figure 2: The impact-action chain of the climate risk analysis covering the assessment of climatic changes, land cover changes, impacts on crop and livestock production as well as the evaluation of suitable and viable adaptation strategies.

Study approach

The study combines model-based climate impact assessments with economic and multi-criteria analyses to evaluate adaptation strategies under two different greenhouse gas (GHG) emissions scenarios covered in the Intergovernmental Panel on Climate Change (IPCC) reports. SSP1-RCP2.6 (low-emissions scenario) represents a scenario that remains globally below 2 °C above pre-industrial temperatures and is thereby in line with the upper end goal of the Paris Agreement. SSP3-RCP7.0 (high-emissions scenario) refers to the “without climate policy” scenario. The study thereby models the whole chain from the impact dimension of climatic changes for the agriculture and livestock sectors, to an action dimension assessing specific adaptation strategies, as well as including a discussion on the uncertainty of results (Figure 2).

Furthermore, due to the importance of the protection of forest areas in Cameroon and its link to agricultural production, the study provides an assessment of land cover changes in the Departments Mbam and Kim in the Central region. Another special component of the study is the in-depth analysis of gender-related challenges and opportunities in adaptation planning based on a literature review.

The crops that were analysed in this study were selected according to the list of priority crops by economic importance provided by the Cameroonian government. The selection of adaptation strategies was carefully designed in alignment with local priorities and interests of different stakeholders from government, academia, the private sector and civil society as well as Cameroonian government initiatives, such as the National Agriculture Investment Plan (PNIA) or the National Agricultural Seed Development Plan (PNDSA) which aim to increase the competitiveness, resource use efficiency and attractiveness of Cameroon’s agricultural sector (Mafouasson, 2020).

In order to ensure alignment of the study with national goals and priorities, a wide range of local experts and stakeholders has been involved throughout the study process via stakeholder workshops, farmer surveys and expert discussions. Close collaboration with ministries, such as the Ministry of Environment, Nature Protection and Sustainable Development (MINEPDED), and others, local research institutes, such as the National Observatory of Climate Change (ONACC) and University of Yaoundé I, University of Dschang and others, and other institutions, such as the Food and Agriculture Organization of the United Nations (FAO), allowed us to get continuous validation of our study focus and results. The methodology (I) and uncertainty (II) are described in the annex. The study is organized as follows:

- **Chapter 1** provides an overview of past and projected future climatic changes in Cameroon focusing on shifting temperature and precipitation patterns in the country. All future projected climate impacts are based on outputs of ten global climate models under two future climate scenarios, a low-emissions scenario (SSP1-RCP2.6) and a high-emissions scenario (SSP3-RCP7.0).
- **Chapter 2** analyses the land cover changes in the Departments Mbam and Kim in the Central Region using remote sensing data.
- **Chapter 3** assesses climate impacts on livestock production by analysing the projected grazing potential and associated fodder availability under climate change.
- **Chapter 4** discusses the role of gender and farmer diversity in adaptation planning. and
- **Chapter 5–7** present a comprehensive overview of climate impacts on crop production, ranging from changes in crop suitability under climate change and projected impacts of climate change on crop production and assess selected adaptation strategies. Chapter 5 looks at improved maize varieties, Chapter 6 at integrated soil fertility management (ISFM) for cassava and Chapter 7 at agroforestry for cocoa.
- **Chapter 8** provides a conclusion of the study results and derived policy recommendations.

1. Changing climatic conditions

To identify changes in future climatic conditions in Cameroon, this chapter analyses several indicators concerning temperature and precipitation under the two global emissions scenarios, scenario SSP1-RCP2.6 and scenario SSP3-RCP7.0. Projected climate data was analysed to show the range of possible future climatic conditions by 2030, 2050 and 2090. First, an outline of current climatic conditions is given, followed by the presentation of past as well as future climate trends of mean annual temperature and precipitation, as well as extreme weather events.

> We analyse two emissions scenarios, which cover the range of possible CO_2 emissions pathways: one scenario which assumes that global temperature increases remain below 2 °C (SSP1-RCP2.6), the other scenario represents a world without climate policy (SSP3-RCP7.0).

1.1 Cameroon's climate

Cameroon's geographical location explains the variety of its landscapes, climates and populations, which is why the country's is also referred to as "little Africa". Since 2000, the country is traditionally divided into five AEZs which roughly correspond to the natural regions of Cameroon (IRAD, 2000, MINEPDED, 2021) (Figure 3):

1. The **Sudano-Sahelian Zone (I)** has a semi-arid climate with a high variability of rainfall ranging from 400 to 1000 mm per year. This region is the most populated of Cameroon and besides an important focus on livestock production, main crops grown in the zone include cotton, millet-sorghum, cowpea, onion and sesame (IRAD, 2000; République du Cameroun, 2015; Vondou et al., 2021). Different interrelated risk factors make the Sudano-Sahelian zone particularly crisis-prone, including seasonality of food supply, price volatility on local markets, ethnic conflict and violence, all of which impacts household well-being and income (PARM, 2017; MINEPDED, 2021). The zone is also threatened by desertification, due to persistent low rainfall, uneven spatial and temporal distribution of rainfall, and soil degradation caused by unsustainable agricultural practices (Molua & Lambi, 2006).
2. The (**Guinean) High Savannah Zone (II**) known as the Adamawa plateau has the largest water catchment area of the country, since many of the country's major rivers have their sources here. Rainfall amounts reach 1500 mm per year in 150 days (République du Cameroun, 2015; IRAD 2000). The area is suitable for both agropastoral and forestry activities, but is characterized by a continuous deterioration of agrosylvopastoral resources (Molua & Lambi, 2006). Crops grown in this zone include millet-sorghum, maize, yam, potato and cocoyam (République du Cameroun, 2015).
3. The **High Plateau (Western Highlands) Zone (III)** is an area with a tropical mountainous climate and has the second largest water catchment area of the country after the Adamawa plateau. Rainfall amounts to 1500–2000 mm per year in 180 days. Main crops grown in this zone are coffee, cocoa, maize, potato, yam, cocoyam and dry beans (République du Cameroun, 2015; IRAD, 2000). This area is dominated by subsistence farming of maize, in addition to tubers, plantain, fruits and vegetables, as well as family plantations of arabica coffee and poultry or pig farms (MINEPDED, 2021).

4. The **Monomodal (Rain)forest Zone (IV)** or coastal area has a humid equatorial climate. It is the rainiest area of the country with 2500 to 4000 mm per year. Crops that are mainly grown in this area include cocoa, banana, plantain, palm oil, ginger and pepper (République du Cameroun, 2015; IRAD, 2000).
5. The **Bimodal (Rain)forest Zone (V)** belongs to the South Cameroon Plateau. It is a zone of humid tropical forests with a particularly dense hydrographic network. Rainfall in this area reaches 1500 to 2000 mm per year. Main crops in this area are cocoa, cassava, corn, palm oil and pineapple (République du Cameroun, 2015). This zone is dominated by industrial and export agriculture (oil palm, rubber, bananas) and family farming based on cassava and plantain, combined with cocoa/coffee and small livestock (IRAD, 2000; MINEPDED, 2021).

Cameroon's wide extension in latitude allows for high climatic variation from an abundant bimodal (Centre and South) and monomodal (South-West, West and Coastal) rainfall pattern with 1600–3000 mm to a Sahelian seasonal monomodal rainfall pattern of 500–800 mm. The temperature itself varies from one environment to another and is between 20 and 35 °C with a thermal amplitude ranging from 3 to more than 12 °C in the northern regions of the country (MINEPDED, 2021; Suchel, 1989). Studies on climate variability and climate change have interested the world community after several large-scale climate events. Of these, the droughts in 1972–1973 and 1983–1984 were of particular intensity and hit most of the countries of tropical Africa, where Cameroon is no exception (Tchindjang et al. 2012).

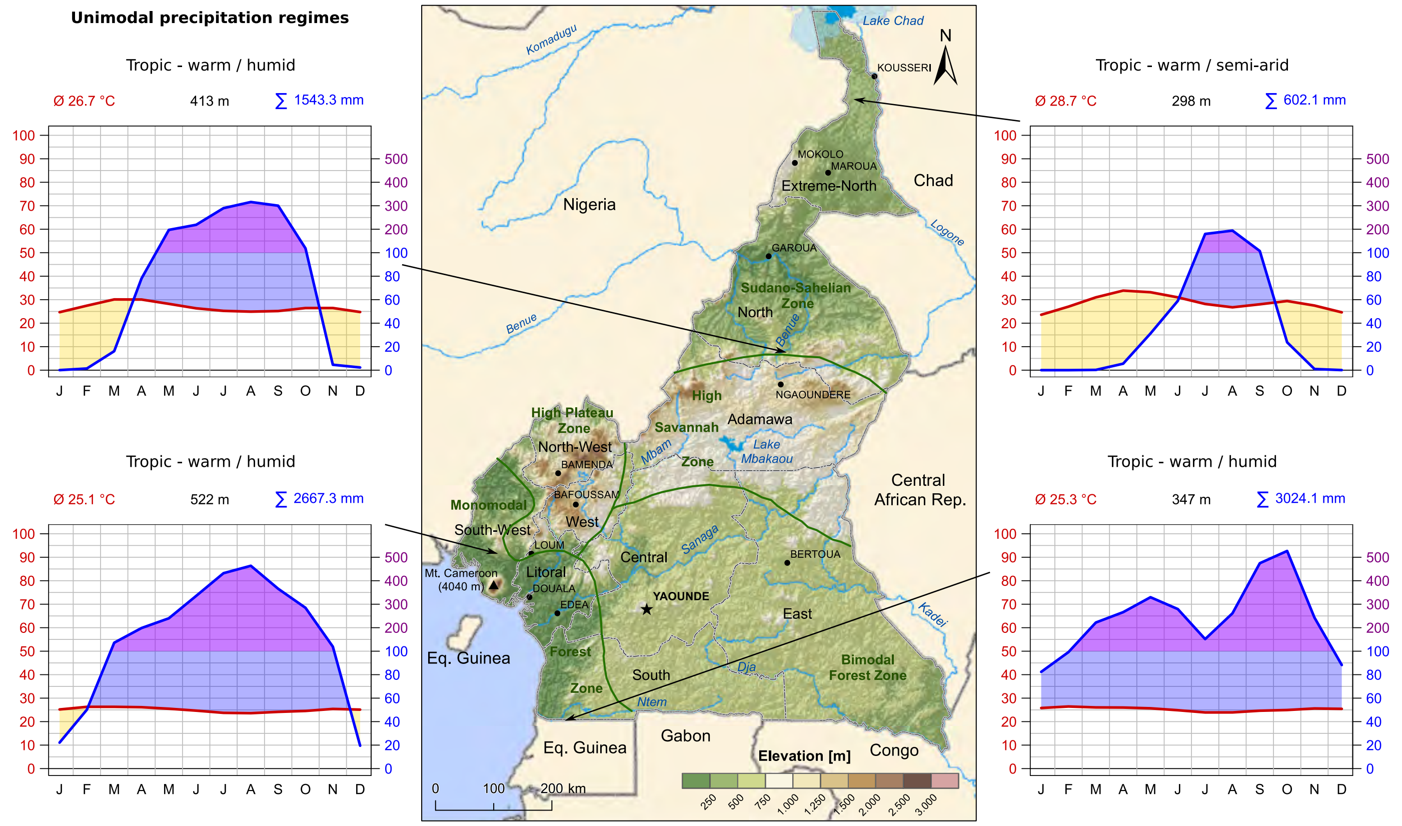

Figure 3: Topographical map of Cameroon with AEZs and location-specific examples of annual temperature and precipitation climate pattern: Sudano-Sahelian Zone (I), High Savannah Zone (II), High Plateau Zone (III), Monomodal (Rain)forest Zone (IV), Bimodal (Rain)forest Zone (V).

1.2 Present climatic conditions

Cameroon currently experiences mean annual temperatures between 22–29 °C, with the exception of cooler temperatures in the mountainous regions. Temperatures in the north are higher than in the south. While the inter-seasonal temperature differences are generally low, the north experiences some inter-seasonal fluctuations with the hottest month being April (Figure 4). The mean annual precipitation sum ranges between 400 and 5000 mm/year with a strong gradient from the dry north to the wet south. The rainfall regime is unimodal for most parts of the country. The rainy season in the most northern part is short, with rainfall between June and September. The length of the rainy season increases steadily towards the south. In the most southern part of the country, December and January are the dominant dry season and July has a shorter dry season.

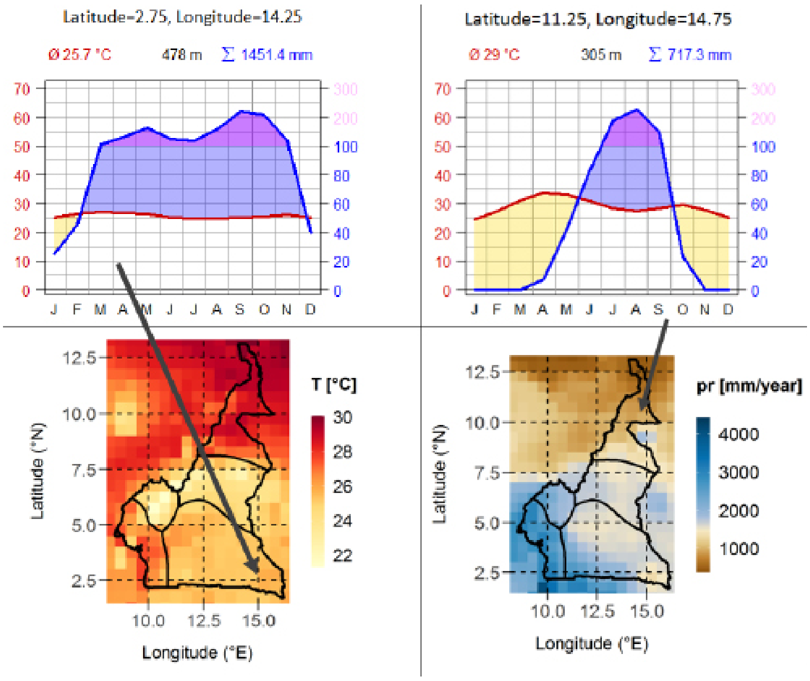

Figure 4: Top: Two climate diagrams displaying the annual distribution of precipitation and temperature in the south [2.75 °N; 14.25 °E] (left) and in the north [11.25 °N; 14.75 °E] (right). Bottom: Mean annual temperature in °C (left) and mean annual precipitation in mm (right) over Cameroon 1995–2014.

1.3 Climate change and variability in the past and the future

Temperature

During the last four decades, mean temperatures showed an average rise of 0.18 °C per decade. Higher increases were observed in the north (Figure 5). The minimum daily temperatures have increased more strongly than maximum daily temperatures. Future projections of temperature show an overall continuation of the recent increasing trend (Figure 6). In response to increasing GHG concentrations, mean annual temperature is projected to increase by 1.1 °C under the low emissions scenario and 1.5 °C under the high emissions scenario by 2050, compared to 2004. Temperatures will stabilize under low future emissions after 2050 and will further rise until the end of this century under high future emissions. The increases are projected over all of Cameroon. The temperature projections are robust with all models clearly agreeing on the trend.

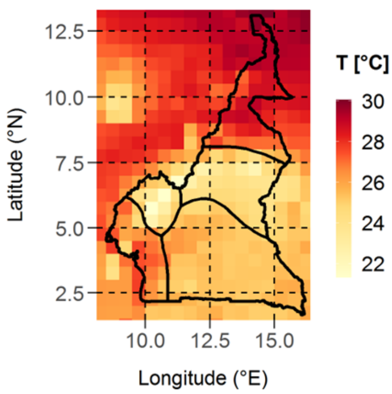

Figure 5: Changes in mean temperature in °C over Cameroon comparing the periods 2000–2019 to 1979–1998.

By 2050, the mean annual temperature is projected to increase by 1.1 °C under the low-emissions scenario and 1.5 °C under the high-emissions scenario, compared to 2004.

Temperature extremes

Temperature extremes can not only have severe health effects for the population, but can also limit crop growth or lead to crop failure, depending on the crop type, cultivars and phenological development stage. In line with recent mean temperature increases, the frequency of temperature extremes has increased as well in Cameroon over the past decades.

North Cameroon currently experiences up to 270 very hot days per year (days in which maximum temperatures exceed 35 °C). No very hot days occur in the south (Figure 7a). In the future, the number of very hot days is projected to increase steadily in the whole country, except in the highlands (Figure 7b). Under the low-emissions scenario, the numbers stabilize in 2050. Under the high-emissions scenario most of the days per year are projected to be very hot days in northern Cameroon and large parts of the south are projected to experience more than 100 very hot days per year by the end of the century.

Hot nights (minimum temperatures exceeding 25 °C) are currently occurring only in the north of the country (Figure 8a) Hot nights are projected to increase in the north of the country until 2050. Until the end of the century under the high-emissions scenario, the south is projected to also experience hot nights (Figure 8b).

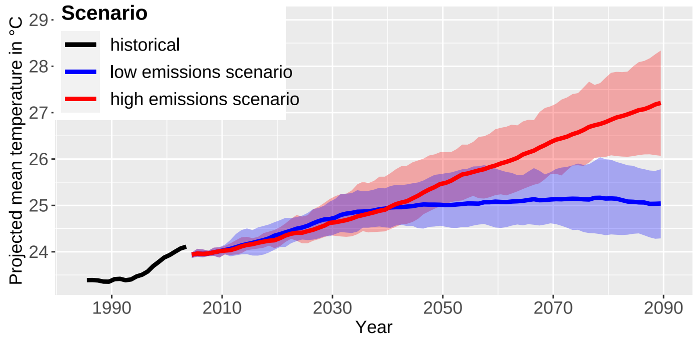

Figure 6: The 10-year moving average of historical and projected mean temperature in °C. The black line displays historical observations, the red and blue lines show projections under the high and low-emissions scenario. Solid lines display the multi-model median.

> The number of very hot days per year (>35°C) is projected to steadily increase in whole Cameroon, except the highlands. Increases are especially strong under the high-emissions scenario.

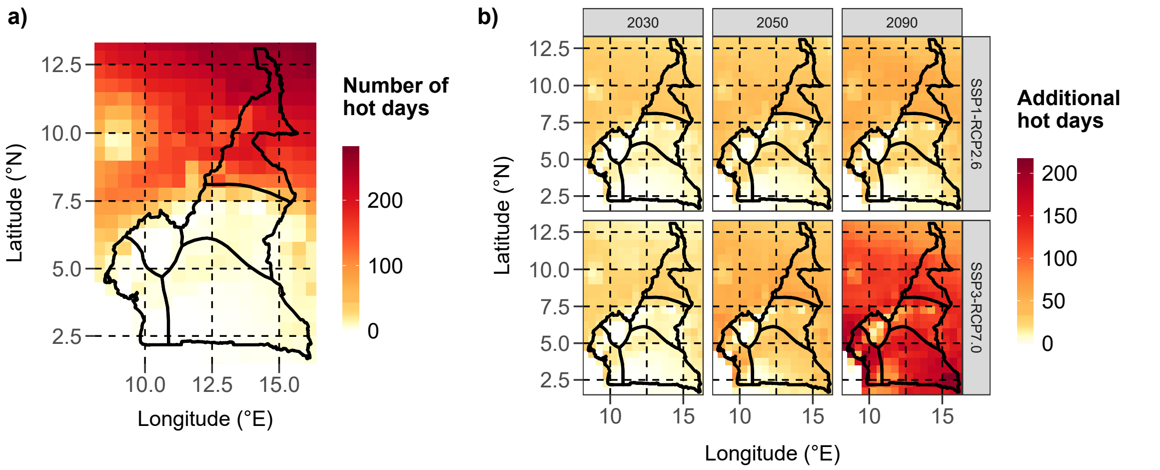

Figure 7: Maps with the a) observed values (1995–2014) and b) projected changes by the multi-model median in the number of hot days per year for the 20-year period averages 2030, 2050 and 2090 under SSP1-RCP2.6 and SSP3-RCP7.0.

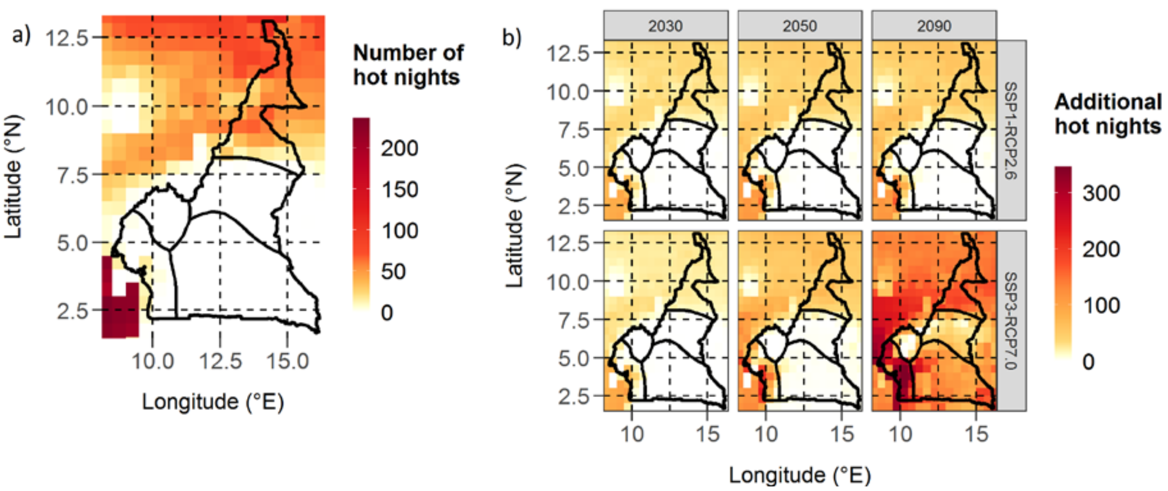

Figure 8: Maps with the a) observed values (1995–2014) and b) projected changes by the multi-model median in the number of hot nights per year for the 20-year period averages 2030, 2050 and 2090 under SSP1-RCP2.6 and SSP3-RCP7.0.

Precipitation

Annual precipitation (rainfall) amounts changed slightly in the last four decades with regional differences. Precipitation decreased in the southern most parts of the country and in parts of the west. Precipitation increased in the most the north while it remained close to stable in the rest of the country (Figure 9).

There is much less confidence in projected precipitation changes than in temperature changes, as not all models agree on a changing trend in precipitation. The multi-model ensemble median, and the majority of models project future increases of annual precipitation sums averaged over Cameroon until mid of this century. Projected changes under the low-emissions scenario are small, while higher GHG emissions are projected to lead to higher changes in precipitation (Figure 10). Even though the majority of climate models point to small precipitation changes or a wetter future climate in Cameroon, it cannot be ruled out that the country or parts of it could experience a drier future climate, as some models and past trends suggest.

> Precipitation projections are much more uncertain than temperature projections. The model median projects an increase in precipitation and heavy precipitation, which is stronger under the high-emissions scenario.

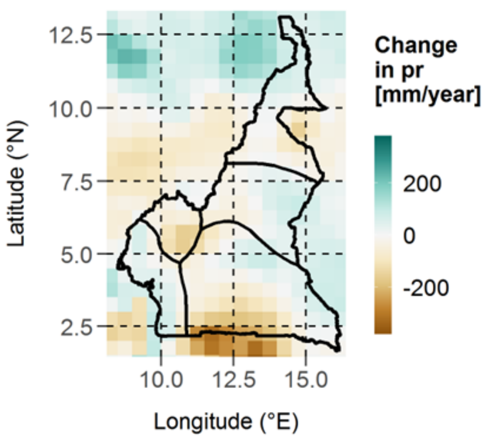

Figure 9: Changes in mean annual precipitation in mm over Cameroon comparing the periods 2000-2019 to 1979-1998.

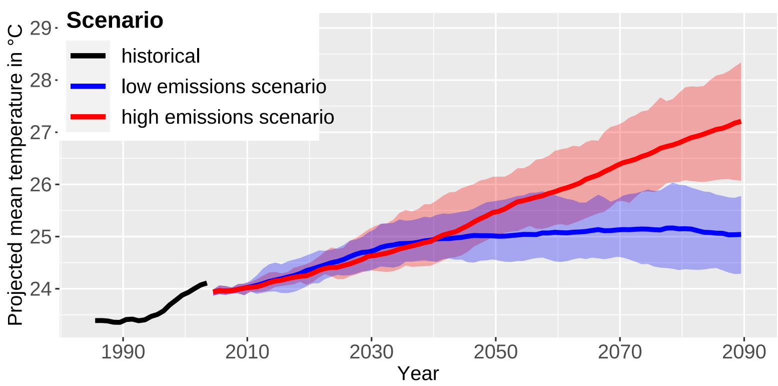

Figure 10: The 10-year moving average of historical and projected annual rainfall in mm per year. The black line displays historical observations, the red and blue lines show projections under the high and low-emissions scenario. Solid lines display the multi-model median and shades display the range given by all ten models. Values are averages over Cameroon.

Heavy precipitation events

Heavy precipitation can not only destroy infrastructure and threaten human life, it can also have a negative impact on crop production by creating crop damage and leaching of nutrients in the soils. To quantify changes in heavy precipitation we analysed the 95th percentile of days with precipitation (> 0.1 mm). According to this indicator, the west of Cameroon, close to the coast, experiences the highest heavy precipitation intensity with the 95th percentile of rainfall well above 30 mm per day (Figure 11a). Past changes in heavy precipitation intensity showed increases, especially in the west of the country (Figure 11b). Despite the past decrease in precipitation in some parts of Cameroon, heavy precipitation intensity has not decreased in these regions.

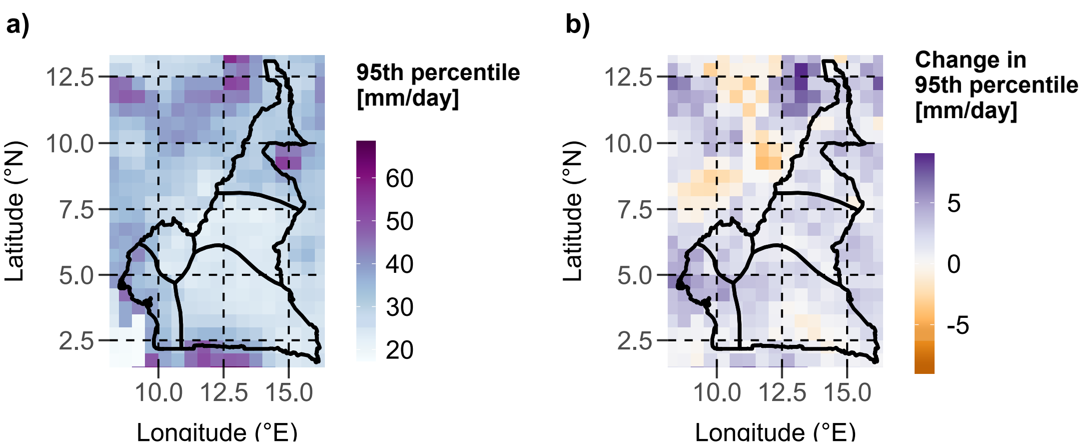

Figure 11: a) 95th percentile of daily rainfall in the period 2000–2019; b) change in the 95th percentile comparing the periods 2000–2019 to 1979–1998.

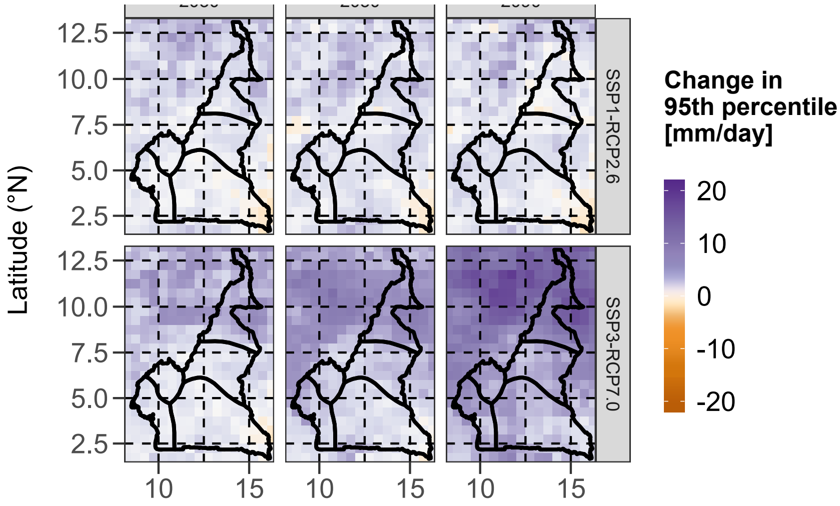

Figure 12: Maps with projected changes by the multi-model median in the 95th percentile of daily rainfall for the 20-year period averages 2030, 2050 and 2090 under SSP1-RCP2.6 and SSP3-RCP7.0.

Heavy precipitation intensity is projected to increase in the future (Figure 12). Under the low-emissions scenario, small changes are projected and not all models agree on the increasing trend. On the contrary, under the high-emissions scenario, the projected increases in heavy precipitation intensity are strong with especially high increases in the north and the projections are subject to high model agreement.

Rainy seasons

Rainy season onset, cessation and length are subject to high spatial and temporal variability. The year-to-year variability is especially high for the onset of the rainy season and a bit lower for the cessation date. The past trend in the onset of the rainy season points at a later onset in the north and at the coast as well as an earlier onset in the central west, compared to the late 20th century (Figure 13). The cessation dates only changed in the southern parts of Cameroon with a later cessation (not shown). Thus, all in all, the rainy season became shorter in the north and at the coast and became longer in the central west and in most parts of the south.

The second rainy season, which is only occurring in the south of the country, shifted with later onset and cessation dates. Projections of rainy season onset, cessation and length are uncertain. Climate models tend to project a large year-to-year variability in rainy season characteristics for the future. A shift of the rainy season in the north towards later dates is possible.

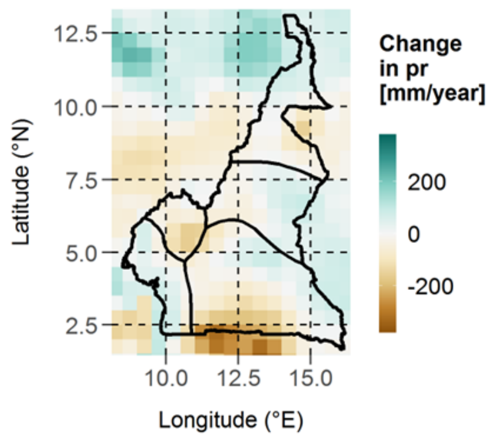

Figure 13: Changes in the onset date of the first rainy season comparing the periods 2000–2019 to 1979–1998. Brown colour indicates a later onset and blue colour an earlier onset in recent years.

1.4 Summary

The results show, that by 2050 mean annual temperature is projected to increase by 1.1 °C under the low emissions scenario and 1.5 °C under the high emissions scenario compared to 2004. Some uncertainty exists for annual precipitation projections, the model ensemble projects an increase in precipitation, which is stronger under the high emissions scenario while also projecting an increase in precipitation intensity.

Climate Impact	Past trend[1]	Future trend[1]	Confidence[2]
Mean annual temperature	Increasing	Increasing	Very high
Number of hot days & nights	Increasing	Increasing	Very high
Mean annual rainfall sums	No significant trend	Increasing	High emissions: Medium
		No significant trend	Low emissions: Medium
Heavy rainfall intensity	Increasing	Increasing	High emissions: Very high
		No significant trend	Low emissions: Very high

Table 1: Summary of climate impacts in in Mbam and Kim.

1) The trend is determined by a Mann Kendall Test with significance level 0.05 for the years 1979–2016 in the past and the years 2015–2070 under the respective emissions scenario in the future. If at least 60% of the models show a trend (on any significance level) in the same direction, we speak of a trend with a specific uncertainty level (see next foot note).

2) The certainty level of future climate projections is determined by the percentage of models agreeing on the trend (with significance level of 0.05) (compare IPCC, 2014). ≥ 90%: very high; ≥ 80%: high; ≥ 50%: medium; ≤ 50%: low.

2. Land cover change

Cameroon is situated on the coast of West Africa and has an estimated total land area of about 475,440 km^2, mainly covered by forests (42 %), agricultural land (20.6 %), and other land uses (37.7 %) (Ekoungoulou et al., 2018) such as grasslands and savannahs and built up areas. Mainly found in the southern zones of the country, these forests constitute the western margins of the Congo Basin Forest. Due to the increasing demand for forest resources and products, a myriad of anthropogenic activities imperils these natural ecosystems and biodiversity.

Forests play a crucial role in storing carbon and are considered vital in mitigating climate change. The preservation of forests as carbon sinks is essential in the fight against climate change. Efforts to reduce deforestation, promote reforestation and afforestation, and ensure sustainable forest management can significantly contribute to carbon sequestration, biodiversity conservation, and the overall well-being of the planet. However, the continued reliance on forest resources by the surrounding rural communities poses a serious challenge to forest survival usually leading to deforestation, in situ biodiversity loss and associated forest degradation. This should not be the case because the forests play a crucial role in mitigating climate change by acting as carbon sinks, meaning they absorb and store large amounts of carbon dioxide (CO_2) from the atmosphere. This process helps to reduce greenhouse gas emissions, which are the primary drivers of global warming. Therefore, preventing deforestation and protecting existing forests are vital for maintaining a stable climate. The reliance on forest by communities is related to subsistence agricultural practices and the harvesting of forest tree resources which provide various ecosystem services and goods (Mukete at al., 2018).

The observable forest disappearance and conversion is often linked to a combination of several factors, including the increasing demand for wood, fuelwood, settlement and the effects of agricultural expansion (Ewane et al., 2015; Mukete et al., 2018). The deforestation process takes different forms and, in most cases, degradation does not manifest itself as a decrease in the area of woody vegetation but instead as a gradual reduction in biomass, changes in species composition and soil degradation (Modica et al.,2015).

According to results from the Sustainability Consortium, the World Resources Institute, and the University of Maryland, in 2010, Cameroon had 30.4Mha of natural forest, extending over 66 % of its land area. However, in 2021, it lost 167kha of natural forest, equivalent to 105Mt of CO_2 emissions. From 2002 to 2021, 797kha of humid primary forest was lost, which makes up 48 % of its total tree cover loss in the same time period. The total area of humid primary forest in Cameroon decreased by 4.2 % in this time period. From 2001 to 2021, 1.4 % of tree cover loss occurred in areas where the dominant driver of loss was deforestation. The top two regions (Centre and East) were responsible for 52 % of all tree cover loss between 2001 and 2021. The Central region had the most tree cover loss at 518kha compared to an average of 170kha. A total of within just one week, between 10th of March 2023 and the 17th of March 2023, 77,970 deforestation alerts were reported in Cameroon, covering a total of 956ha. This indicates clearly how vulnerable the forest in Cameroon is.

Class	Surface 2019 (hectar)	Percentage Land cover 2019	Surface 2022 (hectar)	Percentage Land cover 2022
Hydrology	7577	0.292839066	7677	0.296703908
Primary forest	1882350	72.74985043	1880750	72.68801296
Flooded forest	621	0.024000668	715	0.027633619
Crops	5049	0.195135865	5070	0.195947481
Buildings	5137	0.198536925	5748	0.222151109
Savannah and bare soil	686694	26.53963704	687468	26.56955092

Table 2: Landcover change in Mbam et Kim for the period 2019–2022.

Studies such as those conducted in the threatened forest Koupa-Matapit Gallery Forest in West Cameroon (Momo et al., 2018), Melap Forest Reserve in West Cameroon (Temgoua et al., 2021), Ajei Community Forest in North West Region of Cameroon (Temgoua et al., 2018) and the greater Congo Basin (Laurance et al., 2015) identified deforestation as a major factor driving both forest loss and degradation (Ordway et al., 2017; Aleman et al., 2018). To reduce deforestation, forest mapping and the monitoring of their evolution are very important, in addition to addressing the numerous driving factors behind deforestation. Land cover change monitoring and modelling is very important as it provides vital information which can be used to achieve a better perspective of landscape dynamics as well evaluating the sustainability of natural resources. Ground cover monitoring and mapping have been helpful for spatial planning and environmental examination (Cheng & Wang, 2019; Tripathy & Kumar, 2019). Such land cover and land use analysis will help in the reliable prediction of future circumstances. For example, forest cover can be predicted with historical data sets and remote sensing observations (Hamad et al., 2018) using a change detection methodology to model changes over time through a time series analysis. Assessing land use and land cover changes and trajectories at the global, national, and local levels is, therefore, useful for sustainable development policies, monitoring food security, and climate change and environmental-related research (Wang et al., 2016).

Mapping areas of forest cover change is essential for developing locally adapted strategies to control these dynamics better (de Wasseige et al., 2014). To carry out such monitoring, remote sensing is a less-expensive method that has proven its effectiveness for the assessment of forest cover dynamics and degradation over several decades and at different scales (Loveland et al., 2012; Hansen et al., 2013; Nagendra et al., 2013; Mukete et al., 2018). This study builds on previous research in the area on forest loss in Cameroon between the period of 2000 and 2017 (ONACC, 2021b). However, the previous research looked at the land cover in terms of either forest or non-forest. This study forms the baseline for comparison.

According to the Global Forest Watch, in 2010, the Central region had 5.71Mha of natural forest, extending over 83 % of its land area. In 2021, it lost 51.0kha of natural forest, equivalent to 33.7Mt of CO_2 emission. In 2010, Mbam et Kim had 1.93Mha of tree cover, extending over 74 % of its land area. In 2021, it lost 10.7kha of tree cover, equivalent to 6.65Mt of CO_2 emissions as shown in Table 2.

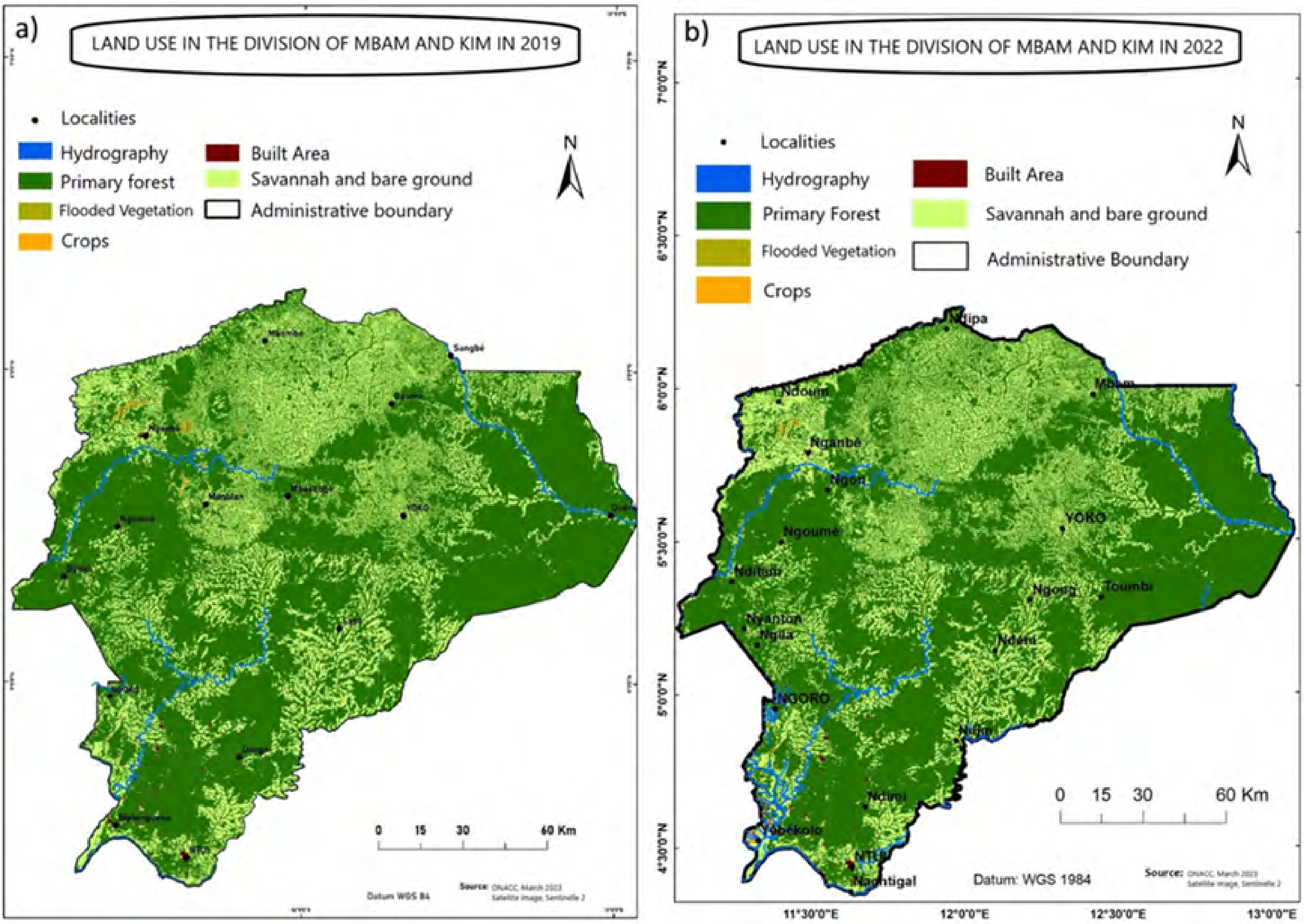

Figure 14: Land use cover change in Mbam et Kim for the years 2019–2022.

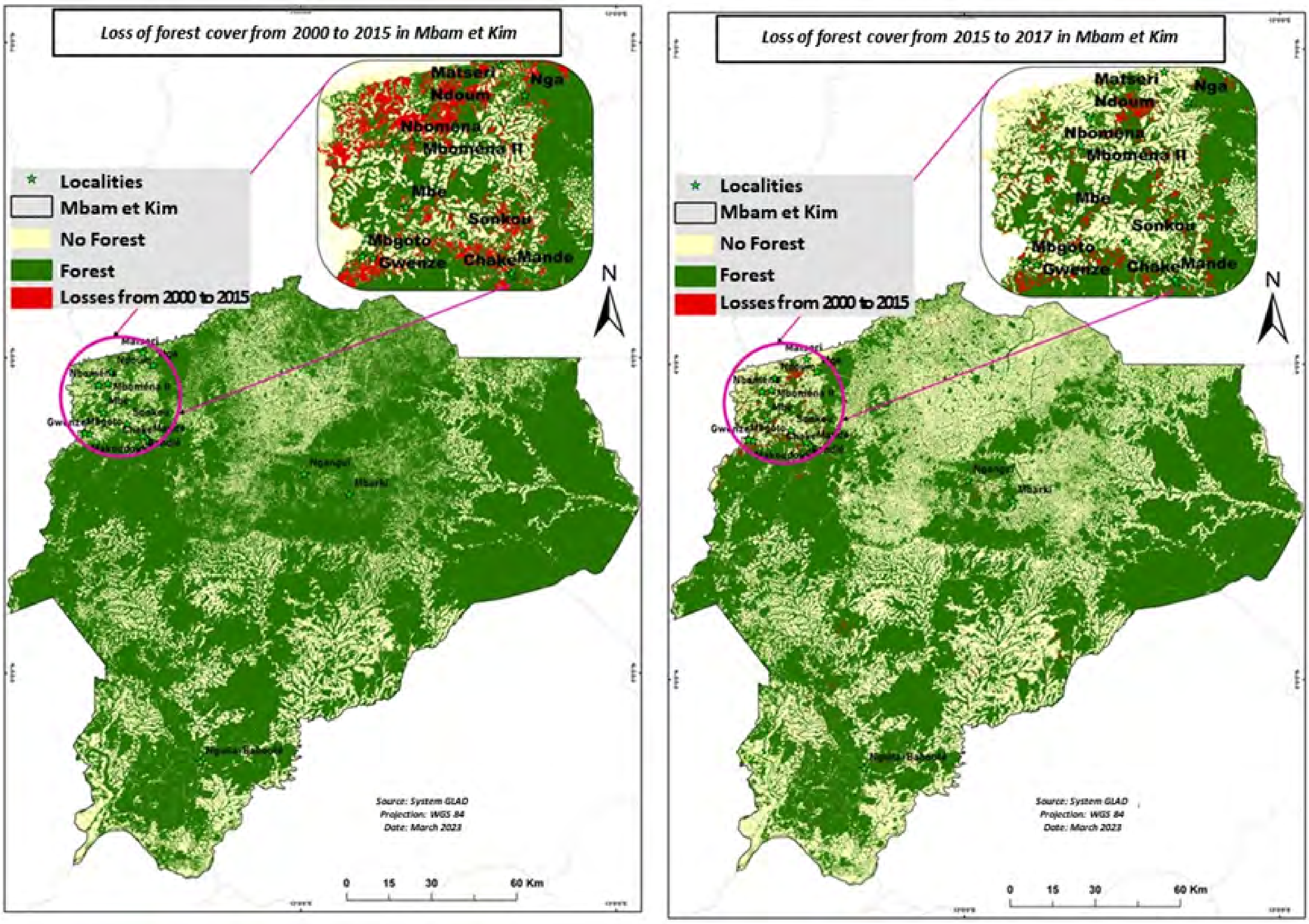

Figure 15: Change of forest cover in Mbam et Kim for the years 2000–2017 (ONACC, 2021b).

Landcover Change	Trend past	Confidence
Hydrography	Increase	Medium
Primary forest	Decrease	Medium to high
Flooded forest	Increase	Medium to high
Cropland	Increase	Medium to high
Built-up area	Increase	Medium to high
Savannah and bare ground	Increase	Medium to high

Table 3: Summary of climate impacts in Mbam-and-Kim.

Figure 14 and 15 show the sentinel images, where bands 5, 4, and 3 are represented by the red, green, and blue colors, respectively. Visual interpretation of all the resulting sentinel images was performed to identify the main deforestation within the study area. Also, expert judgment using field information, helped in interpreting the image classes. Table 2 presents the six classified LULC classes/groups in the study area along with the corresponding total surface area (in km²) and the percentage of each LULC class. The greatest change can be found in the primary forest with a decline in forest cover underlining the importance of the integration of land cover change assessments into further assessment with regard to resilient land use planning.

2.1 Summary

The analysis showed that deforestation is continuing, especially in the Central region of Cameroon. This has many negative consequences for the ecosystem and the capability of forests as carbon reservoirs. Efforts to **reduce deforestation, promote reforestation and afforestation, and ensure sustainable forest management** can significantly **contribute to carbon sequestration, biodiversity conservation, and the overall well-being of the planet**.

Assessing these land cover changes at the local, but also on national or global level is, therefore, important for resilient adaptation and mitigation purposes

3. Climate impacts on grassland productivity

In addition to crop production, many smallholder farmers have livestock, either to complement farming activities or with pastoralism as their main livelihood. Pastoralists can be further differentiated depending on their mobility: (1) **nomadic pastoralists**, who do not have a permanent home and move around with their livestock in search of pastures and water resources; (2) **transhuman pastoralists**, who have a home but move with their livestock in the dry season, returning in time for the rainy season; and (3) **sedentary pastoralists** who have a permanent home and graze their livestock close to their home (Azuhnwi et al., 2017). Livestock refers broadly to a range of terrestrial animals kept for transport, meat, milk, eggs, skins, fibres and feathers, among other uses, including for example cattle, goats, sheep, pigs, ducks and chicken (FAO, n.d.).

In 2020, Cameroonian pastoralists held a total of 6.1 million cattle, 5.5 million goats, 3.6 million sheep and 2 million pigs (FAOSTAT, 2020). In terms of the geographical distribution of livelihood systems, the north of Cameroon is dominated by pastoral livelihoods, while the south is dominated by farming livelihoods, due to progressively higher amounts of rainfall in southern Cameroon (Lange, 2019). In particular the mountainous North West region, the Adamawa plateau and the northern regions of Cameroon are the main livestock producing areas (Kelly et al., 2016). However, in many parts of the country, smallholders combine farming and pastoral activities, partly as a mixed farming strategy to build resilience to climate impacts and other shocks (Azibo et al., 2016)with about 85 % of the indigenous populations relying on it for their survival. Both long and short term climatic oscillations have succeeded, and will continue to disrupt crop and livestock output thus signaling threats to food security. Although the communities have either consciously or unconsciously made use of some indigenous adaptation strategies, they are judged to be weak at the moment. This requires the designation of contextspecific agro-pastoral adaptation frameworks. Using focus group discussions (FGDs. While the number of livestock heads has continued to grow in recent decades, the per capita number of livestock heads has been decreasing. For example, the per capita number of cattle decreased from 0.3 in 1990 to 0.14 in 2020 (FAOSTAT, 2020). Similar trends can be observed for other types of livestock, where the number of livestock heads has not developed in line with the human population. Possible reasons include climate impacts, rapid population growth and degradation of natural resources like that of pastures and water bodies through excessive agricultural production, deforestation and other human activities.

In particular, climate change has negatively affected pastoral livelihoods in Cameroon through impacts on essential agro-pastoral resources like pastures, land and water (Kongnso et al., 2021)water. Dry spells have led to the reduction of pastures and water bodies, with some areas being gradually transformed into bare and unproductive land. These losses are particularly dramatic given the fact that some livestock grazing destinations and transhumance corridors have been used by pastoralists for decades, who would typically move south during the dry season (Motta et al., 2018). Hence, a reduction of pastures and water bodies has severe impacts including changing and longer transhumance routes as well as growing pressure and competition over scarce resources, which in turn has led to conflicts, in particular between pastoralists and farmers (Mbih et al., 2022). In addition, rising temperatures have favoured the emergence of pests like that of the tse tse fly, which can cause *trypanosomiasis* and result in death of livestock. More than 90 % of cattle in Cameroon are considered exposed to trypanosomiasis infection, and eradication efforts have been focused on the

Adamawa plateau and the northern regions (Sevidzem et al. 2022). Rising temperatures have also favoured the emergence of extreme weather events like sudden and intense rainfall, accompanied by thunder and lightning, which have equally killed livestock in the recent past (Kongnso et al., 2021)water. Finally, rainfall variability has made it difficult for pastoralists and farmers to determine agro-pastoral seasons and to coordinate grazing and farming activities. For example, when the onset of the rainy season is late, pastoralists might not be ready to leave, but farmers already want to prepare their land for the planting of crops (Mbih et al., 2018).

In addition to climate change, the degradation of natural resources, including soil erosion, is also driven by socio-economic factors like overgrazing, bush encroachment and poor management of pastures. A study of the Northwest region confirms this trend: Here, pastoralists reported declining levels of livestock populations and production constraints, such as insufficient and poor pastures, livestock diseases, conflicts between farmers and pastoralists, and insufficient drinking points for livestock (Awalu et al., 2019). Although conflicts largely occur between farmers and pastoralists, other constellations are also common, including between fishing people and pastoralists, or between different pastoral groups both from within Cameroon and neighbouring countries like Nigeria or Chad (Ehiane & Moyo, 2022; Mbih, 2020).

Although these factors primarily impact livestock production, they have further consequences for livestock-dependent communities, including poverty, food insecurity, loss of cultural heritage, rural exodus to urban centres like Douala and Yaoundé, social conflicts and higher crime rates (Awalu & Nformi, 2022) pastoralists are known to have extensive ecological knowledge which could complement scientific knowledge and contribute to improved understanding and sustainable management of savanna Ecosystems. This study was aimed at exploring pastoralists' perceptions regarding rangeland degradation in the Adamawa highland plateau. More specifically, it was geared to examine their awareness of rangeland degradation, the current status/condition of the rangelands, the drivers and major root causes of degradation, negative consequences, existing management practices, and a methodological framework to make these measures more resilient.

The study applied a descriptive statistics method. Focus group discussions, field observations and structured/semi-structured survey questionnaires, were used for data collection, where 240 pastoralists were targeted. The study covered 4 sub-divisions within Faro & Deo District of the plateau based on the intensity of degradation (high, medium and less. Many rural households keep livestock not only for its direct benefits, but also as a form of insurance for times of crisis or as savings, for example, for education (Forbang et al., 2020). Hence, reduced livestock herds make rural households more vulnerable to different types of shocks. Climate-related and socio-economic impacts on livestock have different impacts on different social groups. For example, in many rural households in Cameroon, women are responsible for the food and nutrition security of their families, with livestock providing important proteins for a balanced diet. A balanced diet, however, is threatened where livestock heads are decreasing (Forbang et al., 2020).

Overall, pastoralists will have to consider a variety of adaptation strategies including mixed farming, adjusting grazing periods, crop and livestock rotation, planting of improved pastures, raising improved and livestock varieties as well as more unfavourable strategies, like destocking of livestock herds or greater mobility (Awalu et al., 2019; Azibo et al., 2016)compared to researchers and Government officials. This study was aimed at breaching this gap, by empirically exploring pastoralists' perceptions regarding rangeland degradation in Donga-mantung. The pastoralists' perceptions were studied through a descriptive statistics method. Focus group discussions, field observations and structured/semistructured survey questionnaires, were used for data collection, where 200 pastoralists were targeted. The study covered seven Ardorates based on intensity of rangeland degradation (high, medium and less. However, to be able to make these adaptation decisions and to ensure a viable livestock production today and in the future, knowledge about changing climatic conditions and related impacts on grassland productivity is key.

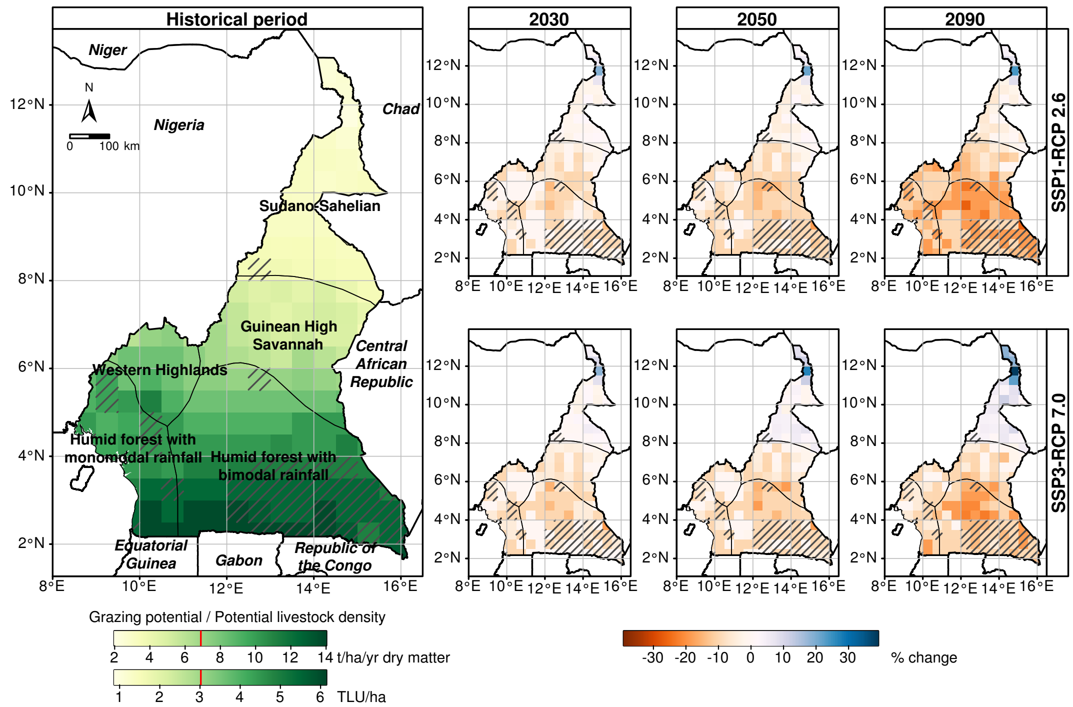

Figure 16: Left panel: Multi-model ensemble median of simulated annual grazing potential for the historical period in Cameroon. The area-weighted average grazing potential across Cameroon is marked by a red line in the colour scale. Grazing potential in t/ha/yr is converted into a potential livestock density assuming a daily fodder demand of 6.25 kg per tropical livestock unit (TLU). Right panels: Multi-model ensemble median of change in annual grazing potential compared to the historical period for three time periods (columns) and two emissions scenarios (rows).

3.1 Grazing potential under climate change

In this chapter, **grazing potential** refers to the maximum amount of grass biomass available to livestock from dedicated grazing land. In regions where forests, grazing land, cropland and other classes of land cover co-occur, the grazing potential refers only to grazing land.

> The analysis is relevant for major grazing animals including cattle, sheep and goat. Daily forage requirements vary by animal type. To make them comparable, animal types can be converted to a generic Tropical Livestock Unit (TLU) based on their live weight using example conversion factors (see annex).

The left map in Figure 16 shows the multi-model ensemble median of annual grazing potential for the historical period 1995–2014. Diagonal hatching marks regions where less than 1 % of the area is covered by grazing land according to the HYDE land-use dataset (Klein Goldewijk et al. 2017). Grazing potentials are highest in southern Cameroon, approaching close to 14 tons dry matter per hectare per year along the border with Equatorial Guinea and Gabon. It should be noted that many of the most productive regions are densely forested with limited presence of grazing lands. Grazing potentials decrease towards the north following the decreasing precipitation gradient across Cameroon. The average grazing potential is 7.8 t/ha in the High Plateau (Western Highlands) Zone and 5.9 t/ha in the (Guinean) High Savannah Zone. Grazing potentials are lowest in the Sudano-Sahelian Zone with an average of 3.1 t/ha, but going as low as 2.1 t/ha in parts of the Far North. The area-weighted average grazing potential across all of Cameroon is 6.8 t/ha (denoted by a small red line in the colour scale in Figure 16), with a range across the 10 Global Climate Models (GCM of 6.4–7.2 t/ha).

At country scale, grazing potentials are projected to decrease in Cameroon over the course of the 21st century (Figure 17). These changes are smallest in the 2030 period and intensify towards the end of the century. Losses in grazing potential are more pronounced under the low-emissions scenario SSP1-RCP2.6, where they increase from a multi-model median of 3 % in 2030 to 7 % in 2050 and 11 % in 2090. In contrast, losses in grazing potential under the high-emissions scenario SSP3-RCP7.0 increase from about 4 % in 2030 to 6 % in 2050 and 9 % in 2090. While there is some climate model spread regarding the magnitude of losses in grazing potential, GCMs mostly agree on the direction of change and the general trend of larger losses under the low-emissions scenario SSP1-RCP2.6 later in the 21st century. In the 2030 time period, 4 out of 10 GCMs project a slightly larger loss in grazing potential in the SSP3-RCP7.0 scenario than in the SSP1-RCP2.6 scenario, while one GCM even projects a slight increase. The effect of higher warming under SSP3-RCP7.0 may be partially offset by an increase in precipitation, combined with a better water-use efficiency of

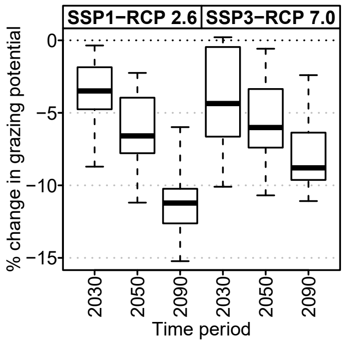

Figure 17: Change in country-scale annual grazing potential for the two emissions scenarios and three time periods. Boxplots show the range over 10 GCMs.

plants due to the higher atmospheric CO_2 concentration, whereas lower warming is projected to coincide with lower precipitation during the second half of the 21st century in SSP1-RCP2.6 (see Chapter 1). Atmospheric nitrogen deposition is also higher in the high-emissions scenario SSP3-RCP7.0 than in the low-emissions scenario SSP1-RCP2.6, alleviating some of the soil nitrogen depletion that results from continuous grazing. Still, both scenarios show decreasing soil nitrogen and soil carbon stocks over the course of the 21st century as a result of the grazing pressure, which partially explain the decreasing grazing potentials simulated under both scenarios.

The picture becomes more varied when going from the national to the regional scale (right side maps in Figure 16 and boxplots for all AEZs in Figure 18). While the overall trend for Cameroon is negative, grazing potentials in the Sudano-Sahelian Zone are projected to increase under the SSP3-RCP7.0 scenario. The increase is consistent across all future time periods and all GCMs, reaching on average 9 % above historical levels in 2090 (Figure 18). Grazing potentials in the Sudano-Sahelian Zone are also projected to increase between less than 1 and 3 % under 7 out of 10 GCMs in the SSP1-RCP2.6 scenario, with the other 3 GCMs projecting a decrease of 1–2 %, but only until the 2050 time period. By the 2090 time period, 6 out of 10 GCMs project a decrease of grazing potentials in the Sudano-Sahelian Zone under SSP1-RCP2.6. Grazing potentials are projected to decrease on average by 4 % until 2030 under both emissions scenarios in the (Guinean) High Savannah Zone. Grazing potentials decrease further to −7 % in 2050 and −10 % in 2090 under the SSP1-RCP2-6 scenario, and to −6 % in 2050 and −8 % in 2090 under SSP3-RCP7-0. The two Rainforest AEZs have the highest grazing potentials during the historical period and are also the zones with the highest projected losses in grazing potential towards the end of the 21st century, with 12 and 9 % loss under SSP1-RCP2.6 and SSP3-RCP7.0, respectively, in the Monomodal Rain(forest) Zone, and 15 % loss under both emissions scenarios in the Bimodal (Rain)forest Zone. The higher losses in the latter AEZ are partially caused by a higher risk of fire occurrence in that zone.

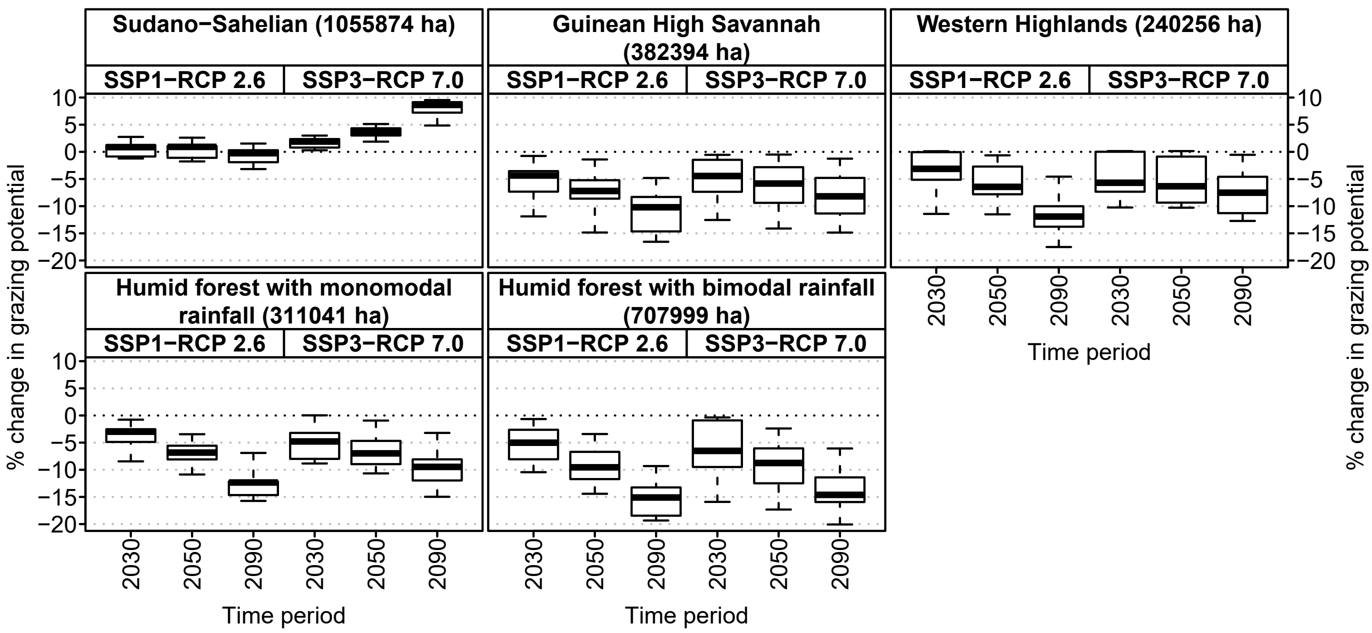

Figure 18: Regional change in annual grazing potential in each of the five AEZs of Cameroon for the two emissions scenarios and three time periods. Boxplots show the range over 10 GCMs. Numbers in brackets after the AEZ name show grazing areas in each AEZ according to the HYDE land-use dataset.

Sensitivity to starting conditions

The simulated grazing potentials depend on a number of assumptions. For example, results presented so far in the text and in Figures 16–18 assume that grazing lands are established on land with no prior land use history. As mentioned previously in this chapter, continued land use can lead to soil degradation. However, data on actual land use history (e.g. stocking rates, resting periods, grazing land provenance) are generally not available. To test the sensitivity of the modelling results to the land use history, we repeated the simulations with the same climate projections but initialized grazing lands on degraded soils with a prior history of cropland use. As shown in Figure 19, the land use history can have a major impact on the grazing potential under historical climate conditions. The average historical grazing potential across Cameroon decreases from 6.8 t/ha under “pristine” conditions to about 5.1 t/ha. Losses are most pronounced in the two Rainforest AEZs (−34 and −32 %) where climatic conditions would support high grazing potentials. Losses are far less pronounced in the Sudano-Sahelian Zone (−5 %) where climatic conditions are less favourable. Historical grazing potentials decrease by 20 % on degraded soils in the (Guinean) High Savannah Zone and High Plateau (Western Highlands) Zone. The land use history also has a significant effect on the future trends of grazing potentials under climate change. Positive trends in the Sudano-Sahelian Zone under the SSP3-RCP7.0 emissions scenario are more pronounced when grazing lands were started from degraded soils. While all other AEZs still show projected future losses in grazing potentials under climate change, these losses are less pronounced when grazing lands were started from degraded soils. For example, grazing potentials in the (Guinean) High Savannah Zone are projected to decrease by 6 and 3 % in the 2090 time period under SSP1-RCP2.6 and SSP3-RCP7.0, respectively, when grazing lands were started from degraded soils, compared to losses of 10 % and 8 % when grazing lands were started on pristine soils without a prior land use history. Despite the higher relative yield gains in the Sudano-Sahelian Zone and the lower yield losses in the rest of the country, the absolute grazing potentials in this sensitivity experiment are lower than the absolute grazing potentials in the simulations with pristine starting conditions during all time periods under both emissions scenarios.

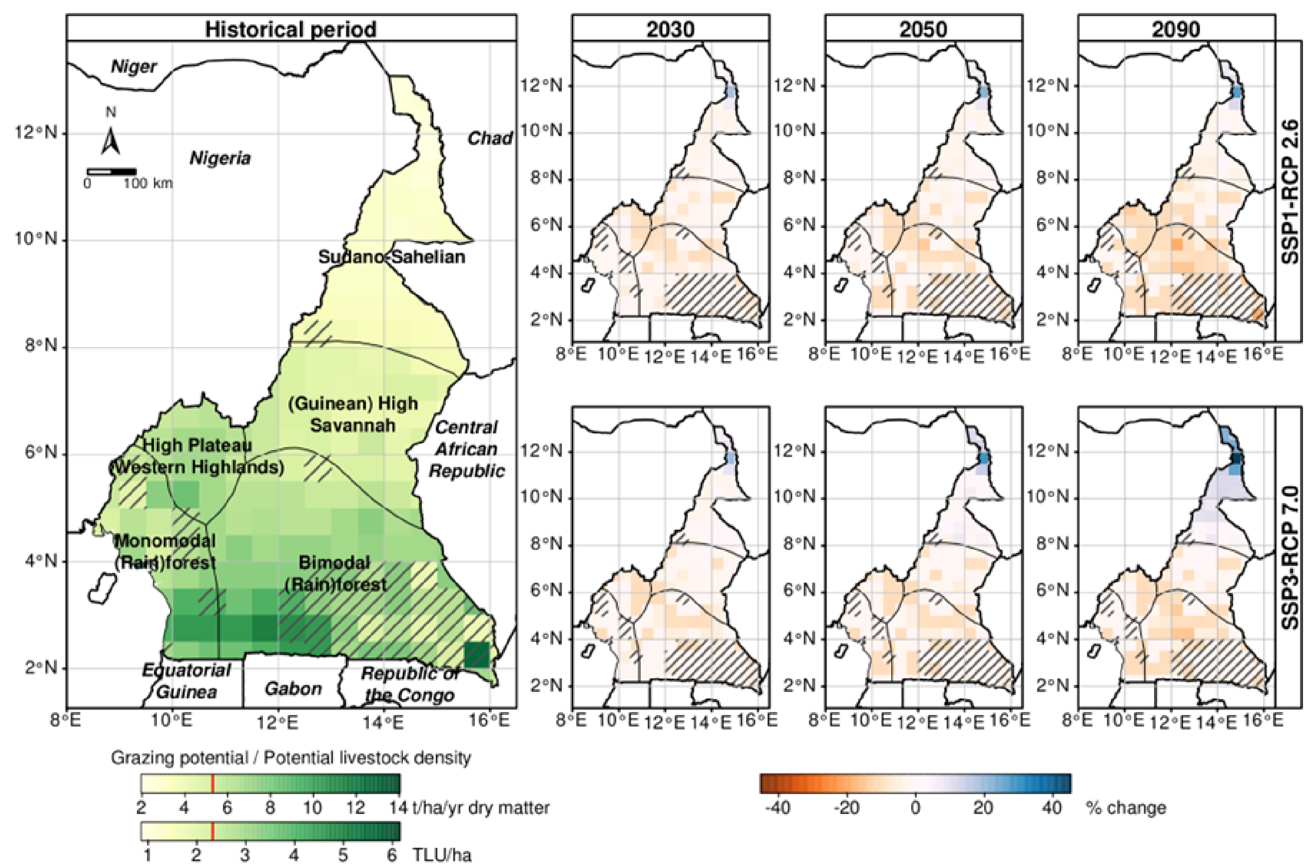

Figure 19: Sensitivity of grazing potentials to land use history. Compared to Figure 18, grazing lands in this figure are established on degraded cropland soils.

3.2 Summary

Grazing potentials are projected to decrease under both emissions scenarios in all regions except the Sudano-Sahelian Zone. Under SSP1-RCP2.6, increases in grazing potentials are limited to parts of the Far North region. The losses in grazing potentials projected for most parts of the country are a result of both changes in climate and progressive soil degradation due to continuous grazing pressure. Soil degradation may be alleviated by management of grazing lands such as stocking densities well below the maximum grazing potential, resting periods that allow pasture soils to recover or fire suppression in areas where grazing lands burn frequently.

Impacts on grassland productivity		Trend past	Trend future
	Grassland productivity	Decrease	Decreasing
	Grazing potential without no prior land use	Decrease 7.1t/ha to 4.22t/ha	SSP1-RCP2.6: Decreasing by 3 to 8 % SSP3-RCP7.0: Decreasing by 2 to 5 %
	Grazing potential with prior land use history	Decrease 7.1t/ha to 6t/ha	SSP1-RCP2.6: Decreasing but less than without wildfires

Table 4: Summary of impact of climate change on grassland productivity.

4. Climate change and gender

The impacts of climate change are not gender-neutral. Women and men experience climate change differently and their capacity to cope and adapt varies. The vulnerability and the opportunities for adaptation are deeply linked with gender and other social factors, such as age, ethnicity, marital status or disability (Ahmed et al., 2016). Women play a key role as agricultural producers, managers of natural resources and in securing food for their families, and they are more vulnerable to climate impacts and have limited opportunities for adaptation. This is a result of deeply anchored patriarchal structures and gendered roles and responsibilities in households, agricultural production and communities as well as of limited access to resources and decision-making power (Alston, 2013; Carr and Thompson, 2014). If combined, different social factors can increase the burden on women and other social groups in a process of "cumulative disadvantages" (González de la Rocha, 2007) and serve to reinforce existing inequalities. Due to this intersectionality, a widowed female farmer from an ethnic minority, for example, will face a very different reality than a married female farmer from an ethnic majority, although they may be living in the same rural community. In addition, the widowed female farmer may be of advanced age and have a disability and, therefore, find it even harder to adapt to climate impacts. Hence, gender constitutes only one layer, among other overlapping social factors. And climate change is likely to amplify and exacerbate existing patterns of (gender) disadvantages (Alston, 2013).

This chapter recognises this fact by providing an overview of different challenges experienced by different types of farmers in adapting to climate impacts. The analysis is based on a review of relevant literature as well as on focus group discussions, which were conducted with 40 women in the villages of Maroua and Papa in the Far North Region of Cameroon in May 2022. While this chapter serves as an introduction, gender and intersectionality are considered more specifically in the evaluation of each adaptation strategy in Chapters 5–7.

4.1 Gender in national policies and plans

Gender equality plays an increasingly important role in Cameroon's national development policy and plans. For example, in 2009, Cameroon launched its medium-term development strategy „Vision du Cameroun 2035". Among other objectives, the document formulates how Cameroon plans to promote gender equality until the year 2035. The economic empowerment of women through income and employment is named as one priority.

Also, in other national plans like the "Stratégie Nationale de Développement 2020–2030" (SND30), the government aims to further promote equal access to education, training and information for men and women, to promote entrepreneurship among women and youth, and to open up access to credit and investment support for these groups (Republic of Cameroon 2020). The new 2022–2026 UN Sustainable Development Cooperation Framework for Cameroon also shows a focus on gender mainstreaming. UN Women aims to increase gender equality in Cameroon's education system and labour market and decrease gender-based inequalities and violence (UN, 2021).

The country's national adaptation plan (NAP) incorporates gender as an important theme in several areas. It tries to support Cameroonian women in leadership positions in regional and international organizations. Furthermore, it positions Cameroonian women as a group that is particularly vulnerable to climate change, and at the same time as beneficiaries of adaptation action where the government plans on increasing the resilience of productive (agricultural) practices and strengthening the capacity of specific actors (especially young women and elderly, indigenous people, small-scale farmers, etc.) concerning new crops as part of intensified and sustainable production methods. The NAP therewith identifies gender equality as a cross-cutting issue (MINEPDED, 2015).

The main institution for gender-related public policies in Cameroon is the Ministry of Women's Empowerment and the Family (MINPROFF), founded in 2004. The ministry is tasked with the implementation of the National Gender Policy (PNG) promoting equality between women and men. However, despite increases in the budget, the ministry faces several challenges to fulfil its mission. Furthermore, other ministries have a gender focal point whose work is to be guided by the MINPROFF and some ministries have also received additional budget determined especially for gender activities (GIZ, 2021).

4.2 Factors of gender-specific vulnerability to climate change and adaptive capacity

> There are several factors why women and men are impacted by climate change differently and why their ability to adapt to those changes varies.

For example, **traditional gender roles** in households, communities and agricultural production increase women's vulnerability to climate change. Women often take on a triple role in productive, reproductive and community-managing activities and, therefore, have little capacity to do paid work, which ultimately means that they are less financially independent and more vulnerable to poverty. 50 % of Cameroonian women live below the poverty line, most of them in rural areas (GIZ, 2019). This is limiting women's access to and control over income and assets. Men, on the other hand, tend to be the decision makers, for example, in financial spending and agricultural management both on the household and community level.

While employment in the agricultural sector is generally high in Cameroon, the **gendered division of labour** in the sector also has an impact on how climate change is affecting men and women differently. Men are traditionally more involved in the production, processing as well as marketing of cash crops, such as cocoa (MINEPAT, 2020). Those crops are mainly grown on medium-sized family plots, that are often owned by men, or larger industrial plots and produced for sale (GIZ, 2019). In terms of livestock, men are generally in charge of cattle farming. Women, on the other hand, cultivate mainly food crops, such as maize and cassava, that are often grown on small family plots, with the work being often unpaid (GIZ, 2019). This gendered division of crop production has also been confirmed by the focus group discussions.

As will be described in chapter 5, maize is among the most climate-sensitive crops in Cameroon and likely to see lower future yields across large parts of the country. As maize is cultivated and processed mainly by women, these results mean that Cameroonian women in particular will have to adapt their agricultural practices. In terms of livestock, female farmers are in charge of the breeding and care of small animals such as chicken, sheep and goats, and in addition to playing a key role in subsistence agriculture, they also perform domestic tasks, such as housework and childcare. This double role "contributes to increases in workload, time constraints and in some cases poor health" (Azong et al., 2018). Certain tasks concerning the procurement of resources like collecting firewood and fetching water are also mostly assigned to women and girls. Due to the changing climate and resulting water scarcity, women and girls often have to travel longer distances to find water or wood (participant from focus group, 2022). Rising temperatures and extreme weather events can make trips to faraway water bodies or forests more exhausting and even life-threatening. Because of their different roles in agriculture and the household, women and men are exposed to different climate shocks, they experience impacts differently, and they have different capacities to adapt and recover from climate impacts (Huyer and Partey, 2020).
As women are mostly involved in the planting stage of crop production, they are more directly affected by crop yield losses (Azong et al., 2018).

> Limited access to finance and customary law and land rights, cultural norms and gendered division of labor are factors that have an impact on women's ability to adapt to climate change.

Furthermore, Cameroonian women have **limited access to finance and customary law**, with limiting factors such as the lack of collateral through land ownership, low levels of education and information about financial products, lack of access to bank accounts in rural areas and socio-cultural reasons (e.g. financial products not being adapted to women's needs). Female farmers have therefore limited financial resources available, such as access to credits, subsidies, grants, or even bank accounts (Eloundou Etoundi, 2015). For example, only 10.9 % of women in Cameroon have accounts at formal financial institutions, compared to 18 % of men (GIZ, 2021). On the one hand, this constraint complicates savings and long-term financial planning for times of crisis. Furthermore, having limited access to micro-credit opportunities prevents women from buying much needed agricultural inputs like drought-adapted seeds. Financial limitations have been confirmed by the women in the focus groups who also emphasized the need for better organization among farmers and better agricultural advisory services (focus group 2022).

Another factor that limits women's ability to adapt to a changing climate are **land rights**. Formally, women's rights in Cameroon are protected by international, national and sub-regional legislation. However, while the constitution guarantees every person the same access to land (Republic of Cameroon, 1966), customary law systems restrict women's actual opportunities to own dispose of land. Under customary law, land ownership is exclusively reserved to men, making it extremely difficult for women to buy, own or inherit land. In most regions of Cameroon, women are only allowed to use land through secondary rights, for example, via their husbands, or via resource rights, which are given to them for the collection of firewood, water or food (Fonjong et al., 2010). Even under civil law, the husband is allocated the authority to manage and decide over marital property without requiring consent of his spouse. He is also legally authorised to decide if and where his wife is allowed to "work and where to live by the interest of marriage and children" (Cameroon´s Civil Status Registration, 1981). Widows are also not legally protected against dispossession of their husband's land.

As land rights in Cameroon are marked by a prevailing patriarchal system, female farmers have little decision-making power over land-related farming decisions (GIZ, 2019). Although women make up a large proportion of the agricultural workforce, only 2 % of land titles are owned by women (Union Européene, 2019) and among new land title registrations, between 2005 and 2013, only 18 % of titles were registered in the name of women (78 % men, 3 % collectives) (INS, 2017). Due to insecure tenure and social customs, few women own land and are dependent on their husbands or fathers. As a result, women tend to rent land, while men tend to own and inherit it. These circumstances discourage women from making longer-term investments and implementing climate adaptation strategies.

Women's adaptive capacity is furthermore limited due to different **cultural norms**. For example, during floods, long traditional clothing can complicate a quick escape and, when soaked with water, it can lead to drowning more easily. Responsibilities for care work of young children, sick or elderly people may also limit women's ability to act quickly and seek protection from hazards (Neumayer and Plümper, 2007). Due to cultural norms, many girls do not learn to swim and are expected to not engage in physical activities like running or climbing. Low levels of education, along with widespread illiteracy, limited access to information and lack of radios and mobile phones further limit women's knowledge about climate threats and jeopardize their safety during extreme weather events (Sikod, 2007). Among Cameroonian women, 31 % are illiterate, compared to 19 % of men (GIZ, 2021). Even though this gap is slowly closing within younger generations, it is still a problem in some regions and within older generations. A participant from the focus group discussions stated, "We are not informed about how to deal with climate change." Access to information can be further limited for women through certain interpretations of Islam which prohibits women's role in the public sphere and thus their access to education and productive work (GIZ, 2019).

Not only do women experience the impacts of climate change differently, female farmers in Cameroon also face several **institutional and structural barriers that** often hinder them to adapt their farming practices to changing climatic conditions. These barriers include the gendered division of labour (GDOL), constraints on the use of resources, little or no use of agricultural inputs like drought-adapted seeds or fertilizers, limited access to climate services, and limited access to decision-making processes at all levels which stems from cultural, traditional and religious norms and can entangle them in a low productivity trap (Huyer and Partey, 2020). In addition, it is more difficult for women to adapt agricultural production to new climatic conditions because local agricultural organizations, that would provide access to relevant tools, fertilizers or information, often restrict the participation of women (Huyer and Partey, 2020).

Climate change is also likely to increase migration from rural to urban areas, and in many cases, it is men who migrate and women who are left behind in rural areas. This increases the workload of rural women, who perform both paid and unpaid work and are more directly affected by natural disasters, environmental degradation, and deforestation (Jahan, 2008). In some households where men work in urban areas, their absence may not give women the authority or decision-making power to make timely agricultural decisions or to convince their husbands to agree to new practices even though they often are the de-facto managers of the household (World Bank et al., 2015).

It is, therefore, important to ensure an understanding of gender differences in relation to needs and capacities in policies and actions to promote the resilience in the agricultural sector in the face of climate change and its impacts in order to ensure successful implementation of adaptation measures (Ampaire, 2017). Due to the demonstrated limitations and structural barriers, female farmers are less likely to adopt adaption strategies and therefore have a diminished adaptive capacity (Huyer and Partey, 2020).

4.3 Summary

In conclusion, the adverse effects of climate change have made the already difficult lives and livelihoods of female smallholder farmers more difficult and complex (Republic of Cameroon, 2020). The different aspects in this chapter need to be unequivocally recognised as intersectional factors which constrain the adaptive capacity of women and other social groups in facing climate impacts and need to be carefully and systematically considered in the development of NAPs, NDCs and other relevant policies and plans. Despite their specific vulnerability and limited adaptive capacity, women have the potential to act as agents of change and transformation. Moreover, men must be seen as part of the solution and taken on board to achieve gender equity. Provided that women and other social groups are moved to the centre of these processes – both as a target group and leaders of action – agricultural systems can be transformed towards greater gender equity, inclusion and climate resilience.

5. Assessment of climate impacts and adaptation option for maize

Maize *(Zea Mays)* is the most widely grown crop in Cameroon. It is grown both for direct household consumption, as well as for storage as dry flour, which can be used or sold and thus serve as a form of social protection in times of crisis (Epule & Bryant, 2014). It is the predominant crop in the North, North West, Adamawa and West regions (Tchuenga Seutcheng & Saha, 2017) and the most consumed cereal nationwide (Manu et al. 2014). Maize is also used as the predominant source of cattle and poultry feed, making it a highly coveted input for Cameroon's livestock sector (Manu et al. 2014). Major constraints to maize production include limited availability of improved seeds, low soil fertility and post-harvest losses (Mafouasson et al. 2020), resulting in low average yields of 1.8 t/ha in the North and 3.3 t/ha in the North West (Manu et al. 2014; Takam-Fongang et al. 2018). Maize requires high amounts of water during the growing season, making it highly vulnerable to droughts which occur regularly in Cameroon's North and Far-North regions (Epule, 2021). Adoption of improved maize varieties is low, with more than half of farmers relying on traditional open-pollinated land races saved every year, making seed supply vulnerable to climate shocks such as recurring droughts (Takam-Fongang et al. 2018).

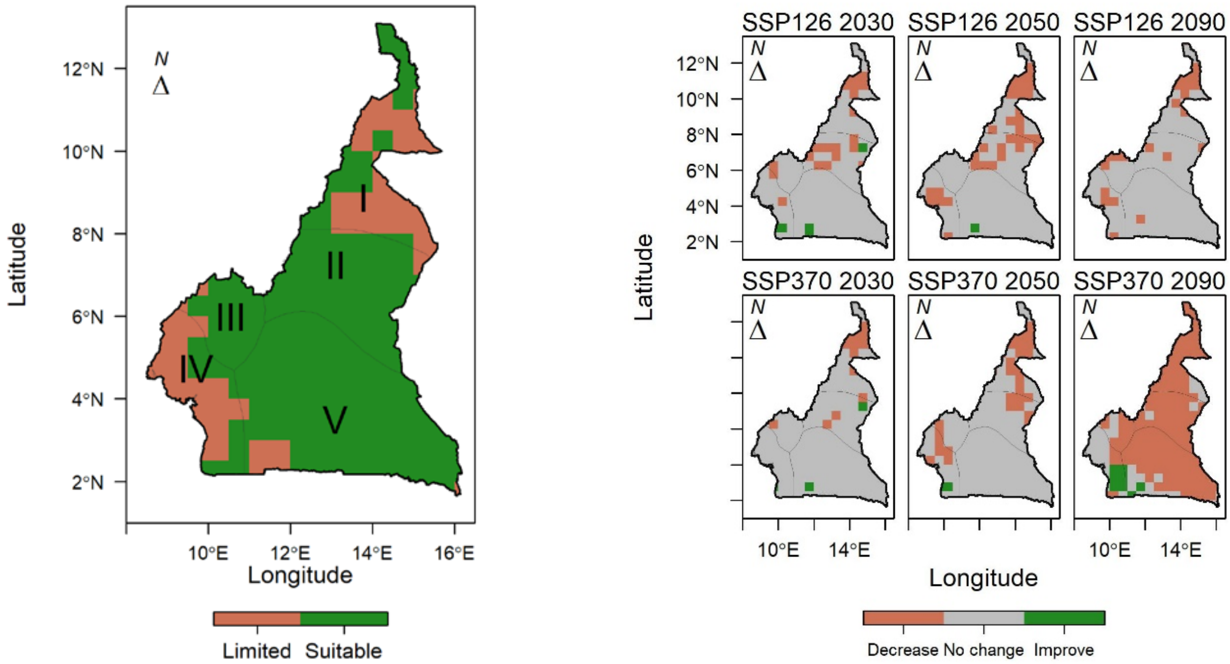

Figure 20: Current suitability (a) and projected changes in climatic suitability (b) for maize in Cameroon for the 2030s (left), 2050s (middle) and 2090s (right) under the SSP1-RCP2.6 (upper row) and SSP3-RCP7.0 scenarios.

5.1 Crop suitability assessment and changing climatic conditions

Current suitability for maize is shown in Figure 20 pointing out that more than 77% of the country's territory is considered suitable for maize production under current climatic conditions (see Figure 21). These areas are located in the (Guinean) High Savannah Zone (II), High Plateau (Western Highlands) Zone (III), Bimodal (Rain)forest Zone (V) and marginally in the Monomodal (Rain)forest Zone (IV) and the Sudano-Sahelian Zone (I) (Figure 20a).

However, climate change will have a considerable impact on maize suitability with marginal decreases in 2030, but considerable decreases in 2050 and especially 2090 under the high-emissions scenario (SSP3-RCP7.0) where more than 70 % of the suitable area is negatively affected (Table 5). Maize is a weather-sensitive crop and as such it was expected to respond more to climate change – especially temperature changes - than other crops. The projections (see 1.2) indicate high increases in temperature in Cameroon, especially for the high-emissions scenario, which is reflected by the decreases in suitability. These findings correspond to other studies that, for instance, outline especially the northern region as highly vulnerable towards climate change, especially to changes in precipitation (Epule et al. 2021).

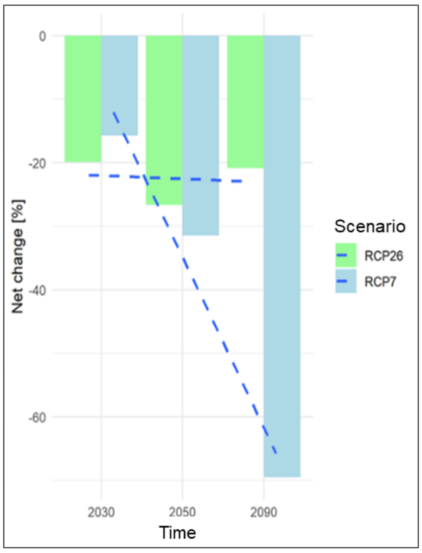

Figure 21: Net changes [%] of suitable areas for maize in Cameroon.

Scenario	Year	Decrease	No change	Improve
SSP1-RCP2.6	2030	21.79	76.27	1.94
	2050	27.6	71.43	0.97
	2090	21.79	77.24	0.97
SSP3-RCP7.0	2030	18.65	78.45	2.9
	2050	33.17	65.13	1.7
	2090	71.43	26.63	1.94

Table 5: Changes of suitability [%] under climate change.

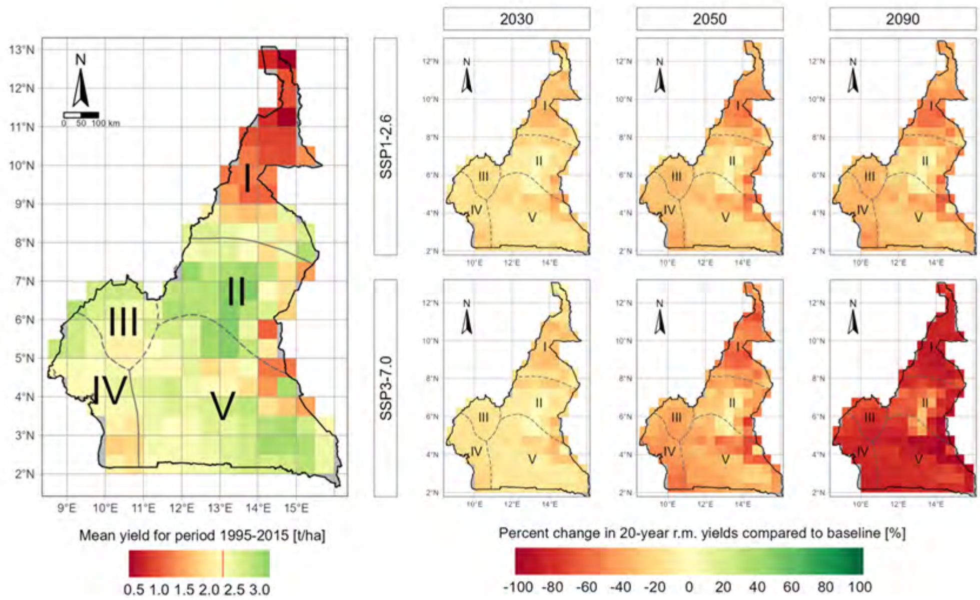

Figure 22: Simulated baseline yields (large map, left) and relative changes in future yields (small map multiples, right) of the unadapted baseline cultivar for scenarios SSP1-RCP2.6 and SSP3-RCP7.0 and three reference time slices (2030, 2060, 2090). Grey areas indicate missing values for that area. Red line in baseline yield legend the mean yield (2.23 t/ha) across all grid cells of the baseline yields.

5.2 Maize yield loss assessment under future climatic conditions

Current maize yields reach on average 2.1 t/ha in observed data (Iizumi, 2019) and 2.2 t/ha in simulated data for the chosen baseline cultivar. Yield baselines (Figure 22, large map) for the simulated climate change yield impacts typically range from 2.3-2.5 t/ha except for the semi-arid AEZ I where mean yield is much lower at 1.5 t/ha. The most productive region of the country is situated in AEZ II, the (Guinean) High Savannah Zone, closely followed by AEZs III and V (High Plateau (Western Highlands) Zone and Bimodal (Rain)forest Zone).

> The process-based crop model APSIM was used for projecting maize yields under climate change. APSIM simulates maize growth based on weather data, soil characteristics and information on crop management.

Figure 23 shows the current distribution of absolute yield levels in Cameroon as well as relative changes in yields under future projection scenarios SSP1-RCP2.6 and SSP3-RCP7.0. Climate impacts on projected future yields are universally negative but differ in magnitude by scenario and AEZ due to regional differences in climate change. The largest declines are expected towards the end of the 21st century. National average yield declines are -34% by 2090 and -79% by 2090 for scenarios SSP1-RCP2.6 and SSP3-RCP7.0, respectively. The largest losses by 2090 are experienced in AEZ I for both scenarios, with average yield declines of -43% and -84% by 2090 under scenarios SSP1-RCP2.6 and SSP3-RCP7.0, respectively (Figure 23). As yields in AEZ I are already marginal under current conditions, this indicates an almost complete yield collapse in AEZ I in the long-term future for the high-emissions scenario. The smallest losses are found in AEZ II with average relative yield declines of -27% and -70% by 2090 under scenarios SSP1-RCP2.6 and SSP3-RCP7.0, respectively, but losses are still significant. Variability of yields is also impacted by climate change, with the national average Coefficient of Variation (CV)[2] of yields across both scenarios increasing from 11% in the baseline period to 18% and 43% under scenario SSP1-RCP2.6 and SSP3-RCP7.0, respectively.

Annual time series of AEZ mean yields show distinct trends for climate change scenarios SSP1-RCP2.6 and SSP3-RCP7.0. AEZ mean yields stabilise after 2050 for scenario SSP1-RCP2.6 and even show a slight upward trend, but differences in yield levels between AEZ stay constant, with AEZ II performing best and AEZ I performing worst. Yield levels continuously decrease for all AEZs under scenario SSP3-RCP7.0 with steeper declines in AEZs II to V until differences in yield levels between AEZs almost disappear by 2100. Differences between scenarios become apparent by 2060. A unique trajectory is observed for the second growing season in AEZ V which starts with low yields comparable to AEZ I but exhibits much more stable yield levels under both scenarios. Yield declines are only seen under SSP3-RCP7.0 after 2070, making it the best-performing AEZ in 2100. The presented yield impacts were found to be almost entirely driven by temperature increases, as there are no significant rainfall trends over time except for a slight drying trend in AEZ V which is a very humid region and simulated yield changes corresponded mainly with temperature changes rather than changes in precipitation. Maize is a heat-sensitive crop and threshold temperatures for maize development are already reached today in Cameroon (Epule, 2021).

3) CV is calculated as the ratio between means and standard deviations of 20-year running mean yields.

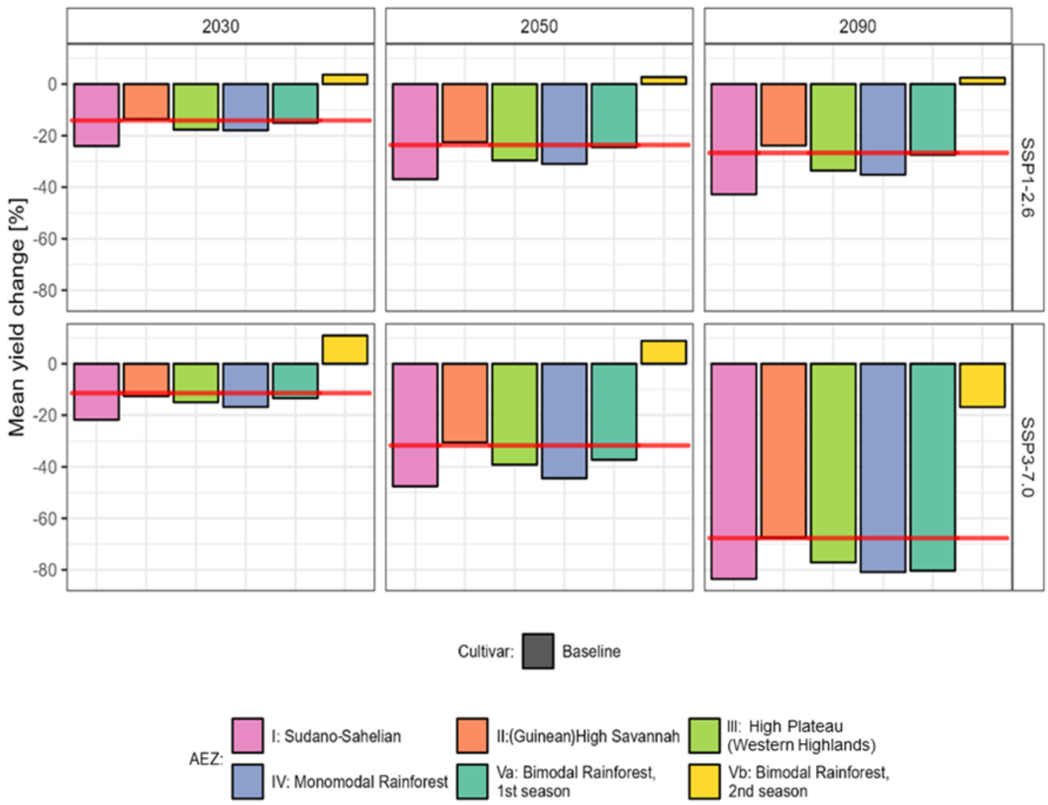

Figure 23: Barplots of changes in 20-year rolling mean yields of the baseline cultivar by AEZ and climate change scenario for the three reference time periods 2030, 2050 and 2090. Red horizontal lines indicate mean change by cultivar for each period.

5.3 Adaptation option: Heat-tolerant varieties

Maize yield levels in Cameroon are very low averaging 2.1 t/ha (Iizumi 2019), with low use of inputs such as improved varieties and drought stress being cited as common reasons as only 1% of arable land is irrigated (Mafouasson, 2020; Takam-Fongang et al. 2018). Most seeds used by smallholders in Cameroon are landraces with variable yield levels (Mafouasson et al. 2020) and they are distributed through local, informal seed systems. Seeds are saved year-to-year or exchanged within local communities. While the role of the informal seed system is essential for Cameroon's seed supply, climate shocks could severely deplete household seed stocks through successive poor harvests which might leave farmers with insufficient seed stocks to replant in the next season (Mafouasson, 2020). Improved varieties provide higher yield levels and yield stability, improved climate resilience such as resistance to drought or better harvest quality and nutritional benefits (Cairns et al. 2013; Minoli et al. 2019). The use of new varieties combined with improved management may offset climate change-related yield losses by almost 40% (Cairns et al. 2013). Locally adapted improved varieties may enable farmers to maintain sufficient yields under climate change conditions, but current adoption of improved variety seedstock in Cameroon is low (Mafouasson, 2020), with the most commonly used variety (Cameroon Maize Selection) CMS 8704 having been developed in 1987 by IRAD (Etoundi et al. 2008) and as such not being adapted to current or future climatic conditions. Given the wide array of options for variety improvement this study focusses on adapting the heat tolerance of maize. Maize is considered a heat-sensitive crop due to its flowering biology, where pollen exposed to high temperatures can become infertile, inhibiting pollination, grain set and yields considerably (Tesfaye et al. 2017). Temperatures in Cameroon are universally predicted to rise under climate change in line with global warming, and many maize growing areas in the country already routinely approach temperature thresholds for maize production during the growing season, especially in the North (Cairns & Prasanna 2018; Epule 2021). While heat tolerance is a complex trait in plant physiology, it is parametrised with relative ease in the APSIM crop model in order to illustrate the potential of a synthetic, climate-resilient maize variety by raising temperature stress values for grain set. Heat tolerance has so far been an under-researched trait and many farmers are not aware of maize's heat sensitivity, with most participatory breeding and selection trials in Cameroon focussing on pest resistance or early maturity instead (Mafouasson et al. 2020; Tadesse et al. 2014). As breeding is a long-term and committal investment, breeding goals need to be assessed for efficacy and suitability before implementation. A shift towards heat tolerance in breeding efforts by e.g. IRAD should thus be backed up by a thorough anticipative impact modelling approach. Not all maize varieties may be suited for all of Cameroon's maize growing regions which is why this study employs grid-based modelling for spatial disaggregation of suitability and yield impacts under two climate change scenarios in Cameroon.

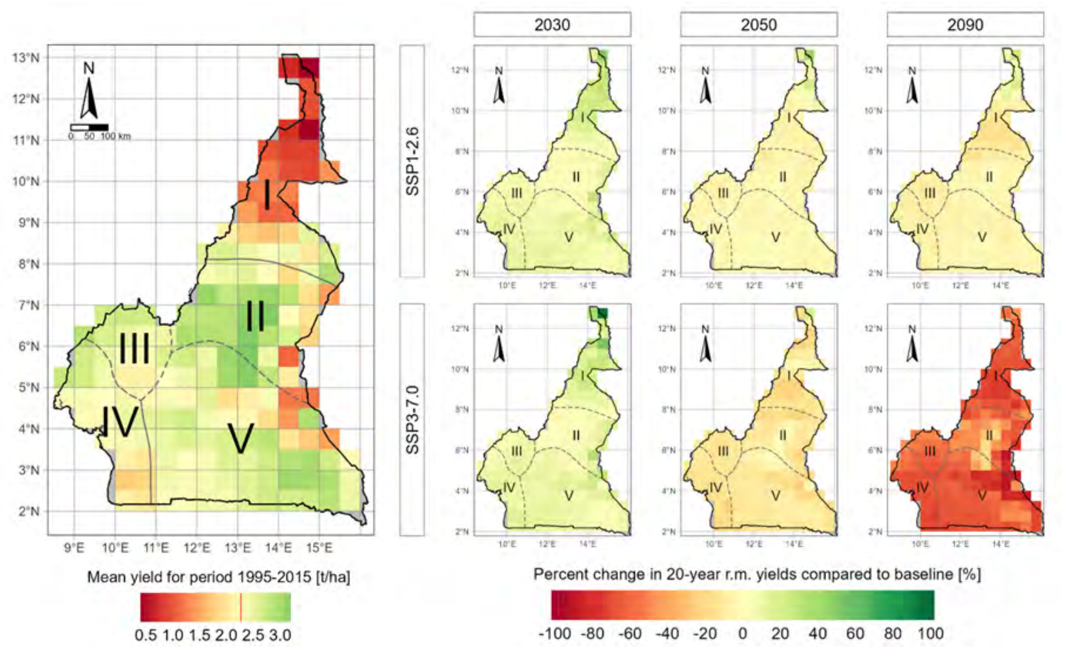

Figure 24: Baseline yields (large map, left) and relative changes in future yields (small map multiples, right) of the heat-tolerant cultivar for scenarios SSP1-RCP2.6 and SSP3-RCP7.0 and three reference time slices (2030, 2050, 2090).

5.3.1 Risk mitigation potential

Climate impacts on yields of the synthetic heat-tolerant cultivar are markedly different from the unadapted baseline cultivar. While impacts on 20-year rolling mean yields under scenario SSP3-RCP7.0 are still overall negative by 2050, they only become significant by 2090 and impacts are much less detrimental under SSP1-RCP2.6 with little to no overall change in yield trends (Figure 24). National average mean yield losses in 2090 under SSP1-RCP2.6 only amount to -6%, which stands in stark contrast to SSP3-RCP7.0, where national average losses amount to -62%. The heat-tolerant cultivar achieves yield gains in all AEZs in the short-term future which is especially apparent in AEZ I where yield gains are highest, averaging 14% and 18% under SSP1-RCP2.6 and SSP3-RCP7.0, respectively. Relative mean yield gains are lost by 2050 and turn into significant losses by 2090 scenario SSP3-RCP7.0 – but mean yield losses of the adapted cultivar are always smaller than of the unadapted cultivar for all AEZs. Differences in mean yield changes between AEZs are low for both scenarios. The smallest loss under scenario SSP3-RCP7.0 is found for AEZ II at -56% and the highest in AEZ I at -67%. AEZ Vb experiences no decline in yields under both scenarios (Figure 25), but absolute yield levels in the second growing season of AEZ V are low so the other AEZs still perform better under SSP1-RCP2.6 until 2100 and until 2070 under scenario SSP3-RCP7.0. Yield variability of the adapted cultivar as measured by its CV is also less impacted under climate change, with national average CV increasing slightly to 18% from its baseline value of 11% under SSP1-RCP2.6, and to 29% under SSP3-RCP7.0.

A majority of variability is again found in AEZ I. Differences in yield levels between scenarios become apparent in 2050 (Figure 24). Yield levels keep continuously decreasing for all AEZs, except AEZ V under scenario SSP3-RCP7.0 with steeper declines in AEZs II to V but differences in yield levels between AEZ II and I persist.

> Using improved maize varieties leads to higher levels of maize yields, both under current conditions, as well as under climate change conditions.

The heat-tolerant cultivar thus manages to considerably mitigate climate impacts under the low-emissions scenario, but cannot offset all projected yield losses for the mid- and long-term time periods. Yield losses are still significant under scenario SSP3-RCP7.0 for the long-term future time period, indicating that the degree of heat tolerance simulated is not enough to withstand temperature increases expected for the high-emissions scenario in the late 21st century. The second growing season in AEZ V contrasts results of all other AEZs, hinting at a pronounced effect of seasonality on climate change impacts on yield. If improved varieties are developed, their implementation should be accompanied with suitable management and extension service offers to participating farmers. Adapted sowing dates may be a suitable additional measure to safeguard and improve maize yields according to our results.

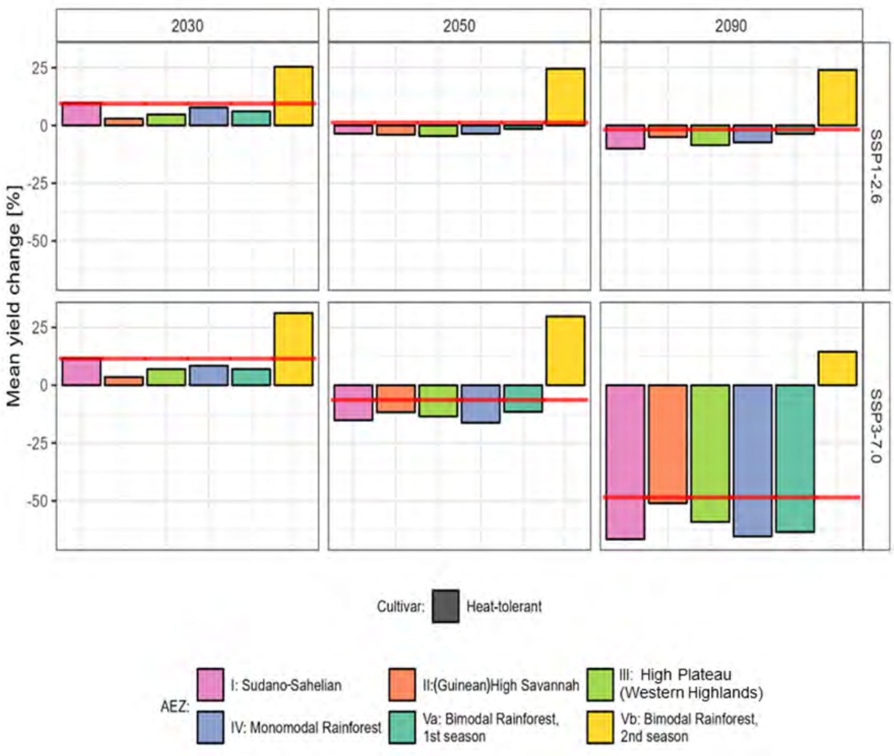

Figure 25: Barplots of changes in 20-year rolling mean yields of the heat-tolerant cultivar by AEZ and climate change scenario for the three reference time periods 2030, 2050 and 2090. Red horizontal lines indicate mean change by cultivar for each period.

5.3.2 Cost effectiveness

The following cost-benefit-analysis (CBA) evaluates whether switching from traditional maize varieties to improved heat-tolerant varieties is an economically feasible adaptation strategy. Costs and benefits of using improved varieties are compared to a non-adaptation scenario (baseline) and projected until 2050, considering two emission scenarios. The profitability of the investment is tested and compared at the national level assuming average national yields, and in the high-yielding Adamawa region in central Cameroon.

> The initial investment needed to switch from local maize varieties to improved maize varieties already becomes economically beneficial from the second year onwards.

The results of the two region-specific CBA show that investing in heat-tolerant varieties is worthwhile both at the national level and in the high-yielding region Adamawa (3 and 4). At the national level (3), the Internal Rate of Return (IRR) is highest in the SSP1-RCP2.6 scenario, where it is 110 percent. The IRR is slightly lower (90%) in the SSP3-RCP7.0 scenario, as maize yields perform worse under the high-emissions scenario than under the low-emissions scenario. The very high IRR values presented here are not uncommon for investments in improved varieties as only small changes in expenditures are contrasted with often very substantial yield increases and subsequently greater revenues (see also Lotze-Campen et al., 2015). The Benefit-Cost Ratio (BCR) of over 2.1 in both emissions scenarios shows that the benefits are more than twice as high as the costs.

In Adamawa too, the investment in the heat-tolerant variety is profitable. The return here is 64% in the low-emissions scenario and 49% in the high-emissions scenario (4). Also, the BCR is slightly worse than at the national level, but still represents a good ratio at 1.75 and 1.74.

Even though the absolute maize yields in Adamawa are significantly higher than at the national level, the yield difference between the conventional Cameroon Maize Selection (CMS) and the improved variety is lower than at the national level. The reason for this could be that the CMS variety has already a location advantage in the high-yielding region of Adamawa (see explanation above). This means that the potential for improvement, although still substantial, is therefore not as great as at the national level (in the case of a lower reference/baseline yield), which is why the CBA performs slightly better at the national scale than in Adamawa.

	Adaptation under SSP1-RCP2.6	Adaptation under SSP3-RCP7.0
NPV (Net Present Value)	782,036 FCFA	768,912 FCFA
IRR (Internal Rate of Return)	110%	90%
BCR (Benefit-Cost Ratio)	2.18	2.16

Table 6: Summary of key CBA indicators for switching to heat-tolerant maize varieties at the national level in Cameroon.

At the national level, the net cash flow[4] is already positive from the second year onwards under both emissions scenarios (Figure 26) starting at 31,000 FCFA (SSP1-RCP2.6) and 25,000 FCFA (SSP3-RCP7.0) respectively. Looking at the coming decades, it develops in a similar way reaching up to approx. 50,000 FCFA per hectare by mid-century. The highs and lows result from the fluctuating yields and, accordingly, the fluctuating farmer income.

The net cash flow for the investment in heat-tolerant varieties in the Adamawa region is positive from the second year onwards, although not quite as high as at the national level (Figure 27). It starts at about 15,000 FCFA in the SSP1-RCP2.6 scenario and at about 7,000 FCFA in the SSP3-RCP7.0 scenario. Over the course of time, it increases, reaching almost 40,000 FCFA under the high emissions scenario. As with the cash flow at the national level, the highs and lows mark the fluctuating farmer income from the annually fluctuating yields.

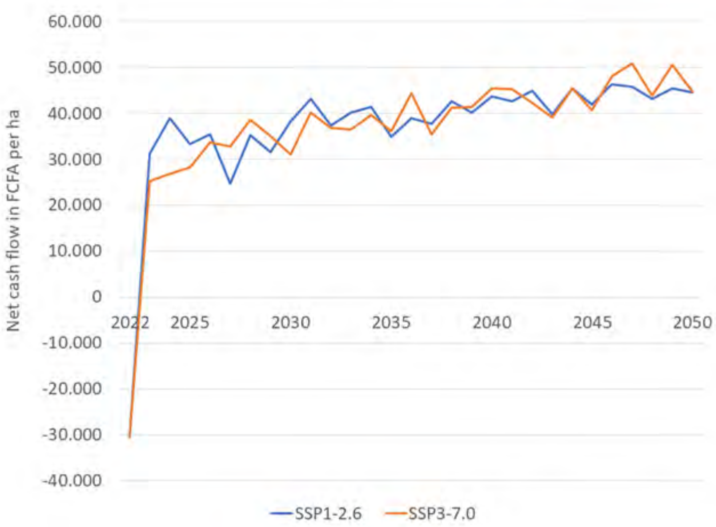

Figure 26: Net cash flow in FCFA per hectare up to 2050 for investing into improved seeds under SSP1-RCP2.6 and SSP3-RCP7.0 at the national level.

	Adaptation under SSP1-RCP2.6	Adaptation under SSP3-RCP7.0
NPV	501,380 FCFA	492,116 FCFA
IRR	64%	49%
BCR	1.75	1.74

Table 7: Summary of key CBA indicators for switching to heat-tolerant maize varieties in Adamawa region in Cameroon.

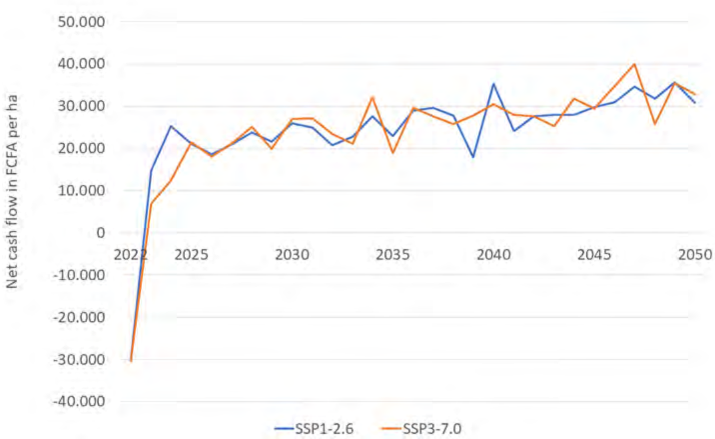

Figure 27: Net cash flow in FCFA per hectare up to 2050 for investing in improved seeds under SSP1-RCP2.6 and SSP3-RCP7.0 in the Adamawa region.

5.3.3 Co-benefits and challenges

Previous economic assessments have shown that the use of improved seed varieties can generate high interest rates (see, e.g., Lotze-Campen et al., 2015). As maize is a heat-sensitive crop, improvements in heat tolerance are particularly effective, as shown by this CBA. However, the comparison of two different regions in Cameroon shows that the extent of these benefits may differ depending on factors that affect maize production and marketing in different regions of Cameroon or in other countries (Kaliba et al., 2017). Specific agroecological conditions and management practices used by the farmers can affect yields, while, for example, market demand for the crop can highly affect its prices.

Furthermore, most seeds in Cameroon are farmer-saved landraces (Mafouasson et al. 2020). Maize is the most widely farmed cereal in the country and provides above 20% of total calories consumed in Cameroon (Etoundi & Dia, 2008; Manu et al. 2015). It is also the major source of income for more than 3 million smallholder farmers (Engwali et al. 2019). Upscaling of improved maize varieties has therefore a great potential as a climate adaptation strategy. As the demand for maize in Cameroon and neighbouring countries is high (Mireille et al. 2009), generated economic benefits could be significant as well. However, formal distribution

4) As required by a CBA, the net cash flow refers only to the investment made and subsequently changing production variables, not to the entire maize production system.

Impacts on maize cultivation			Trend past	Trend future	Confidence
	Suitability		77% suitability of the country's territory	SSP1-RCP2.6 Decreasing by 19 to 71% SSP3-RCP7.0 Decreasing by 22 to 28%	High
	Yield		2.1 t/ha	SSP1-RCP2.6 Decreasing by 34% in 2090 SSP3-RCP7.0 Decreasing by 79% in 2090	High
	Potential yield with improved varieties		-	SSP1-RCP2.6 Decreasing by 6% in 2090 SSP3-RCP7.0 Decreasing by 62% in 2090	High
	Cost-benefit-analysis (CBA) for improved maize varieties	National level	-	SSP1-RCP2.6 Increase NPV 782,036, IRR +110%, BCR 2.18 SSP3-RCP7.0 Increase NPV 768,912, IRR +90%, BCR 2.16	related to the confidence of the yield projections and other input data
		Adamawa	-	SSP1-RCP2.6 Increase NPV 501,380, IRR +64%, BCR 1.75 SSP3-RCP7.0 Increase NPV 492,116, IRR +49%, BCR 1.74	related to the confidence of the yield projections and other input data

Table 8: Summary of climate change impacts on conventional maize yields and heat-tolerant maize yields.

of improved seeds is difficult Takam-Fongang et al. (2018), for example, found that their adoption decreased with distance to the nearest IRAD facility in Cameroon. The country also faces a lack of a coherent extension and promotion program regarding improved variety seeds, with low involvement of the private sector in seed distribution and access (Mafouasson, 2020). Furthermore, the number of private seed producers and processors for maize, which might support seed distribution and propagation, has been declining (Mafouasson, 2020).

One of the main concerns with improved seeds is their cost. Many smallholder farmers may not be able to afford the higher prices of improved seeds, which can limit their access to these resources. Another issue is the availability of improved seeds in rural areas. Farmers in remote or hard-to-reach areas may not have access to these seeds, due to logistical and transportation challenges. And even if access can be given, this can further increase costs and therefore ultimately affect farmers' economic profit. Due to the lack of specific data, these challenges could not be reflected in this CBA. Further research would therefore be needed to account for these additional aspects.

5.3.4 Opportunities for women and other social groups in the adoption of improved seeds as an adaptation strategy

Different studies suggest that gender and other social factors can influence the adoption of improved maize varieties as a climate adaptation strategy. Women more often than men face difficulties in adopting improved varieties, which is reflected in low adoption rates of improved maize varieties in Cameroon (Manu et al., 2015). Awareness as a combined result of education, visits from extension agents and access to relevant information has been highlighted as an important factor which influences the adoption of improved maize seeds in other parts of Africa (Fisher et al., 2019). Furthermore, different studies emphasize the role of networks for the adoption of improved seed varieties (Fisher et al., 2019; Otieno et al., 2021). While men tend to have better access to improved varieties via formal seed networks and extension services, women are more likely to rely on local and more informal farmer-to-farmer networks, with poorer access to improved varieties and, in turn, negative consequences for their income and food security (Otieno et al., 2021).

5.4 Summary

While showing spatial and temporal disparities, climate change is projected to negatively affect maize. Maize yields will decrease in AEZ I up to -84% by 2090 under SSP3-RCP7.0. Crop models show that the areas suitable for maize will decrease in Cameroon, especially under SSP3-RCP7.0. Improved varieties as adaptation strategy is economically beneficial and can be recommended to adapt to the projected climatic changes. Successful implementation will depend on a context-specific design that takes the different biophysical realities in which they are implemented into consideration, e.g. the agroecological conditions.

6. Assessment of climate impacts and adaptation option for cassava

Cassava *(Manihot esculenta)* is a starchy tuber and a key staple crop in Cameroon's more humid regions, as it requires a lot of water over a long growing season. It is the most consumed root and tuber crop in the country (Poubom et al. 2005) and its leaves are widely consumed as a nutrient-rich vegetable as well (Sarr et al. 2013). Despite its versatility and industrial processing potential, cassava has long remained a subsistence crop due to its cultivation in areas with limited infrastructural development and inadequate storage capacities leading to rapid spoilage and major post-harvest losses (Njukwe et al. 2014a; 2014b).

Cassava grows well in acidic, low-fertility soils common in the humid tropics, but can lead to significant nutrient exhaustion when grown continuously without fallow. This has become common in Cameroon due to demographic pressure and thus resulting in increases in demand by both urban centres and the food industry (Sarr et al. 2013). Sustainable soil fertility management is a promising adaptation strategy to make cassava more climate-resilient (USAID, 2018).

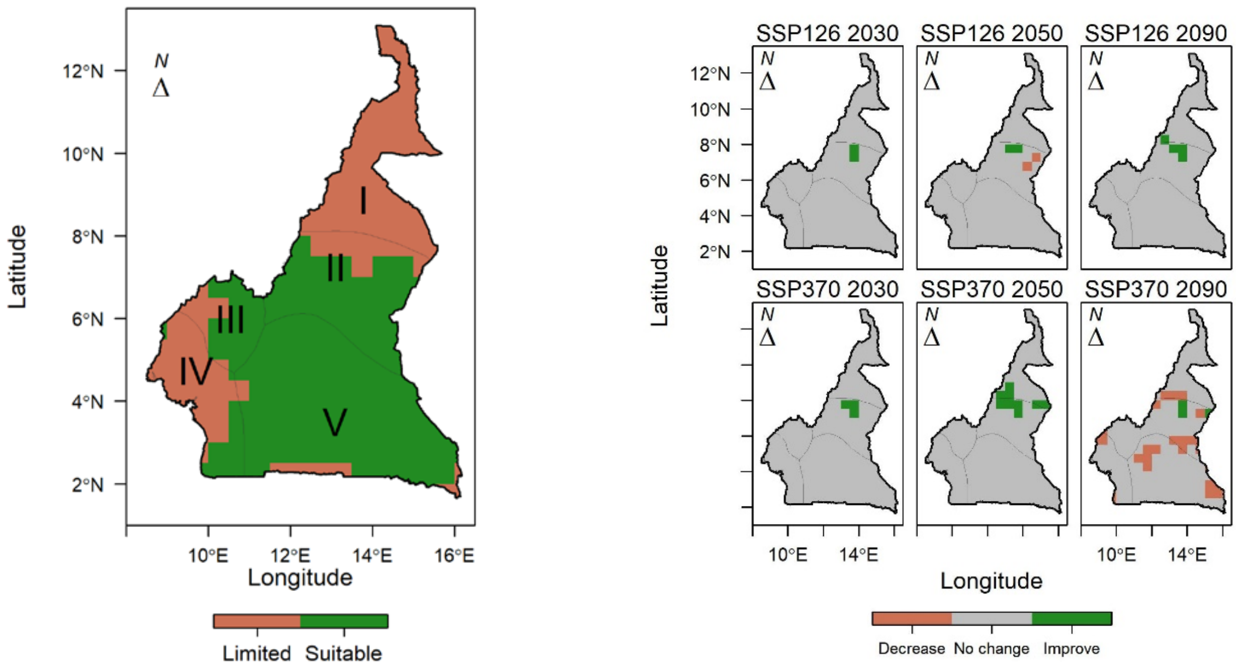

Figure 28: Current suitability (a) and projected changes in climatic suitability (b) for cassava in Cameroon for the 2030 (left), 2050 (middle) and 2090 (right) under the SSP1-RCP2.6 (upper row) and SSP3-RCP7.0 scenarios.

6.1 Crop suitability assessment and changing climatic conditions

Climate impacts on the suitability of cassava are shown in Figure 28. The majority of the country is projected to maintain suitability levels for cassava production, especially under the low-emissions scenario. In contrast to maize, cassava is less vulnerable to hazards, such as drought or erratic rainfall, for example, during the flowering stage (Jarvis et al. 2012), which can explain the marginal effect of climatic changes on future suitability. Under the high-emissions scenario, some marginal decreases are projected for 2090, mainly in AEZ V, and even slightly more areas that will become more suitable for cassava production in 2050 at the border of AEZs I and II. The interaction between temperature and precipitation increases in the Sudano-Sahelian Zone (I) determine here the increase in suitability. In conclusion, net changes in cassava suitability at the national level are indicating that the suitability will largely remain unchanged in Cameroon for the low-emissions scenario and marginal variation for the high-emissions scenario (Figure 29).

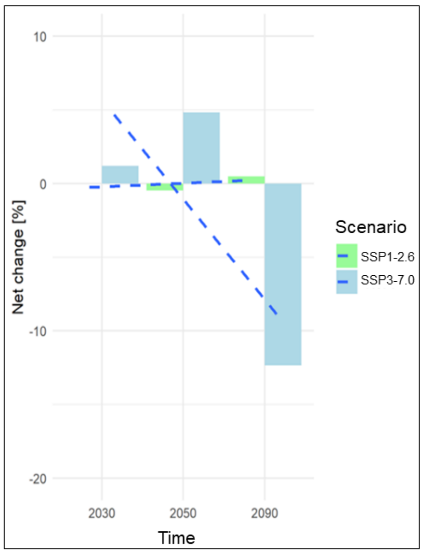

Figure 29: Net changes [%] for cassava suitability.

Scenario	Year	Decrease	No change	Improve
SSP1-RCP2.6	2030	0.73	98.54	0.73
	2050	1.94	96.61	1.45
	2090	0.97	97.58	1.45
SSP3-RCP7.0	2030	0.24	98.31	1.45
	2050	1.21	92.74	6.05
	2090	14.77	82.81	2.42

Table 9: Changes of cassava suitability [%] under climate change.

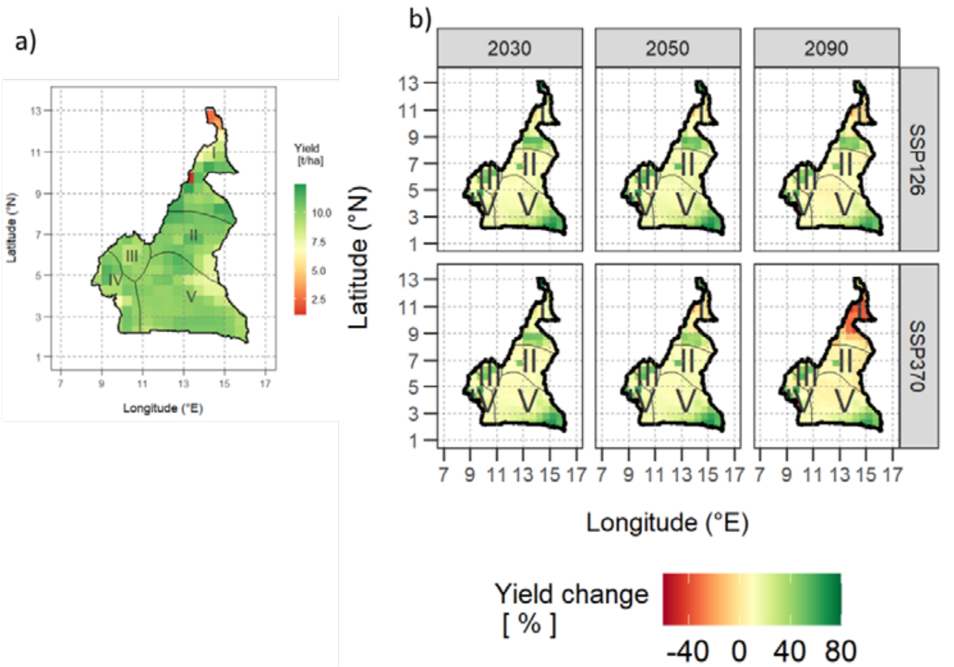

Figure 30: (a) Current and (b) projected future cassava yield changes (%) in Cameroon at 0.5° grid spacing under SSP1-RCP2.6 (top row) and RCP7.0 (bottom row) for around 2030, 2050, and 2090.

6.2 Cassava yield loss assessment under future climatic conditions

The national average cassava yield for smallholder farming systems in Cameroon from 1995 and 2015 was 10t /ha and our model estimates this at 9.7t/ha. The distribution of cassava yield from the model is shown in Figure 30a. These yields are far below the expected yields of cassava that are obtainable under either the environmental conditions or the genetic characteristics of the cassava varieties that are planted in the country. Cassava production intensity is higher in the Centre, Southern and Western regions of the country. Still, potential yields are highest in the south-eastern parts of the country where rainfall amounts tend to be higher. The Western Highlands, the monomodal rainforest and the bimodal rainforest have vast areas with high potential yield for cassava (>10t/ha) for current climate conditions (Figure 30a). The (Guinean) High Savanna Zone and the Sudano-Sahelian Zone have areas with the lowest cassava yields in Cameroon.

> The process-based crop model APSIM was used for projecting cassava yields under climate change. APSIM simulates cassava growth based on weather data, soil characteristics and information on crop management.

Figure 30 shows the projected future percentage changes relative to the baseline in cassava yields across Cameroons AEZ for 2030 (first column), 2050 (second column), and 2090 (third column) under SSP1-RCP2.6 (upper row) and SSP3-RCP7.0 (lower row) per AEZ. Climate impacts on cassava yields show spatial and temporal disparities with general trends showing that they worsen with time from 2030 to 2090 and with scenario from SSP1-RCP2.6 to SSP3-RCP7.0. We project a yield loss at AEZ scale of up to 30% (SSP1-RCP2.6) and 35% (SSP3-RCP7.0) by around 2030, 30% (SSP1-RCP2.6) and 35% (SSP3-RCP7.0) by around 2050, and 35% (SSP1-RCP2.6) and 40% (SSP1-RCP7.0) by near the end of the century (Figure 30b).

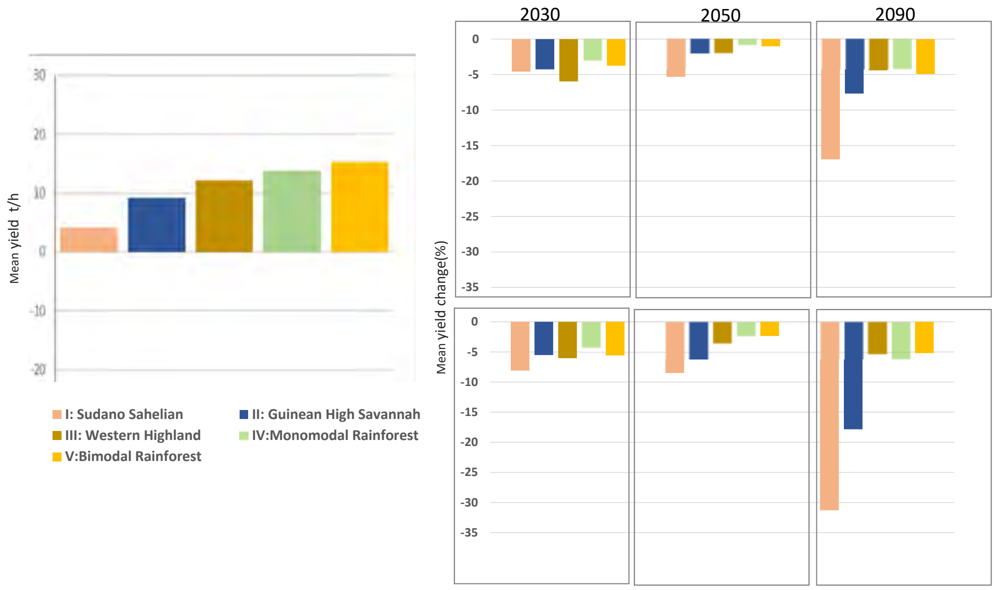

Figure 31: Simulated climate impacts on cassava yield at regional level in Cameroon for around 2030, 2050 and 2090 under SSP1-RCP2.6 and SSP3-RCP7.0.

The highest cassava losses under most periods and scenarios are projected for AEZ I, where by 2090 yields will decrease by 6% and 30% for SSP1-RCP2.6 and SSP3-RCP7.0, respectively, and up to 10.5% (SSP1-RCP2.6) and 38.8% (SSP3-RCP7.0) by the end of the century. Over 30% of yield losses for cassava are projected for AEZ I and II by the end of the century under the SSP3-RCP7.0 scenario. Some positive cassava yield effects are projected in the AEZ III, IV and V under SSP1-RCP2.6. Climate impacts on cassava yields are worse under SSP3-RCP7.0, compared to SSP1-RCP2.6 for all scenarios. At national scale(Figure 31) we project a yield loss at scale of up to 15% loss under SSP1-RCP2.6 by 2090 and up to 28% loss under SSP3-RCP7.0 by 2090.

We conclude from this assessment that climate change will have an impact on cassava yields in Cameroon, especially in the AEZs IV and V where cassava density is the highest from around 2030 onwards, with more severe impacts under the SSP3-RCP7.0 scenario. This is because, despite the area having and maintaining a suitable climatic environment as shown in the suitability projections, yield performance is influenced by other factors besides climate and climate change affects these factors as well. Our projections indicate yield losses of up to 60% towards the end of the century. Both water and temperature effects explain the changes in yield with temperature increases having more significant impacts than the projected changes in precipitation as cassava yields are projected to remain the same for areas where rainfall is projected to remain the same or increase (see Chapter 1). It is also important to note that not only drying leads to yield reductions in cassava in Cameroon but also flooding and waterlogging of the root zone is detrimental to cassava growth and yield, especially if it occurs during the early stages of cassava growth. The loss of cassava yields is less than losses for other cultivated crops in Cameroon, which shows that cassava is indeed a climate-resilient crop, compared to other crops.

> The analysis shows that climate change will have a negative impact on cassava yield in Cameroon with more severe impacts under the SSP3-RCP7.0 scenario.

6.3 Adaptation option: Integrated soil fertility management

Meeting food demand on existing cropland without further encroaching on natural ecosystems such as forests, wetlands and savannahs is one of the greatest challenges of the present time (Cassman & Grassini, 2020). There are large yield gaps, defined as the difference between potentially attainable yields under optimal management and the actual realized yields under current management (Cassman, 2012) for crops such as cassava, maize, bean, cocoyam and plantain, among others (Sadras et al. 2015, Djurfeldt et al. 2019. As projections show, a decrease in suitability and already low yields of essential crops such as cassava there is a need for sustainable intensification methods that can increase production and buffer climate shocks, while minimizing environmental degradation. Among the most promising strategies for the sustainable intensification of cropping systems is Integrated Soil Fertility Management (ISFM).

ISFM includes management practices which are tailored to local conditions and make efficient use of mineral and organic sources of fertility, improved crop varieties to replenish soil nutrients, and improve agronomic efficiency and crop production (Vanlauwe et al.2010). In other words: Improving soil fertility is about the adoption of several methods in a coherent, appropriate and integrated manner, based on the knowledge of the farmer and environmental factors. Thus, increasing crop productivity is influenced by the nutrient of the soil in combination with effective and efficient farm management skills. ISFM interventions vary and can include the application of fertilizer (organic and inorganic), water harvesting (mulching), intercropping and farm yard manure. As an alternative to mineral fertilizers, organic manures have been recommended for improving soil productivity in African agricultural systems because of their beneficial effects on soil productivity (Harraq et al., 2021), soil physical and chemical properties and crop yields (Al-Gaadi et al., 2019; Biratu et al., 2019; Ngosong, et al, 2015). Studies on cassava fertilization in Cameroon (e.g. Temegne & Ngome, 2017; Bilong et al., 2017) show positive results on cassava yields.Bilong et al., (2022) used *Tithonia diversifolia* to determine the effects of organic manures on soil physical properties, and cassava growth and yield. The Chemical parameters for *Tithonia diversifolia* are Carbon 24.8 %, Nitrogen 3.47%, C/N ratio 7.15, Phosphorus 0.6 %, Potassium 3.8 %, Calcium 3.06 %, Magnesium 0.54 % (Bilong et al.,2022). Their results like those of other studies indicate that Tithonia demonstrates strong potential for soil rejuvenation (Ojeniyi, 2012, Agbede et al., 2014), and plant health management due to the presence of sesquiterpene lactones (tagitinins-terpene) and other antimicrobial substances that prevent pests and diseases (Adoyo., Mukalam, and Enyola, 1999). Studies have shown that ISFM can have positive effects on crop productivity, compared to conventional practices (Dai et al., 2010; Manzeke et al., 2012; Ram et al., 2016, Ngosong et al., 2015). Different environmental, economic and production benefits of ISFM have been reported across different systems and climatic gradients (e.g. Ngwira, Aune et al. 2014, Mupangwa, Mutenje et al. 2017, Jat, Choudhary et al. 2020, Devkota, Devkota et al. 2022), Muyayabantu et al., 2013) and on cassava yields (e.g. Pypers et al., 2011; Biratu et al.,2018).

Despite the overwhelming evidence on the positive effects of ISFM on crop yields, the upscaling of this strategy remains a challene (e.g. Vanlauwe et al., 2015) in Cameroon. The heterogeneity of environmental and crop management systems, the response of crop yields, yield stability and profitability to ISFM vary. For example, Vanlauwe et al. (2015) noted that at farm scale, a better understanding of the interactions between soil fertility conditions, crop and land management practices, and yields as a basis for disentangling the often-observed large variability in responses to ISFM practices is necessary in order to develop household- and site-specific recommendations. Therefore, site-specific results from ISFM performance experiments may be one of the yard sticks for the upscaling of ISFM at the national level as on-farm biophysical and socio-economic factors constrain the impact of ISFM on crop yield responses.

6.3.1 Risk mitigation potential

We applied a gridded crop modelling approach to simulate the yield response of cassava to ISFM in Cameroon to provide a better understanding of the performance of ISFM across space and time in order to avoid maladaptation and enhance more targeted agronomic recommendations and sustainable intensification investments. In addition, we also provided an assessment of the potential performance of ISFM as an adaptation measure under projected climatic conditions in the country. Many studies have simulated the impacts of ISFM with APSIM using experimental values for model parameterization, calibration and evaluation (Nezomba et al.,2018; Dimes et al.,2003). However, no studies have developed protocols for simulating the impacts of ISFM on cassava yield response at a grid scale. Therefore, specific assumptions with regard to the effects of ISFM on soil and water dynamics in the soil were used. The following adjustments were therefore made in the APSIM model to emulate ISFM across grids in Cameroon:

> Using ISFM leads to higher levels of cassava yields, under current conditions, and in most of the areas under climate change conditions.

- Increasing weed management
- Increasing initial soil nitrogen (Dusserre, Autfray et al. 2020, Rani, Bandyopadhyay et al. 2020); Bilong et al., 2017; Adams et al., 2020)
- Increasing soil carbon content under ISFM (Bilong et al., 2017; Adams et al., 2020)

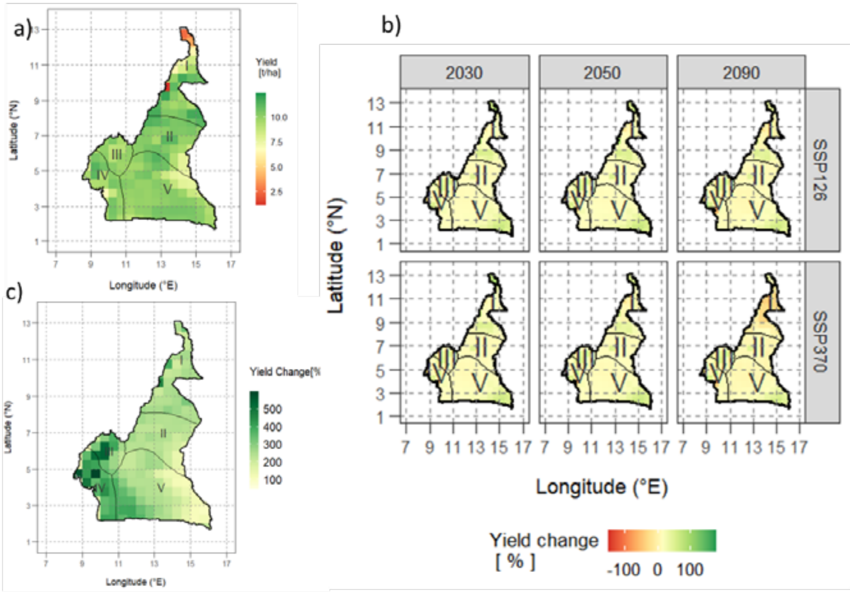

Figure 32: The grid-level spatial distribution map for projected yields of ISFM on cassava in Cameroon under different projected scenarios and periods.

In our analysis, we do not consider mulching and rotations because sources and quality of external materials for mulching beyond residues are highly uncertain for smallholder farmers. Furthermore, we are considering a continuous cassava crop with a fallow period to enable long-term climate change assessment. We are also considering an ISFM system that reduces labour and fuel input requirements by limiting as much as possible external inputs. The APSIM model was used for modelling soil organic components.

Our results show that ISFM increases yields in all AEZs under current climatic conditions. With regards to Figure 32b the results show that compared to the baseline, the greatest increases in yields are to be found in the High Plateau (Western Highlands) provinces (500%). No negative impacts of ISFM is seen under current climatic conditions.

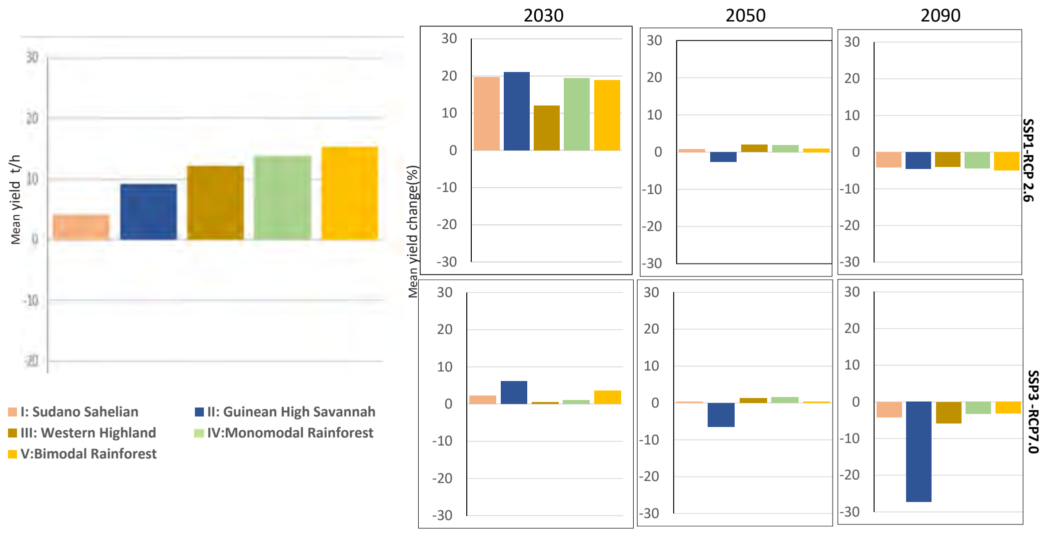

Figure 33: Potential impact of ISFM on cassava yields per AEZ in Cameroon for the periods 2030, 2050 and 2090 under SSP1-RCP2.6 and SSP3-RCP7.0.

Figure 34: Net cash flow in FCFA per hectare up to 2050 for investing into ISFM under SSP1-RCP2.6 and SSP3-RCP7.0.

Our projections show that under SSP1-RCP2.6, the yield responses vary being higher in the parts of AEZ III, IV and V when compared with the baseline yield (Figure 33a) and in the northern parts low to negative in AEZ I and II parts of the country, although it is positive for all AEZ under current climate (Figure 33b). The climate change effect of ISFM corresponds to its current yield response: Benefits will be higher for those AEZs where they are also high under current climatic conditions. The AEZs IV and V have the greatest potential for ISFM with yield increases of up to 40%, depending on the time and scenario at the provincial level. However, under SSP3-RCP7.0, all AEZs show loss in climate change buffering potential for ISFM, possibly due to the increased temperature effect on yields when the main effect of ISFM is on soil quality. Under SSP3-RCP7.0, yield benefits of ISFM decrease with time, being highest in the near future and least towards the end of the century for all AEZs.

6.3.2 Cost effectiveness

The following cost-benefits-analysis (CBA) intends to evaluate whether applying ISFM, based on *Tithonia* and *Mucuna* biomass mulching, in cassava production is an economically feasible adaptation strategy. Costs and benefits of using ISFM are compared to conventional cassava production and projected until 2050, considering two climate change scenarios.

> The initial investment needed to invest into ISFM is relatively low and highly profitable with a IRR of almost 500% under both emissions scenarios.

The results clearly show that the implementation of ISFM on cassava fields in Cameroon is highly profitable. The key economic indicators, as depicted in Table 10, perform almost equally well under both climate scenarios, with the low emissions scenario performing slightly better. The extremely high return of almost 500% in both climate scenarios and the very high NPV are due to the fact that yield projections predict an enormous increase in cassava yields through the application of ISFM, which causes the sharp increase in benefits. Furthermore, the cultivation of *Mucuna* creates an additional revenue stream for the farmer at only marginal additional costs and labour. Even the high labour costs of *Tithonia* are easily compensated in our model: In both climate scenarios, the benefits are almost six times as high as the costs.

	Adaptation under SSP1-RCP2.6	Adaptation under SSP3-RCP7.0
NPV (Net Present Value)	74,588,373	73,473,560
IRR (Internal Rate of Return)	487%	485%
BCR (Benefit-Cost Ratio)	5.64	5.57

Table 10: Summary of key CBA indicators for investing into ISFM.

Due to the low initial investment costs, the net cash flow[5] (Figure 34) is positive from the second year onwards, at almost FCFA 3.5 million per ha. Over the years, it still increases under both scenarios, while the SSP126 scenario performs slightly better over time. The highs and lows in the figure express the fluctuating yields and, accordingly, the fluctuating farmer income.

Consequently, the extraordinarily high cash flow can also be explained in our model by the enormous differences in earnings between the non-adaptation and adaptation scenarios. In 2050, the net cash flow under SSP1-RCP2.6 arrives at 3,743,976 and the net cash flow under the SSP3-RCP7.0 scenario at 3,612,574.

5) As required by a CBA, the net cash flow refers only to the investment made and subsequently changing production variables, not to the entire cassava production system.

Impacts on cassava cultivation	Trend past	Trend future	Confidence
Suitability	-	SSP1-RCP2.6 Relatively stable SSP3-RCP7.0 Relatively stable	High
Yield	Decrease	SSP1-RCP2.6 Decreasing by 35% in 2090 SSP3-RCP7.0 Decreasing by 40% in 2090	Medium to high
Potential yields under ISFM	-	SSP1-RCP2.6 Increasing SSP3-RCP7.0 Decreasing	Medium to high
Cost-benefit-analysis (CBA) of ISFM for cassava	-	SSP1-RCP2.6 Increase NPV 74.588,373, IRR +487%, BCR 5.64 SSP3-RCP7.0 Increase NPV 73,473,560, IRR +485%, BCR 5.57	-

Table 11: Summary of climate change impacts on conventional cassava yields and cassava yields with ISFM.

6.3.3 Co-benefits and challenges

With the initial investment costs of ISFM being relatively low, additional yields and economic gains are directly benefitting smallholder farmers. Based on data suggesting that the fertilizing effect of *Tithonia* and *Mucuna* is enormous compared to unfertilized cassava cultivation and, according to our yield projections, leads to a yield increase of around 200%, the measure proves to be extremely profitable.

However, it must not be forgotten that the workload for the application of *Tithonia* is extraordinarily high with 200 days for one hectare and is only affordable because it is remunerated relatively low. Especially in the case of *Tithonia*, the huge biomass amount needed and the related labour cost required for collection, transportation and application represent a major constraint for the use of organic materials based on *Mucuna* and *Tithonia* biomass (Ngosong et al., 2015). This negative economic effect resulting from *Tithonia* application due to high labour costs stays problematic even if weeding is reduced to almost zero by cultivating *Mucuna* as cover crop on the same field.

Labour and transportation costs of *Tithonia* could be reduced by planting close to the farm site. Although *Tithonia* is widely distributed and available for free on abandoned lands and roadsides in Cameroon, the targeted cultivation near the farm-side could still enhance availability and reduce associated costs (Ngosong et al., 2015). In terms of food security, especially the cultivation of *Mucuna* has additional benefits for small-scale farmers as *Mucuna* represents an additional potential food source. It can help to compensate critical food shortages throughout the year and broaden the food base for farmer households. Furthermore, targeted *Mucuna* cultivation gives farmers the opportunity to spread risk in times of crop failure, as e surplus produce can be sold at the market. This aspect does also explain the very high benefits from *Mucuna* and *Tithonia*-based ISFM in the context of Cameroon, as presented in our calculations above.

6.3.4 Opportunities for women and other social groups in the adoption of ISFM as an adaptation strategy

Previous studies on the effect of gender on the adoption of ISFM in Cameroon are limited. Studies from Ethiopia and Zimbabwe emphasize in particular the high labour requirements that come with ISFM (Hörner & Wollni, 2022; Rusinamhodzi, 2015). Hörner and Wollni (2022) found that while ISFM increased productivity, it also increased the number of labour days per hectare from 139 to 169 days, where three core practices of ISFM – organic fertiliser, inorganic fertiliser and improved varieties – were applied. Accordingly, different scholars consider high labour requirements as a major constraint for women to adopt ISFM practices. For example, Jaza Folefack (2015) studied composting in the Yaoundé region of Cameroon and found that more men than women adopted composting, ascribing this difference to the need for moving heavy and bulky compost, compared to other types of fertilisers which were lighter (Jaza Folefack, 2015). Similarly, in a study of ISFM in Tanzania, female household heads tended to either not adopt ISFM practices or to focus on one ISFM practice only, compared to male household heads, who adopted multiple practices at a time, with high labour requirements given as a reason for this difference (Kihara et al., 2022). The authors of the ISFM study also found that more men than women adopted soil and water conservation practices, explaining this difference with predominantly male land ownership in the country (ibid). Similar constraints are likely to be faced in Cameroon, where only few women own land (Pemunta, 2017).

6.4 Summary

Showing spatial and temporal disparities, over 30% of yield losses for cassava are projected for AEZ I and II by the end of the century under the SSP3-RCP7.0 scenario. Significant positive cassava yield effects are projected in the AEZ III, IV and V under SSP1-RCP2.6. Crop models show that the areas suitable for cassava will remain stable. ISFM can be highly recommended for smallholder farmers, resulting in very positive effects for societies and environment.

7. Assessment of climate impacts and adaptation option for cocoa

Cameroon is part of the so-called "West African cocoa belt" that is stretching from Sierra Leone to southern Cameroon. The cocoa belt produces 70% of the world's cocoa *(Theobroma cacao)*, employing an estimated two million farmers (Schroth et al. 2016). Cocoa is mainly produced as a cash crop for export in Cameroon's Centre, South and South West regions with an average farm size of 5.7 ha (Alliance of Bioversity International and CIAT et al. 2020). Cameroon is currently the world's 5th-largest producer of cocoa, but the sector's relative importance has diminished considerably due to poor producer prices and cuts to fertilizer and pesticide subsidies, leading to a shift from cash crops to food crops for many smallholders (Kumase et al. 2010; Mukete et al. 2018). Still, cocoa accounts for about 14% of the country's non-oil exports (Mukete et al. 2018). Yields are well below their potential of 2-3 t/ha at an average of only 400 kg/ha, due to a lack of inputs, labour, agricultural services and governmental support as well as poor organization of producer cooperatives (Alliance of Bioversity International and CIAT et al. 2020; Nfinn, 2005) coupled with the advanced age of many trees (Wessel & Foluke Quist-Wessel, 2015). Damages due to pests, diseases and post-harvest losses are routinely estimated to account for 30% of production (Mukete et al. 2018; Nfinn, 2005). Increases in production are thus mostly reached through expansion of farm areas, leading to widespread deforestation (Wessel & Foluke Quist-Wessel 2015). Climate impacts on cocoa cultivation differ widely between different countries and regions: Models predict limited suitability for current cocoa producing areas in Africa, for example, Côte d'Ivoire, while in other areas, the climatic suitability for growing cocoa might increase, for example, the Kwahu Plateau in Ghana (Läderach et al., 2013; see also Ofori-Boateng, 2012).

7.1 Crop suitability assessment and changing climatic conditions

Currently, 68% of the country is climatically suitable for cocoa production, covering the AEZs III, IV, mainly Zone V and southern parts of the (Guinean) High Savannah Zone II. The projections (see Chapter 1) indicate high increases in temperature in Cameroon, especially for the high emissions scenario (SSP3-RCP7.0), which will have a considerable impact on cocoa suitability in the long term (Figure 35). Only marginal decreases and slightly positive suitability changes, e.g. in the (Guinean) High Savannah Zone (II), are projected in the near and mid future. These findings concur with projections by Schroth et al. (2016) which show that due to its equatorial location, cocoa suitability in Cameroon will be only marginally influenced by climate change up to 2050, compared to other cocoa producing regions in Western Africa. In addition, the slight increases in the (Guinean) High Savannah Zone (II) could provide a potential to further expand the current cocoa plantation outside the traditional cocoa producing regions.

We therefore project a slight northward extension of the suitable areas for cocoa under both scenarios. However, under the high-emissions scenario, it will increasingly become difficult to produce cocoa in the traditional production areas where suitable areas will decrease by more than 42% (Table 12). This is also reflected by the net changes, which are pointing to a slightly negative trend under the low-emissions scenario, but rapidly deteriorating trend under the high-emissions scenario (Figure 36). Therefore, technical and policy adaptation plans are required to maintain agricultural production at current levels.

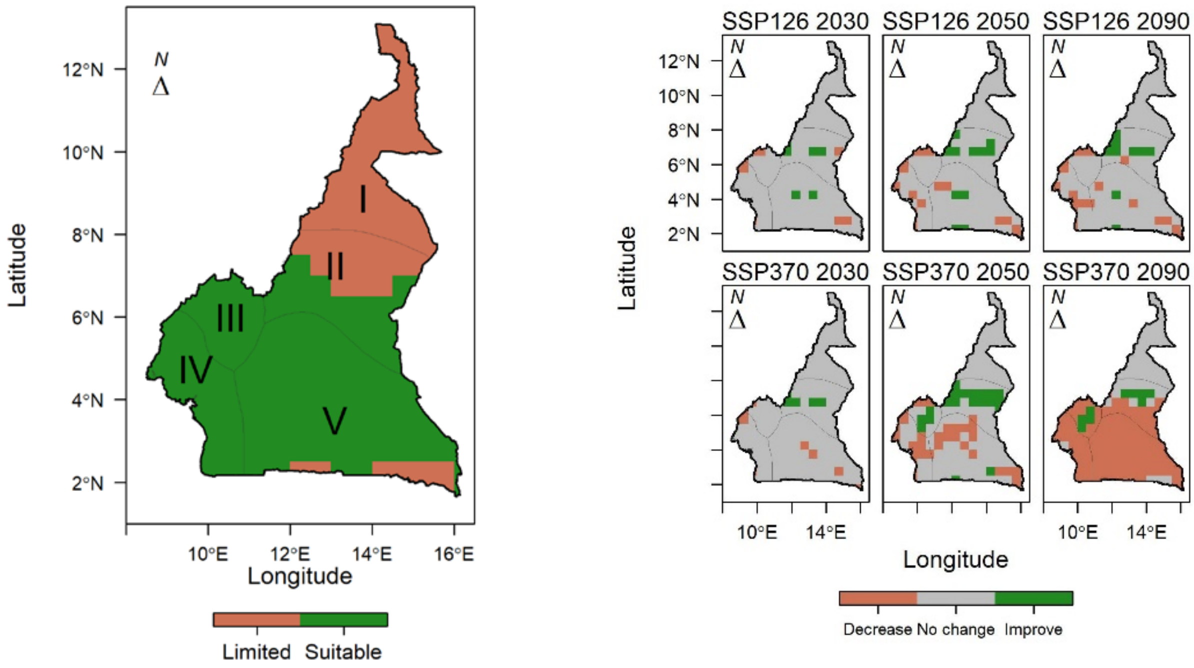

Figure 35: Current suitability (a) and projected changes in climatic suitability (b) for cocoa in Cameroon for the 2030s (left), 2050s (middle) and 2090s (right) under the SSP1-RCP2.6 (upper row) and SSP3-RCP7.0 scenarios.

7.2 Adaptation option for cocoa: agroforestry systems with fruit trees

Agroforestry can be defined as a 'practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions' (Burgess, Graves et al. 2019). The association with shading trees can provide various co-benefits, such as improved pollination (De Beenhouwer et al. 2013), long-term stability of yields (Bisseleua et al. 2013), carbon sequestration through an amendment of soil organic matter (Schroth et al. 2013) (Jagoret, Deheuvels et al. 2014), improved soil fertility (Mbow, 2014) and contribution to afforestation (Jagoret, Michel-Dounias et al. 2011). In terms of climate change risk mitigation potential, the overstory trees within an agroforestry system can regulate the microclimate (temperature and moisture regimes) or mitigate the negative effects of climate extremes on the understory trees or crops (Chemura, Kutywayo et al. 2022, Mbow, Smith et al. 2014).

> Agroforestry can mitigate climate change impacts and provides various co-benefits such as improved soil fertility.

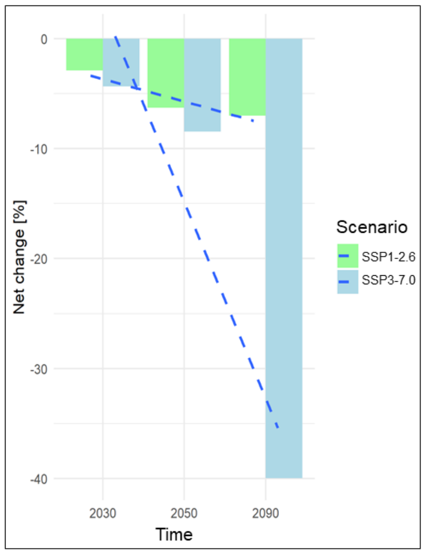

Figure 36: Net changes in cocoa suitability.

Scenario	Year	Decrease	No change	Improve
SSP1-RCP2.6	2030	6.05	90.8	3.15
	2050	9.69	86.92	3.39
	2090	10.17	86.68	3.15
SSP3-RCP7.0	2030	7.03	90.31	2.66
	2050	14.29	79.9	5.81
	2090	42.37	55.21	2.42

Table 12: Changes in cocoa suitability [%] under climate change.

In Cameroon, most of the cocoa production is traditionally already associated with trees, either in natural forests or in orchards with fruit, medical or timber trees. Either the farmers preserve some native forest tree species that have grown naturally in the plots, such as *Ceiba pentandra L., Erythrophleum ivorense A. Chev.* and *Milicia excelsa Berg*, for shade but also for their economic and fertilising potential or they plant fruit trees such as orange (*Citrus sinensis*), safou (*Dacryodes edulis*), avocado (*Persea americana Mill.*) and cola (*Cola nitida Vent.)* alongside the cocoa trees for their fruit production (Asare, 2005). The Safou tree is for instance a common agroforestry tree that has a lot of nutrition benefits and provides shading (Ayuk, Duguma et al. 1999). Although cocoa production is a major driver for deforestation in Cameroon, setting up cocoa-agroforestry systems can thus also contribute to afforestation, for instance in the savannah region with its naturally rather treeless landscape and grassland (Jagoret, Michel-Dounias et al. 2011). Interestingly, some studies are underlining the idea that resilient land use planning should rather consider intensification of cocoa and preservation of forests separately (Alemagi et al., 2015; Gockowski & Sonwa, 2011). Traditional agroforestry systems are still assumed with low cocoa productivity, however, studies in Cameroon showed that the productivity of cocoa associated with service trees remains comparable with monoculture systems and additionally providing carbon sequestration up to seven times the value compared to monoculture (Saj, Durot et al. 2017).

With regard to adaptation planning in Cameroon, agroforestry is indicated in various national strategies such as the PNIAC (National Investment Plan for Adaptation to Climate change) as promising option to reduce vulnerability of ecosystems towards climate change (MINEPDED, 2015). Furthermore, the framework for deforestation-free cocoa production signed by Cameroonian government (MINADER, MINFOF, MINCOMMERCE, MINEPDED), private sector and civil society organization (e.g. GIZ, WWF Cameroon) and research has been established to promote cocoa agroforestry systems as an alternative to cocoa monoculture (without shading trees) (Framework for Action, 2021).

Besides its benefits, agroforestry can foster inter-species competition depending on the distance between the associated tree and cocoa tree, which can have a negative influence on the cocoa productivity (Saj et al. 2023). Therefore, adequate management practices are key for its economic output: optimal planting density and regular pruning of the associated trees (e.g. twice a year) have positive effects on the shading of the cocoa plants and their resulting yields. Successful agroforestry therefore depends on diligent and knowledgeable management practices of the farmers (Andres et al., 2016; information from local consultant). Furthermore, in order to better understand the appropriate management and potential trade-offs between cocoa and associated trees in Sub-Saharan Africa, more research is needed especially on endemic species (Saj, Durot et al. 2017). For successful implementation of this adaptation strategy, institutional support is needed. For instance, the development of cooperatives to share costs and exchange knowledge on management techniques and how to access markets is reported to have a high positive impact on the adoption of agroforestry (Asaah et al. 2011).

7.2.1 Suitability assessment and indications for land use planning

As cocoa is traditionally cultivated in association with shading trees, it is important for land use planning to assess not only cocoa suitability itself but to consider a system (Singh, Behera et al. 2022). In this study we defined the agroforestry system through the integration of common fruit trees, namely safou or mango. Figure 37 shows the potential for cocoa agroforestry systems based on the combined suitability of cocoa and the respective fruit tree. More than half of the country is suitable for cocoa agroforestry systems based on the Safou, and almost 50% of the country is suitable for systems based on mango, both covering more than 70% of the suitable areas for cocoa production. Both trees have limited suitability for the High Plateau (West Highlands) Zone (III) and the Monomodal (Rain) forest Zone (IV). The interaction of high monthly rainfall and higher annual mean temperature compared to other zones determine the limitation for the fruit trees. However, other trees might be suitable here.

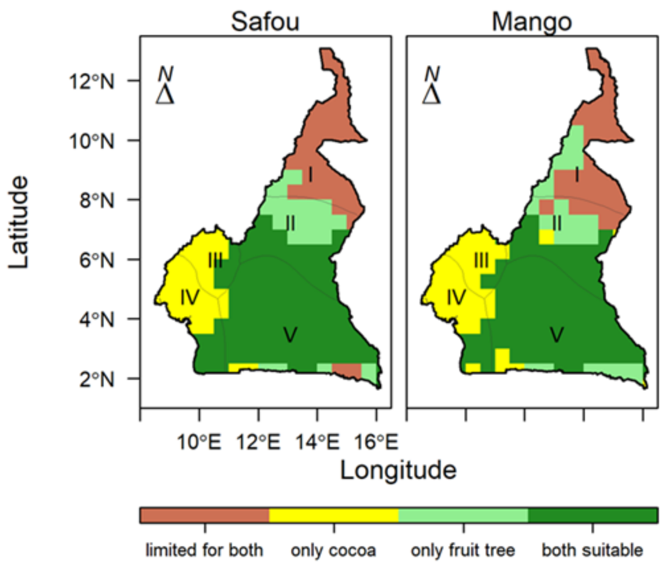

Figure 37: Current suitability for cocoa agroforestry systems with Safou tree

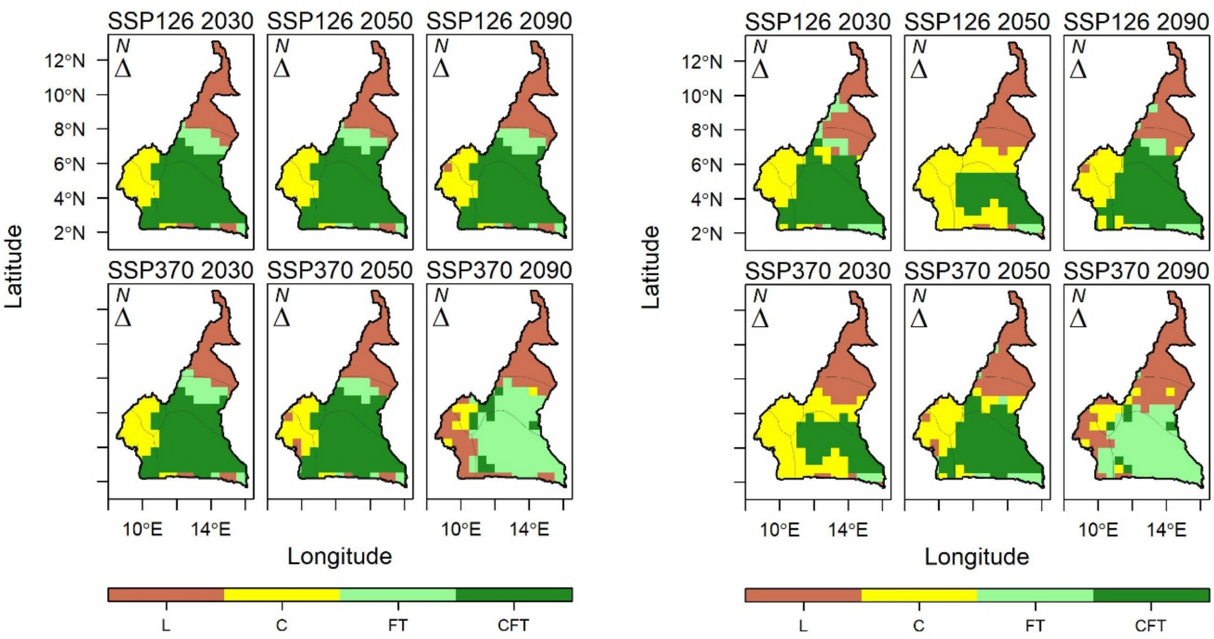

Figure 38:Projected suitability (a) for cocoa agroforestry systems with Safou plum tree (Dacryodes edulis) and mango tree (Mangifera indica) (b) in Cameroon for the 2030s (left), 2050s (middle) and 2090s (right) under the SSP1-RCP2.6 (upper row) and SSP3-RCP7.0. L(limited for both), C (only suitable for cocoa), FT (only suitable for fruit tree), CFT (suitable for both).

The future projections (Figure 38 and Table 13) point out that the area for the safou tree remains very stable under both scenarios which underlines its potential within a cocoa agroforestry system to mitigate potential negative effects of climate change on cocoa. Both safou and mango are suitable for long-term adaptation, whereas mango will be more limited in the short term (2030) and middle (2050) term.

As seen in the previous analysis, a geographical shift and decrease of cocoa production in Cameroon caused by climate change appears likely and this brings up the demand on decision support for adaptation planning.

Fruit tree	Scenario	Year	Both suitable	Only cocoa	Only fruit tree	Both limited
Safou	SSP1-RCP2.6	2030	52.03	15.54	9.46	22.97
		2050	54.05	15.54	8.78	21.62
		2090	52.70	14.86	9.46	22.97
	SSP3-RCP7.0	2030	52.70	15.54	10.14	21.62
		2050	54.05	13.51	7.43	25.00
		2090	7.43	5.41	49.32	37.84
Mango	SSP1-RCP2.6	2030	47.30	20.27	8.78	23.65
		2050	25.68	43.92	2.03	28.38
		2090	47.30	20.27	7.43	25.00
	SSP3-RCP7.0	2030	26.35	41.89	2.03	29.73
		2050	28.38	22.30	4.05	28.38
		2090	4.05	8.78	46.62	40.54

Table 13: Projections for suitability of cocoa agroforestry systems.

Figure 39: Net cash flow in FCFA per hectare up to 2050 for investing into the establishment of fruit trees in a cocoa plantation.

7.2.2 Cost effectiveness

To assess the economic feasibility of introducing different fruit trees into cocoa production, the following CBA compares the costs and benefits of the investment with a conventional cocoa production system without agroforestry. Since no consistent data set could be found for the individual regions under investigation, we created national averages that are based on different data sources.

> Benefits generated through agroforestry systems are more than 7 times higher than its costs. Investments into agroforestry systems are also profitable in the long run as they have the potential to increase not only yields, but also create additional income streams for farmers.

The investment in stocking a cocoa plantation with fruit trees is worthwhile and pays off in the sixth year. As shown in Table 14, all key parameters are positive. At a rate of return of 89%, the NPV in 2050 is 22,210,376 CFA (any positive NPV indicates a profitable investment). Also, the benefits exceed the costs many times over, which is well reflected in the BCR of 7.56. The extremely positive results can be attributed to the fact that in our model, an additional income can be generated by marketing the fruits. Since the care of the trees can be shared to a large extent with the care of the cocoa plantation, only low additional costs are incurred here. The 12% increase in cocoa yields further magnifies the benefit. However, the values presented within this CBA must always be considered and interpreted in the light of the assumptions made, otherwise the results could be misleading.

	Adaptation
NPV (Net Present Value)	22,210,376
IRR (Internal Rate of Return)	89 %
BCR (Benefit-Cost Ratio)	7.56

Table 14: Summary of key CBA indicators for investing into agroforestry fruit trees in cocoa production.

The net cash flow[6] (Figure 39) is negative in the first year due to the initial investment in planting the fruit trees for the agroforestry system. In the second year, it is already zero and from the fifth year onwards it is positive with a net cash flow of 30,773 FCFA per year and hectare. The reason for the delayed income gain is that the fruit trees must grow for a certain time before providing sufficient shade for a positive effect on the cocoa yields. In addition, during this time, they do not bear any fruits, or only very few. Only from the fifth and sixth year onwards, the model assumes a first income generated from fruit sales. The cash flow increases steeply from then on and reaches its peak in 2033. At that point in time, the fruit trees have reached their full size and the highest possible yield. From that point onwards, the cash flow remains stable.

However, in the even more distant future, it must be assumed that yields will either go down due to the aging of trees – or that the then old fruit trees will have to be replaced, which will lead to new investment costs. These costs might reduce the cash flow until the re-planted trees reach their full yielding potential.

6) As required by a CBA, the net cash flow refers only to the investment made and subsequently changing production variables, not to the entire cocoa production system.

7.2.3 Co-benefits and challenges

As shown by Lanre et al. (2020), cocoa farmers in Western Africa are facing a number of other challenges, in addition to changing climatic conditions that can hinder the potentially positive economic impact of an agroforestry system. According to the authors, the main constraints for cocoa farmers in general include price instability, poor road networks and limited access to land. As confirmed by local experts, a lack of infrastructure to quickly access the market for selling the perishable fruits can be a disincentive for farmers to strengthen agroforestry with fruit trees. This can also mean that additional costs for adequately storing the perishable fruits on the farm or additional costs for transport to the next market could be relevant for the total cost calculation. Also, problems like limited access to extension services can hinder the effective implementation of innovative solutions like agroforestry on the ground. Thus, strengthening capacity building and knowledge transfer for farmers regarding the effective management of agroforestry systems will positively support their long-term success. Concerning further inputs, we recognize the need for fertilizer and pesticide application for maintaining agroforestry systems, even though according to local experts not all farms apply fertilizer for their production. Literature as well as local experts suggest that a saving of chemical fertilizer and pesticides can be achieved through the agroforestry system. However, no concrete numbers could be determined for this specific effect. Therefore, this potential cost-saving effect is not monetized in the context of this analysis.

On the other hand, there are also a number of additional positive benefits: For example, the establishment or participation in cocoa farmers' cooperatives can lead to lower costs regarding transport of farm products, machinery and labour, since related costs can be shared by a group of farmers (Madsen et al. 2020). According to local experts, after a certain amount of time, the wood of the fruit trees (dead wood or through pruning) can also be used as an energy source or for medical purposes, which is a positive side effect in particular for women who otherwise tend to invest a lot of work in the collection of firewood.

In addition, a number of cultural and socio-economic restraints might need to be overcome for initiating the planting of fruit trees in the cocoa orchards. As explained by Jaza Folefack et al. (2021), local traditions and customs in certain areas of Cameroon encourage farmers to preserve old tree species as they are considered homes to the ancestors and important for the protection of the village from unlucky events. This might prevent farmers from seeding more productive new fruit trees. According to a local expert, other reasons for keeping old and big trees although they are unproductive, are that farmers are afraid that cutting big trees would damage the cocoa trees (especially in mature cocoa plantations). Other socio-economic reasons can also hinder the planting of productive fruit varieties, such as, farmers' high illiteracy rate or a low educational level. Jaza Folefack et al. (2021) also report that some farmers maintain existing, lower-yielding agroforestry systems, due to short-term financial and labour concerns, without considering the long-term benefits of planting new fruit trees. Thus, it is important to provide information on the long-term economic benefits of agroforestry systems and support with initial investment costs.

Impacts on cocoa cultivation	Trend past	Trend future	Confidence
Suitability	68% suitability in the country's territory	SSP1-RCP2.6 Decrease -6.05 to -10.17% SSP3-RCP7.0 Decrease -7.03 to -42.37%	High
Projected suitability of cocoa agroforestry systems	Safou and mango covering more than 70% of the suitable areas for cocoa production.	Safou SSP1-RCP2.6 Relatively stable SSP3-RCP7.0 Relatively stable	High
		Mango SSP1-RCP2.6 Varying SSP3-RCP7.0 relatively stable in the long term	High
Cost-benefit-analysis for investing into agroforestry with fruit trees	-	Increase NPV 22,210,376 IRR +89% BCR 7.56	

Table 15: Summary of climate change impacts on cocoa suitability and the potential for agroforestry.

7.2.4 Opportunities for women and other social groups in the adoption of agroforestry as an adaptation strategy

Gender and other social factors can influence the adoption of agroforestry as a climate adaptation strategy. The following aspects refer not only to cocoa-agroforestry systems but rather in general the agroforestry practise. A study from Cameroon shows that more men than women tend to adopt agroforestry (Ngaiwi et al., 2023), a trend which can be also observed in other parts of Africa (Gachuiri et al., 2022). This difference may be linked to different barriers, including access to land, decision making, labour, finance and cultural taboos (Kiptot & Franzel, 2011). In many rural contexts in Cameroon, women typically do not have control over land, due to largely patrilineal inheritance systems (Pemunta, 2017). Hence, limited control over land, along with the long-term returns of agroforestry, can discourage women to engage in this practice. A study conducted in Uganda showed that women were less familiar than men when it came to the boundaries of plots, which is an important factor for the design of agroforestry systems (Kalanzi et al., 2021). Furthermore, limited decision-making power puts women at a disadvantage, for example, when having to ask for permission to plant a tree or when negotiating over species preferences. Since women tend to be in charge of household food security and health, they usually have a higher preference for trees which produce fast-growing subsistence products like fruits, medicine or fodder, while men show a higher preference for species which grow straight and can provide high-value products like timber for income generation (Kiptot & Franzel, 2011). According to an ICRAF report, men also tend to have greater control over these resources, with women having limited access to these resources and related economic benefits (Kiptot & Franzel, 2011). Women's access to managing agroforestry systems may also be restricted by cultural norms: Agroforestry systems with larger trees require activities like climbing on trees, for example, for the cutting of twigs, which is considered to be an indecent practice for women of certain communities in Western Africa (ibid). Hence, to foster the adoption of agroforestry by women, in particular access to land needs to be improved, in addition to greater decision-making power in the design and management of agroforestry systems.

> To foster the adoption of agroforestry by women, access to land needs to be improved, in addition to greater decision-making power in the design and management of agroforestry systems.

7.3 Summary

In conclusion, the association with fruit trees has significant potential as an adaptation strategy for cocoa production in Cameroon. By combining the cultivation of trees with cocoa, farmers can mitigate the impacts of climate change, improve soil fertility, and increase biodiversity. The selected trees Safou tree (*Dacryodes edulis*) and mango tree (*Mangifera indica*). show in the long term the potential for association with cocoa trees, however, especially the areas suitable for mango will vary in the short and mid-term. With the right support and incentives, agroforestry can help to ensure the long-term sustainability of cocoa production in Cameroon while also providing a range of other environmental and economic benefits.

8. Conclusion and policy recommendations

This study provides a comprehensive climate risk analysis for Cameroon' agricultural sector with the aim to offer an in-depth decision-basis for national and local decision-makers on current and future climate risks for agricultural production to guide suitable adaptation planning and implementation in the country.

Both, the NDC and NAPCC point out that agriculture is the sector most vulnerable to climate change, as rain-fed agriculture predominates making it highly sensitive to variations in rainfall and drought. Especially the NAPCC promotes several strategies and recommendations to help reduce the sector's vulnerability to the negative effects of climate change. The NAPCC underlines that farming systems shall be improved through agronomic research, dissemination of research finding and the promotion of good practices with adaptation potential.

This climate risk analysis provides thus information on the projected impact of climate change on different selected crops as well as the grassland productivity to contribute to availability of robust data on the vulnerability of the agricultural and livestock sector, for instance on forage availability (grassland) in pastoral areas as mentioned in the NAPCC. Furthermore, the study assesses the risk mitigation potential for specific adaptations strategies such as improved seeds (see heat tolerant maize variety), soil management techniques (see ISFM for cassava production) and agroforestry (see agroforestry in cocoa production) that are highlighted in the NAPCC and other national strategies as well as selected by the stakeholders during the Kick-off workshop in Yaoundé.

Climate change models show a clear trend projecting a continuous increase in temperature, as well as an increase in the frequency of temperature extremes, such as hot days and nights, which can limit crop growth or even lead to crop failure and also negatively impact the aggregation and processing of the crops. In response to increasing greenhouse gas concentrations, mean annual temperature is projected to increase by 1.1°C under the low emissions scenario and 1.5°C under the high emissions scenario by 2050, compared to 2004. Precipitation projections are much more uncertain than temperature projections. Even though the majority of climate models point to a slightly wetter future climate in Cameroon, it cannot be ruled out that the country could experience a drier future climate in parts of the country, as some models suggest. Similarly, precipitation extremes, are projected to increase, but not all models agree on this trend.

Climate change is expected to significantly impact agricultural production. While showing spatial and temporal disparities, climate change is projected to negatively affect maize, cassava and cocoa yields. Maize yields will decrease in AEZ I up to -84% by 2090 under SSP3-RCP7.0 and over 30% of yield losses for cassava are projected for AEZ I and II by the end of the century under the SSP3-RCP7.0 scenario. Significant positive cassava yield effects are projected in the AEZ III, IV and V under SSP1-RCP2.6. Crop models show that the areas suitable for maize and cocoa will decrease in Cameroon, especially under SSP3-RCP7.0, while the suitability for cassava will remain relatively stable. Regarding the livestock sector, it seems very likely that the grazing potential will decrease under both climate change scenarios with higher decreases under SSP1-RCP2.6 than under SSP3-RCP7.0.

Based on the projected impact analysis, we analysed three adaptation strategies: improved maize varieties, integrated soil fertility management for cassava and agroforestry systems for cocoa production. We consider aspects of risk mitigation potential, cost-effectiveness and gender as part of our analysis of adaptation options. The assessment indicates that all selected strategies are promising adaptation strategies. Particularly, ISFM can be highly recommended for smallholder farmers, resulting in very positive effects for societies and environment. Improved seeds have a high potential to improve livelihoods, but is also a support-intensive adaptation strategy. Lastly, agroforestry has a potential to reduce the impact of climate risks on cocoa production, but future climatic suitability needs to be considered.

Generally, there is no single adaptation strategy that is suitable for the whole country, since their effectiveness and co-benefits ultimately depend on the projected climate impacts, as well as on the concrete design tailored to the local context and farmers' needs. The actual impact of the projected climatic changes is not only shaped by the actual hazard, but also by the vulnerability and exposure of the affected farming communities. Differing social characteristics like gender, age, education and health can substantially shape farmers' vulnerability and therefore their exposure to climate change. Taking these characteristics into consideration is an important prerequisite to build resilience across farming communities.

Furthermore, having access to actionable climate information can help farmers to make informed decisions for appropriate adaptation strategies and reduce the impact of climate risks. Moreover, differing social characteristics like gender, age, education and health can, for example, substantially shape farmers' vulnerability and therefore their exposure to climate change. Taking these characteristics into consideration is an important prerequisite to build resilient agricultural production systems.

Furthermore, planning for adaptation should be **regionally specific**, as different areas in Cameroon will be impacted by climate change differently. For instance, the Northern region (AEZ I) will be particularly hard hit and should therefore require special attention.

Based on the findings of this study, the following **policy recommendations** are suggested:

Enhancing the resilience of maize production

- The introduction of improved (heat tolerant) seeds is one option to buffer the projected impacts of climate change on maize production. Ideally, improved varieties are promoted that fulfil several conditions, such as farmer's preference, local suitability, agronomic management and that are available and accessible also for smallholder farmers.

- Equitable access to improved seeds, required inputs and knowledge should be ensured with a particular emphasis on the socio-economic differences of farmers. This may include rapid breeding cycles that provide farmers with a steady stream of improved varieties, information campaigns on the benefits of improved varieties under climate change and building a seed systems model that delivers new varieties to farmers quickly and cost-effectively.

- At the same time the research and promotion of other crops, such as sorghum, should be promoted, that are naturally more nutritious and resistant to the effects of climate change than maize.

Enhancing the resilience of cassava production

- ISFM based on a biomass transfer through the wild plants Mucuna and Tithonia is a promising adaptation strategy under all future climate change scenarios for cassava production in Cameroon and could be beneficial for all regions in the country to manage soil fertility to be able to cope with climate stress.

- Awareness raising and training on the advantages and implementation of ISFM support the effectiveness of this strategy which is relatively time consuming for farmers.

- The consideration of the technology in education and extension programs can also help to support the effective dissemination. Policies towards sustainable land use intensification, as well as the rehabilitation of degraded soils and the necessary mechanisms to implement and evaluate these can help to promote the uptake of ISFM.

- Research on innovative ISFM practices as well as the dissemination of the results can improve the effectiveness of the technology and further strengthen the adoption rate.

Enhancing the resilience of cocoa production

- In the context of cocoa production in Cameroon, **agroforestry** is a traditional practise offering multiple benefits, such as reducing the impact of extreme temperature on cocoa trees through shading, improving soil health, increasing biodiversity, and thereby improving the quality of cocoa. Considering fruit trees as companions for cocoa is also worthwhile for their provision of food and potential for generating additional income. However, the type of tree species and intercropping should be carefully selected, based on local current and future suitability, preferences and opportunities for additional income.

- Tree density should be carefully chosen, and agroforestry set up planned according to the local context, considering possible rivalries over land use.
- The optimal level of shading is an important factor in the setup of agroforestry systems and requires continuous maintaining such as pruning.
- The provision of tree seedlings and trainings on establishment and management of agroforestry systems should be provided to farmers.

Enhancing the resilience of livestock production

- Grazing potentials for livestock will slightly decrease under both future climate change scenarios. Adaptation strategies such as mowing or a pastoral calendar could be promising option to provide and manage fodder reserves, but needs to be researched.
- Considering the current state of security in the country as well as the greater region, along with its low adaptive capacity to the effects of climate change, adaptation projects need to **consider conflict dynamics**. Policy makers should pay special attention to the needs of marginalized communities in agriculture. Transhumance infrastructure is key to elevating much of the underlying intercommunal tensions.

Creating an enabling environment to scale up adaptation efforts

Next to the adaptation strategies which are presented and analyzed within the framework of this study, there are of course further strategies to adapt agricultural production to climate change, which might be even more suitable, cheaper or better implementable, depending on the given circumstances. Agricultural farms are complex systems that require a targeted and tailored design of management practices. Regardless of the specific climate risks addressed, combinations of adaptation strategies are often more effective than single approaches. To avoid negative side effects, each combination should be carefully assessed. In order to create an enabling environment for implementation and upscaling, further recommendations can be derived:

- **Rich and diverse indigenous and traditional knowledge** exists on adaptation in Cameroon's regions, which should be seized for successful adaptation. However, more research into this is needed as well as re-activation of formerly practiced indigenous adaptation strategies, which have partly lost traction in the past decades.
- Farmers need support in **bridging the financing gap** between investment and the break-even point, when the adaptation strategy becomes profitable. In some cases, such as agroforestry, this can take a couple of years. In other cases, such as improved seeds, it requires high upfront investments for seeds and special input. This requires transitional financial support.
- **Research and development** are at the core of innovative, climate-resilient agriculture. Regular investments into national research institutes needs to be upscaled. Adaptation research should be mainstreamed into extension services and university curricula.
- Adaptation strategies should not be developed in isolation, but rather **in collaboration with stakeholders**, including farmers, researchers and policymakers, but also other stakeholders across the value chain. Communities should be engaged at all planning stages, for instance through community conversation sessions. Collecting gender-disaggregated data is key to design gender-responsive adaptation strategies. This would ensure that the strategies are context-specific, inclusive, and sustainable, and would increase their chances of success.
- The implementation of the adaptation strategies should be supported financially by for instance the Global Environment Facility, the Green Climate Fund, NGOs, technical and financial partners.
- The study was designed in alignment with important policy documents and processes in Cameroon, in particular the Climate Change Policy, the Climate Change Act and the Nationally Determined Contribution (NDC) and the National Adaptation Plan for the Agriculture Sector (NAP). Results from this climate risk analysis can thus feed into further development and implementation of **climate adaptation policies and agricultural development planning**.

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