Staple Crops Processing Zone (SCPZ): Promoting Sustainable Agricultural Value Chains.

CLIMATE RISK AND VULNERABILITY ASSESSMENT

African Development Bank

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EXECUTIVE SUMMARY

Climate change is among of the greatest challenges facing humanity in the twenty-first century. Energy and agriculture are two of the priority sectors that are at risk from climate change – the latter is the most at risk. This study examines the vulnerability of seven staple crop processing zones (SCPZs) in Togo (Kara and Niamtougou), Guinea (Boke and Kankan), and Senegal (Kolda, Velingara, and Ziguinchor) to the effects of climate change on agriculture and energy. Using the index method, the vulnerability matrix is displayed with eleven indicators spread across the three categories of exposure, sensitivity, and adaptive capacity.

The degree of vulnerability in the agricultural and energy sectors is measured and divided into four categories: very low to low, low to moderate, moderate to high, and high to very high. The findings indicate an inverse relationship between vulnerability and adaptive capacity, with the latter having a considerable influence on the former. The majority of the SCPZ was found to have medium to high agricultural vulnerability in the current and future climates, except for Boke and Kankan. Between the middle of the 21st century and its conclusion, Boke exhibits high to very high vulnerability under RCP8.5 as well as over the long term under RCP4.5. Similarly in Kankan, RCP4.5 predicts high to very high vulnerability over time, but RCP8.5 predicts that this condition will persist well into the next century. Results from Guinea clearly show how poorly adapted the two regions are. This emphasizes the need for greater adaptability to make the area more resilient and less vulnerable. For energy, the vulnerability assessment revealed that most SCPZs are moderately to highly vulnerable to climate change. On the other hand, a select few areas are extremely vulnerable, particularly at the turn of the century. This suggests that because of climate change, energy production and transmission in SCPZs will continue to face increasing challenges.

In addition, future projections of increased heat stress, increased frequency, and severity of water stress (drought) events and altered precipitation patterns indicate that the SCPZs will face numerous difficulties in the production and delivery of energy. Pressure will be placed on the generation and transmission of thermal, hydroelectric, and fossil fuel energy. As a result, adaptation techniques like the use of renewable energy are required. The findings of this study offer valuable data for planning and formulating policies to support farmers and build the resilience of agricultural value chain in SCPZs.

1. INTRODUCTION

1.1 The Project

The Staple Crops Processing Zone (SCPZ) program is specifically designed to assist program countries in rationalizing interventions in the agriculture sector toward activities that contribute to emission reduction from agricultural activities and improve agroecosystems, agricultural assets, and beneficiaries' resilience. The program aims to reduce climate change vulnerability and greenhouse gas (GHG) emissions in four agricultural value chains in three highly indebted poor African countries. Kara in Togo, Southern Agropole in Senegal, and Boké and Kankan in Guinea are among the host regions (Figure 1). This will help to boost productivity and value addition, competitiveness, create jobs, and raise the incomes of the most vulnerable people and communities in these countries. Because the program focuses on smallholder farmers, who dominate agricultural value chains in Africa, there is very little opportunity for these farmers to pay for investments other than operation and maintenance costs. Accelerated investment in the region is needed to address these issues, especially since the onset of the Covid-19 pandemic, which has had a significant impact on the region's economic development.

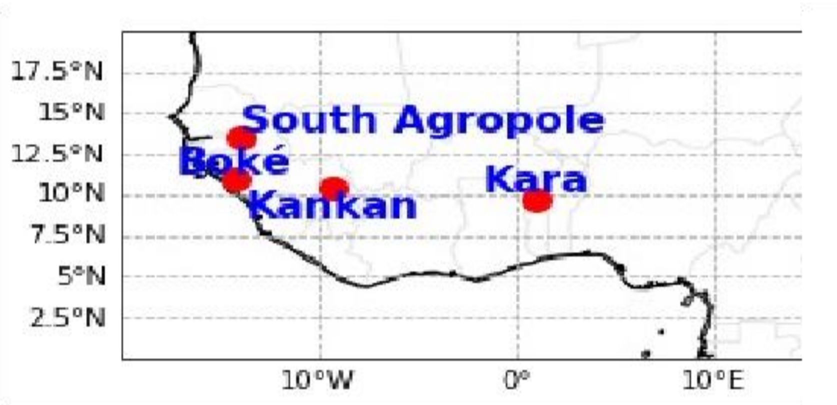


Figure 1 : Map showing the location of the SCPZs

The Green Climate Fund (GCF) funds, along with African Development Bank (AfDB) funds, other program financiers, and contributions from the respective countries, will be used to address critical infrastructure deficits, financial, capacity, and institutional barriers that impede the effective implementation of an integrated approach to climate adaptation and mitigation. The funds will specifically be used to: (i) strengthen the resilience of critical SCPZ value chain infrastructure; (ii) build the resilience of SCPZ agricultural Products Supply Value Chain; and (iii) program management and coordination. The program will invest along agricultural value chains by improving access infrastructure for sustainable agricultural intensification and production of staple crops (such as rice, maize, cassava, banana, sesame, horticulture, mango, cashew, woodlot, vegetables, and others), roads construction, access to water, and small-scale agricultural water management (AWM) infrastructure such as drip and gravity irrigation, as well as equipped boreholes. The program will invest in improving the resilience of SCPZs during the post-harvest and processing stages by utilizing low-carbon energy technologies such as biodigesters and solar PV for processing, lighting, and storage, while during the marketing and transportation stages, the presence of Agro-Processing & Allied Industries Hubs (APHs) and Agricultural Transformation Centres (ATCs) provides adequate infrastructure, logistics, and specialized facilities and services.

1.2 Objective of CRVA

The Climate Risk and Vulnerability Assessment (CRVA) aims to better understand the current and future climate risks that the SCPZs in the host countries face. This will aid in determining the SCPZs' vulnerability to climate-related risks. The CRVA will contribute to the inclusion of adaptation goals and actions that are consistent with the host country's climate action plan. The CRVA seeks to inform design decision making and adapt program infrastructure and investment based on the characterization of historical climate and projected climate change risks to improve program output resilience.

The conventional definition of risk in this assessment is the likelihood of an adverse event and its consequence, with the event being the climate hazard and the consequence depending on the vulnerability of the critical SCPZs agricultural value chain infrastructure and product supply value chain. Because of the nature of the infrastructure, its degree of exposure (e.g., location), and relevant non-climate factors, the agricultural value chain infrastructure is highly dependent on sensitivity factors.

The program interventions were carefully chosen based on the risk and vulnerability assessment to address critical infrastructure deficits, financial, capacity, and institutional barriers that impede the effective implementation of an integrated approach to climate adaptation and mitigation. The SCPZ's resilience will be built on an analysis of observed past climate and projected changes in frequency and magnitude of key climate parameters such as temperature and rainfall, as well as their derivatives such as standardized precipitation index and consecutive dry days.

The assessment was carried out using the following steps below, and the data and methods used are discussed in Appendix I.

i. A desk review of literature and national reports on the sensitivity of SCPZs to specific climate variables (list variables here) that are critical to the performance of the entire agricultural value chain, and how existing agricultural value chain assets are already being impacted by increasing variability and extremes in these parameters under the current climate.
ii. Use of climate model projections to investigate how critical climate parameters are expected to change for different climate periods (i.e., current (2006-2035 and 2011-2040) and future (i.e., 2036-2065 - near future, 2041-2070 - mid-century, and 2071-2100 - far century) relative to a 30-year baseline (1976-2005), including levels of confidence based on model agreement.
iii. Investigate non-climate factors that exacerbate the effects of climate change, such as geographic factors (e.g., proximity to water bodies, topography), geologic factors (e.g., soil nature and characteristics), watershed features (e.g., land use, state of degradation), and relevant socioeconomic drivers.
iv. Assess the vulnerability of critical SCPZ agricultural value chain infrastructure and product supply value chains to climate risk, considering the combined effects of future climate change and related non-climate factors.
v. Identify appropriate adaptation measures to reduce identified risk.

This assessment focuses on the vulnerability of critical value chain infrastructure and agricultural product supply value chain of SCPZs, including Southern Agropole in Senegal, Kara in Togo, and Boke and Kankan in Guinea, under two standard greenhouse gas (GHG) representative concentration pathway (RCP) emission scenarios (i.e., RCP 4.5 and RCP 8.5). The vulnerability assessment is based on the proposed program intervention, the location of the SCPZ and other relevant factors. The program outputs are as follows: (i) strengthening the resilience of critical SCPZ value chain infrastructure; (ii) strengthening the resilience of the SCPZ agricultural Products Supply Value Chain; and (iii) program management and coordination. The assessment will be based on the first two outputs.

2. CLIMATE SENSITIVITY OF THE STAPLE CROPS PROCESSING ZONES (SCPZ)

2.1 Critical Climate parameters

Weather and climate have a significant impact on agricultural production (Gowda et al. 2018; Walthall et al. 2012; USGCRP 2017). Temperatures, precipitation, timing of dry spells or drought onset, length of growing season, soil moisture, pest pressures, and a variety of other climate-related factors influence agricultural productivity and management decisions. When to plant or harvest is an example of a near-term decision that needs accurate climate data; what type of seed to plant for the upcoming growing season is an example of a mid-term decision; and whether to make capital investments, such as building irrigation infrastructure, installing subsurface drainage tile, or planting trees in an agroforestry system is an example of a long-term decision (Hollinger 2009; Prokopy et al. 2013; Takle et al. 2014; Dosskey et al. 2017).

Given that it operates in the complex economic, cultural, and social environment of the larger food system (Walthall et al. 2012), climate has a significant impact on agricultural production and may exacerbate many existing stresses. Measurements or calculations that provide information about the state of an interest system are called indicators, which are of interest here. Temperatures are one example of a direct measurement that can yield an indicator. They could be modeled as crop models used for impact assessment of future crop region migration. Alternatively, they could be derived mathematically from observations or model results, like standardized precipitation index, which is an important indicator for drought detection.

Precipitation and its seasonal distribution are crucial factors in water supply and agriculture projects because they, along with the characteristics of the watershed or groundwater system, determine the amount of water that can be reliably extracted (dependable yield or safe yield). A proxy indicator used to ascertain the need for water storage and other water-conserving measures, as well as the likely recurrence interval of droughts is time series data on the maximum number of consecutive dry days.

The effects of temperature change on water demand, including the rate of water loss to evaporation, and the possibility of heat stress in crops make temperature change important, especially for maximum temperatures.

2.2 Effect of climate parameters on the SCPZs

Among the major climate "hotspots" on the continent are Togo, Senegal, and Guinea, which are in the Sahelian and Sudano agro-ecological zones (AEZs) of Africa. Due to historical warming and rising trends in precipitation intensity, these nations are already feeling the effects of climate change. Future climate scenarios also show a general trend toward warming and less precipitation with an increase in extremes (USAID 2018). Due to the economies' high reliance on rain-fed agriculture, which is controlled by smallholder farmers (about 80%) for daily subsistence, their vulnerabilities to climate extremes are high. Climate variability and change have a significant impact on the livelihoods and food security of these regions and nations because they depend on rain-fed agriculture and pastoralism for income and subsistence. More than 21 million people in West Africa, including Togo, Senegal, and Guinea, will struggle to feed themselves during the lean season (June to August) because of recurrent food crises caused by extreme weather events (prolonged droughts and floods).

2.3 Effect of current weather variability and extremes

The host SCPZ countries have a long history of dealing with dire crises. Global GHG emissions, changes in land use and land cover because of deforestation (clearing land for agriculture, prolonged periods of shifting cultivation, mono-cropping, overexploitation of the already vulnerable land and forests capes, and cutting trees for firewood and as an alternative source of income) and overgrazing of pastureland are some of the main human-influenced drivers of climate change. This results in loss of assets (infrastructure, productive land livestock, etc.), crop losses, lower productivity levels, and even famine and desertification. It also increases the frequency of extreme weather events (floods including riverine floods, wind and dust storms, prolonged dry spells or droughts). All these climatic and non-climatic factors contribute to the countries' increasing food insecurity and poverty. For instance, more than 800,000 households in Senegal experienced food insecurity during the 2012 food crisis brought on by extended drought events. In a similar vein, peasant farmers in Togo have reported lower grain quality and yields of maize, sorghum, millet, and rice, particularly in the northern part of the country due to heat stress, water stress, flooding, erosion, and water logging (USAID 2018). In 2022, heavy off-season rains fully destroyed watermelon harvest and left the fruits decomposing in the fields in the Casamance region (CGIAR 2023a). Frequent prolonged dry season, even in 2022, resulting in scarcity of feed for livestock, difficulty to find water and dry up of ponds (CGIAR 2023b). Reduced crop quality and yields; for example, climate-induced reduction in agricultural production has led to increase in number of households with food insecurity (WFP 2014) in the Casamance and Ziguinchor region including Goudomp (62%), Bounkiling (57%), Sédhiou (55%), Oussouye (52%), Médina Yoro Foulah (51%)

In Togo, flooding in 2010 affected 83,000 people and resulted in over $38 million in damages and losses (GFDRR 2019). Two of the three most severe droughts ever in the country were experienced during 1976/77 and 1982/83, localized in the Savannah, Kara, Maritime and eastern part of the Plateau regions. The drought affected 550,0000 people and cost an estimate of USD$500[1]. Increased prevalence of pests and diseases given the projected increase in temperatures and rainfall, thereby affecting crop yields. Variable rainfall distribution impacts on crop yields and food shortage (Mekimina 2013).

2.4 Biophysical features of the SCPZs and proposed interventions

[1] EM-DAT: The Emergency Events Database — Universite catholique de Louvain (UCL) — CRED, D. Guha-Sapir, Brussels, Belgium. http://emdat.be/emdat_db/

Depending on factors like global circulation patterns, altitude, latitude, proximity to water, and others, changes in climate appear differently in different parts of the world. Local production agriculture, which is closely linked to regional environmental conditions, is consequently impacted differently depending on the location. The availability of information and technology, ecosystem processes, consumer preferences, and production decisions made by individual producers are all influenced by global commodity markets at the same time. Given the interaction of climate, agriculture, and these other factors at all relevant geographic scales of activity, it is extremely situation-dependent to identify pertinent non-climatic indicators.

In Togo, the SCPZ programme covers the Kara region, which consists of seven (7) Prefectures namely: Assoli, Bassar, Bimah, Dankpen, Doufelgou, Kéran, and Kozah, with an estimated population of approximately 769,940 inhabitants. The area of intervention covered by the SCPZs program in Togo is estimated at about 165,000ha located between latitudes 9° 00’ and 10° 00’ North and between longitudes 0°15’ and 1°45’ East. The project appraisal shows[2] that the region is deemed a priority by the Government, considering the current level of poverty and the high agricultural potential (rice in particular). Due to the Food Processing Zone Project (PTA's) involvement in agricultural land development, rice production, and dam construction, it also can contribute to greenhouse gas emissions. The PTA economic model will help to strengthen climate resilience through less-carbon-emitting activities throughout the agricultural production chains. These activities will involve promotion of diversified agro-ecological systems and application of green technologies for waste management, as well as production of renewable energy that helps to reduce greenhouse gas emissions. The potential impacts are the following: (i) reduction of deforestation; (ii) increase in farmers’ incomes; (iii) enhanced food and nutrition security in the communities; (iv) soil productivity; (v) waste management through organic composting; (vi) employment of women and young people; (vii) use of improved, drought-resistant grains and seeds; and (viii) improved management of water resources.

In Senegal, the program activities will focus in the Casamance Natural Region corresponding to the administrative regions of Ziguinchor, Sédhiou and Koldaqui. The SCPZ project in Senegal covers a total land area of 105,000ha inhabited by over 1,872,668 people. Casamance, located along the river bearing the same name, comprises the administrative regions of Ziguinchor and Kolda, in south-western Senegal, and accounts for 14.4% of the national territory. Casamance’s social and economic development has suffered over the last three decades from the region’s conflict conditions. This conflict situation has been compounded by the serious effects of the decline in rainfall recorded since the early 1970s, reflected in the increasing salinization of the rice valleys, erosion of uplands and the hillside, silting of valleys and lowlands, and heavy pressure on the natural environment (forests, mangroves, fisheries resources, etc.). The updated Strategic Environmental Assessment Of The South Agro-Industrial Processing Zone Project (PZTA-Sud Or Agropole Sud) components are reinforced with support from the Green Climate Fund (GCF) whose main activities are: (i) Construction of post-harvest facilities (storage, drying, processing, conditioning warehouses for basic food crops, and powered by solar energy (planned installation of 3,273 kW of solar energy); (ii) Promotion of local small-scale irrigation through the establishment of drip irrigation systems powered by solar pumps to increase production; (iii) Creation of about 20,000 ha of forests managed by farm households in a sustainable manner to generate income; and (iv) Installation of 2.17 MW of renewable energy from biogas production or about 5,219 m^3 of biogas digester to treat livestock effluents and produce biogas for heating or electricity generation; and (v)

[2] https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/TOGO_-__APPROVED__-_Agro-Food_Processing_Zone_Project__PTA-TOGO_.pdf

Increasing community resilience through capacity building, awareness and institutional strengthening on climate information and early warning systems (CIEWS) for risks preparedness and readiness.

For Guinea, the country is divided into four natural regions: Lower Guinea or Maritime Guinea, Middle Guinea, Upper Guinea, and Forest Guinea. The two areas targeted by the programme are in the prefectures of Kankan and Boké, which covers a total land area of about 103,333 km², of which 31,186 hectares lie in the Boké Region with an arable land area of about 2,720,000 ha, about 800,000 ha of which lie solely in the Boké Region. The Boké area is in Maritime Guinea. It consists of a plateau sub-zone and the coastal sub-zone. With the Atlantic coast, this zone constitutes the alluvial basin of important coastal rivers and mangrove formations. The climate is Sudano-Guinean type (2513 mm average rainfall). Regarding the Kankan Department, located in Upper Guinea, it is a region of plains and savannas, and it is also Guinea's most arid zone. The premises of a Sudano- Sahelian climate are emerging in this zone, with rainfall ranging between 1,200 and 1800 mm. The targeted zones have significant resources and potential for multiple economic activities (agriculture, animal breeding, fisheries, forestry, mining, etc.). Broadly speaking, agriculture is the population's main sector of activity. The farming system, dominated by slash-and-burn agriculture, is characterized by a low rate of use of agricultural inputs (fertilizers, phytosanitary products, improved seeds), poor water control, weak production, and marketing channels, etc. Livestock farming system is extensive and relies on natural pastures. The SCPZ programme will cover about 110,000 ha throughout the entire programme area and have a considerable impact on about 220,000 direct beneficiaries and 670,000 indirect beneficiaries, of whom 50.7% will be women. Through the AfDB, the Green Climate Fund (GCF) will also contribute to the financing of additional SCPZ activities. Activities targeted by the GCF aim at reducing greenhouse gas emissions, enhancing carbon sinks, and enhancing the resilience of communities and ecosystems to climate change impacts. The SCPZ, which will contribute to the diversification and improvement of agricultural production and value chains, will generate considerable positive impact and effects on local and national development as well as on natural resources management. However, some activities are also likely to generate potential adverse impact on the biophysical and human environments if prevention or mitigation measures are not considered.

Due to tree cutting for farming and other needs for alternative sources of income, Togo and the Kara region are experiencing severe deforestation. A little over 3,000 hectares per year are replanted, compared to about 15,000 hectares per year of deforestation. By reducing the carbon stock, this situation makes the problem of climate change worse. The consequences of land degradation in the Casamance region have led to a general decline in soil fertility and the unproductiveness of thousands of hectares of saline or acidified valleys. The deterioration of climatic conditions, combined with the devastating effects of the conflict situation prevailing in Casamance, has led to a deterioration of the productive water- soil-forests capital, a drop in production and income, food insecurity, and an overall deterioration in the living conditions of rural populations now increasingly in search of alternatives for livelihood. Both Boke and Kankan in Guinea are rich in natural resources, consisting of vast areas of forests, wildlife reserves, plains, valleys, a dense hydrographic network, and a mineral-rich subsoil. However, these natural environments are facing various threats due to climate change, especially influenced by anthropogenic activities, such as extensive agriculture, bush fires, logging, carbonization, indiscriminate fishing and hunting, inappropriate mineral exploitation, etc. There are almost no significant dense forests left outside certain protected areas that are still relatively well conserved.

3. CLIMATE CHANGE PROJECTION FOR CRITICAL PARAMETERS

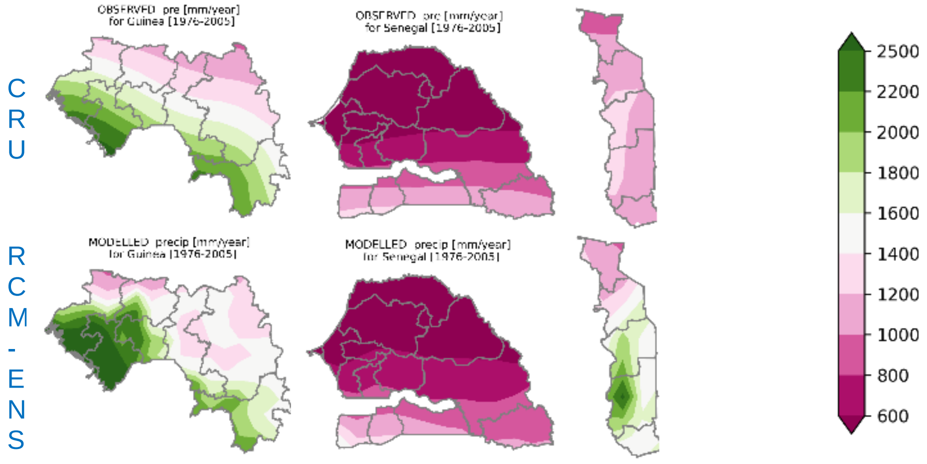
3.1 Climate change modelling and database

Three regional climate models (RCMs) participating in the Coordinated Regional Climate Downscaling Experiment (CORDEX) framework[3]. The RCMs include: (i) the Swedish Meteorological and Hydrological Institute, Rossby Centre (SMHI-RCA v4), (ii) the Climate Limited-area Modelling Community (CCLM v4.8.17) and (iii) the Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology (REMO2009). Common to these regional climate models is the global circulation model (i.e., the Maxx Planck's Earth Systems Model low resolution runs) that was used as initial and boundary conditions to force the historical simulations and future projections. These RCMs have been extensively used for weather forecasts, seasonal forecasts, and climate change studies over Africa (Fotso-Nguemo et al. 2017, Akinsanola et al. 2015, Sawadogo et al. 2020, Dosio et al. 2020, Kebe et al. 2020, Mbaye et al. 2019, Gibba et al. 2019). The CORDEX RCMs downscale many global climate models (GCMs) from the Coupled Model Intercomparison Project, Phase 5 (Taylor et al., 2012; Sylla *et al.*, 2016). The RCMs are run over the whole of Africa at 44 km resolution. To date, the CORDEX-Africa data constitute the most comprehensive RCMs projections available for the continent.

3.2 Historical climate and observed climate impacts

3.2.1 Analysis of historical climate

The average annual rainfall in the host countries ranges from about 600 mm/year to above 2500 mm/year, showing distinct patterns in the spatial distribution of precipitation (Figure 2). In terms of reproducing the decreasing rainfall signal from south to north in Guinea, the driest northern region in Senegal, the wettest western Plateaux sector, and the drying conditions further north of the Kara region in Togo, observations and the model agree. Senegal typically experiences the least amount of annual precipitation overall. The mean pattern of the observed rainfall is conserved and highlights the usefulness of the RCMs for analyzing the potential climate situation in the future, despite the strong RCM response to topographic features such as the Plateaux in Togo and Ocean effects in Guinea.



[3] https://cordex.org/data-access/esgf/

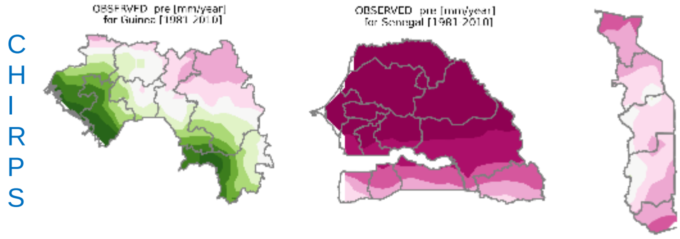


Figure 2. Spatial distribution of average annual total rainfall in the host SCPZ countries for the period 1976-2005.

The RCM ensemble mean compares favorably with most stations at project scale, but with some systematic biases (Figure 3). For instance, Niamtougou, Togo, saw an increase in rainfall. In Kankan, where the observed trends show an increase, the observed and modelled trends in precipitation diverge slightly.

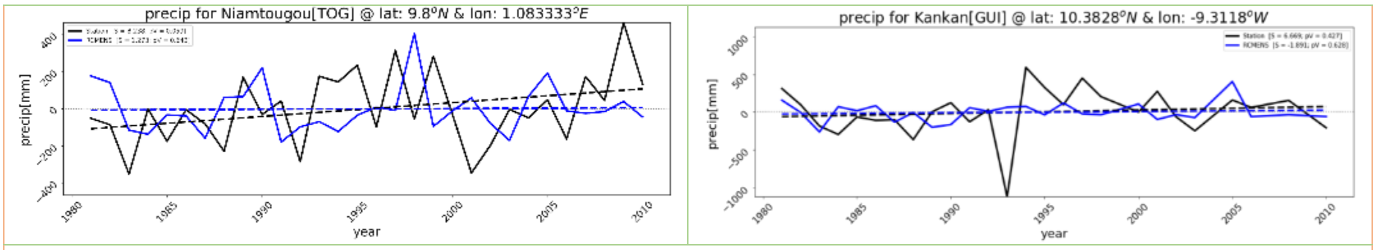
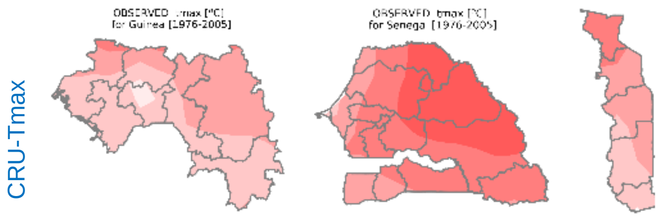


Figure 3. Trends in observed[4] (black line) and modelled (blue line) annual total precipitation for selected SCPZ stations the period 1981-2010.

The ENS model does a good job of simulating the temperature gradient, regional characteristics, and seasonal variations. The areas of cold temperatures, like those along Guinea's coast, and areas of warmer temperatures, like those in northern Senegal and northern Guinea, are well captured by the ENS simulations. However, everywhere in the coastal domain, the ENS model overestimates temperatures. Since increased evaporation from warming favors convection, which depends on near-surface air temperatures in the ENS model, the warm bias in temperature may be a factor in the overestimation of precipitation in coastal areas. The RCM preserves the spatial distribution of annual mean surface temperature for both minimum and maximum temperatures (Figure 4). Temperatures are significantly influenced by complex terrain, such as the Togo Plateaux, and proximity to water bodies, such as the coasts of Guinea and Senegal. In the southern part of Guinea, the minimum and maximum temperatures typically range from 14°C to about 38°C.



4 The observed data are computed from daily rainfall data retrieved from the archives of the respective meteorological services for selected stations within the SCPZs

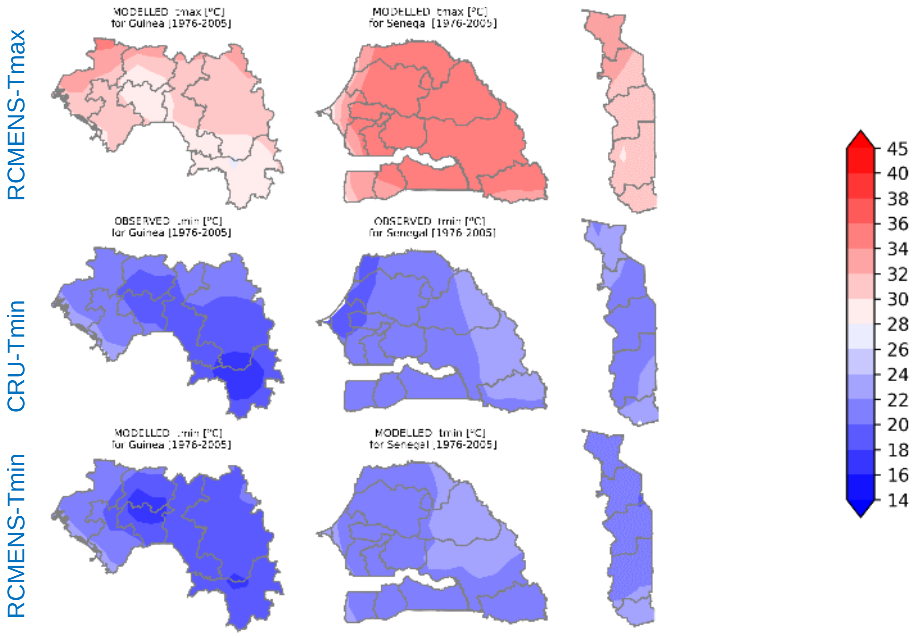


Figure 4. Spatial distribution of annual mean surface temperature for minimum and maximum temperature

Both stations observed and modeled simulated data for local trends in temperature show a general increase for minimum and maximum temperature (Figure 5). Particularly for maximum temperatures, where the mean annual deviation from the climatological mean is between 1 and 2 °C, the warming is statistically significant. Low crop yields in the SCPZs could be caused by soil degradation, which is partially caused by the observed warming. Therefore, a decline in agricultural productivity demoralizes farmers and may result in a change in way of life, particularly in the rural areas of the host SCPZs.

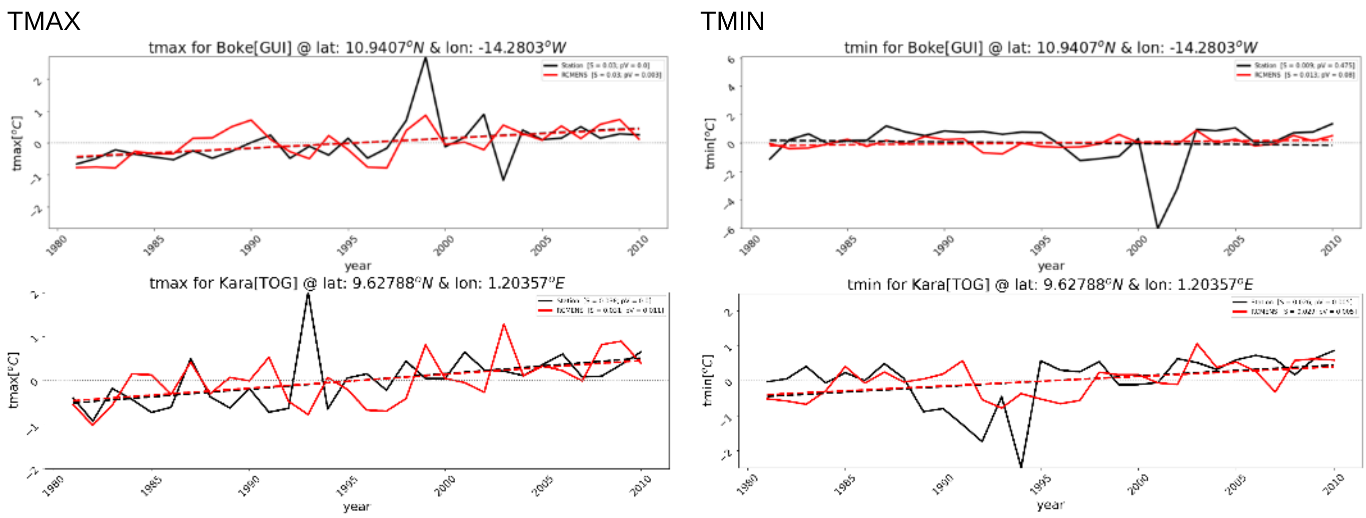


Figure 5. Trends in observed[5] (black line) and modelled (red line) minimum and maximum surface temperature (°C) for selected SCPZ stations the period 1981-2010.

[5] The observed data are computed from daily minimum and maximum temperature data retrieved from the archives of the respective meteorological services for selected stations within the SCPZs

3.2.2 Observed climate impacts

Senegal, Guinea, and Togo's agriculture, biodiversity, health, infrastructure, energy, and water sectors are all extremely vulnerable to climate change. The portfolio of GCF-funded activities should prioritize the need for adaptation in these countries' various sectors. This section provides a summary of the main natural hazards and their related socioeconomic impacts in the host country, based on literature and national publications. Through the spatial comparison of natural hazard data with development data, this provides helpful insight into the most vulnerable areas by identifying exposed livelihoods and natural systems in the SCPZ countries. Given the frequent occurrences of natural disasters like floods and droughts that threaten the national stability upheld over time, Senegal[6] is still susceptible to environmental shocks. Due to increased climate variability, such destabilizing events will become more frequent and extensive, disrupting the steady economic growth seen over the previous ten years. For instance, the country's rural-urban migration is made worse by the protracted droughts recorded between 1970 and 2000. Average surface air temperatures have increased by 0.9°C, according to historical climate records, particularly in the north and between October and December. Since 1960, there have been 27 more "hot" nights per year because of this. Although there has been a slight recovery in rainfall since the middle of the 1990s, the observed decrease is still 15% below pre-1970 levels. During the wet season (June to September), the southern region experiences the greatest rainfall decline. According to climate models, there will be a greater warming of 1.1 to 3.1oC, more hot days, extremely variable rainfall, and an increase of about 1 meter in sea level. Climate change will also affect climate-sensitive industries like agriculture (where 70% of production is rainfed), livestock, and fisheries, which make up 20% of GDP and employ most of the labor force. According to USAID (2017), This has a detrimental effect on food security, which is already under stress from low yields and rapid population growth. The country imports 60% of its cereal needs, primarily rice, the main staple crop in the nation, leaving over 15% of rural households and 8% of urban households with food insecurity, according to estimates. Reduced freshwater supply, increased evaporation of surface water, decreased recharge of groundwater, and impacts on water quality and hydropower output are all climate risks in the water sector.

Rainfall in Guinea varies throughout the year. Reduced rainfall over Guinea has affected the agricultural calendar, changed river regimes, and offset income flow[7]. The nation also experiences droughts, which are predicted to pose the greatest climatic risk and have a detrimental impact on river streamflow between 1961 and 1990. Another effect of reduced streamflow is water scarcity. Droughts are also expected to contribute to biodiversity loss, headwater degradation, an increase in the spread of diseases and plant pests, water scarcity, and an increase in bushfires across the nation. Variability in rainfall has serious effects on agricultural production, food security, and the primary economic activity of 80% of Guineans. Other natural disasters that can have a negative impact on Guinea's socioeconomic activities include flood events. Inadequate human waste disposal and the spread of diseases like cholera, typhoid fever, malaria, and/or polio result from these flood events, which frequently occur and have a negative impact on the already subpar sewage and water systems as well as sanitation facilities. The coast of Guinea has been experiencing sea level rise, which will increase salinization and flooding in coastal areas, influence agriculture, lead to a drinking water shortage, devastate infrastructure, destroy mangrove ecosystems, and result in the spread of diseases. Given this variety of climate risks, it is crucial to invest in better water management,

[6]USAID, 2017: Senegal’s Climate Change Risk Profile, Fact Sheet, https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20ATLAS_Climate%20Change%20Risk%20Profile%20-%20Senegal.pdf

[7] https://climateknowledgeportal.worldbank.org/country/guinea/vulnerability

early warning systems, and saltwater tolerant crop varieties to lower risks in Guinea related to sea level rise. This will aid in reducing the risk of a water shortage and aid in preparing the populace for these severe events. Improved agricultural technologies, the introduction of new crop species, and other likely interventions are also required to lessen the vulnerability of the nation's populations and communities to rainfall variability.

Togo, a low-income nation with a high rate of poverty, will endure additional hardship due to climate risk and its consequences[8]. On inter-annual and inter-decadal timescales, seasonal rainfall in this area varies significantly, in part because of changes in the Inter-Tropical Convergence Zone's (ITCZ) movements and intensity as well as changes in the timing and strength of the West African Monsoon[9]. High temperatures are a defining characteristic of Togo, where the mean annual temperature has risen by 1.1°C since 1960 at an average rate of 0.24°C per decade[10]. Since 1960, it was found that hot days have risen by 15.5% while cold nights have fallen. The effects on livelihoods, animal and human health, and natural resources have been profound. Throughout the nation, variable precipitation patterns are seen. Trends in Togo's climate are likely to make it more likely that local communities will be more at risk of and vulnerable to the severity of extreme events, coastal storms, and natural hazards like heat waves, droughts, floods, and wildfires[11]. Climate conditions significantly impact the nation's agriculture, including crop production, livestock, and fisheries. Climate models predict increasing temperatures, shifting seasonal patterns of rainfall, lengthening dry spells, and an increase in aridity and drought, all of which will have detrimental effects on the nation's agricultural industry.

Togo's adaptation action for the Agriculture Forestry and Other Land Use (AFOLU) sector highlights the need for: (i) capacity building in the AFOLU sector with a focus on building technical capacity of key research institutions on modeling; (ii) strengthening the resilience of crops, livestock, and forests through breeding crops and livestock for resistance to pests and diseases and promoting small scale irrigation; (iii) promoting sustainable forest management; and (iv) sustainable land management, which includes the creation of a national land use monitoring program. The development and/or improvement of reservoirs for micro-irrigation and livestock watering in rural areas across all regions, assistance with the mapping of climate change-vulnerable areas, and promotion of rice production systems with extremely low water use and low GHG emissions are additional benefits for the agricultural sector[12]. The nation has committed to the Climate-Smart Agriculture process outlined in the National Policy for the Agricultural Development of Togo 2013-2022 and the framework for implementing ECOWAS' agricultural policy[13].

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[8] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15859-WB_Togo%20Country%20Profile-WEB.pdf

[9] UNDP (2019). Togo Climate Change Adaptation Overview. URL: https://www.adaptation-undp.org/explore/western-africa/togo

[10] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15859-WB_Togo%20Country%20Profile-WEB.pdf

[11] UNECA (2015). Assessment Report on Mainstreaming and Implementing Disaster Risk Reduction in Togo. URL:https://www.uneca.org/sites/default/files/uploadeddocuments/Natural_Resource_Management/drr/drr_west-africa_english_fin.pdf

[12] Togo (2015). Third National Communication to the UNFCCC. URL: https://unfccc.int/sites/default/files/resource/tgonc3.pdf

[13] Republic of Togo (2016). Nationally Determined Contributions to the UNFCCC. URL: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Togo%20First/INDC%20Togo_english%20version.pdf

The proposed SCPZ program interventions align with the adaptation measures mentioned in each individual country's adaptation action plan based on the literature review and national publications.

3.3 Projected country-wide climate change

Projections from downscaled global climate model projections are used to provide a more refined regional and country specific information, especially for extremes that are particularly relevant for agriculture, to further understand the potential physical risk associated with the future climate. The projections generated from the ensemble mean (ENS) of three RCMs under the representative concentration pathways (RCP4.5 and RCP8.5) emission scenarios are used to assess future climate change. It is important to keep in mind that this ENS only illustrates one of many potential future outcomes that could materialize because of the trajectory of greenhouse gas emissions and other socioeconomic factors.
According to the RCP4.5 emission scenario, Figure 6 shows projected changes in annual total precipitation rates averaged for the climate periods 2011-2040 (the current and near future), 2041-2070 (the middle of the future), and 2071-2100 (the far future). In the three countries, statistically significant drying and wet conditions with 300 mm/year are anticipated. For instance, it is likely that the drying conditions in Boké's central region will worsen significantly in the medium term but less so in the long term. A pattern of high and low precipitation is anticipated in Kankan's southern and northern regions, respectively. Most of Senegal and Togo are predicted to experience a general dryness, particularly in their Casamance and Kara regions.

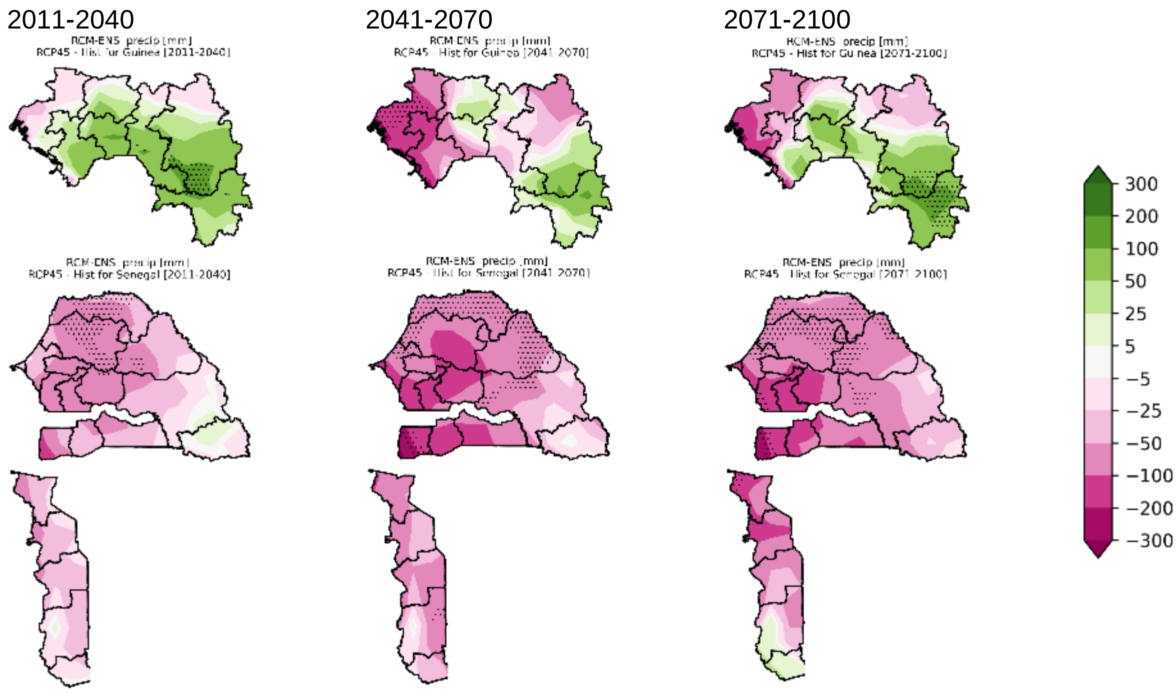


Figure 6. Projected change in mean annual total precipitation (mm) relative to the baseline (1976-2005) for the periods 2011-2040 (current-near future), 2041-2070 (mid-future) and 2071-2100 (far

future) under the RCP4.5 emission scenario. Dotted areas indicate regions where the change is statistically[14] significant at 0.05 significance level.

3.4 Projected change in climate extreme indicators in the SCPZs

This section presents analysis of projected change in climate extreme indices generated from climPACTv2 for the periods 2041-2070 and 2071-2100. The change is computed relative to a baseline period of 1976-2005. The indices are grouped into three indicators: flood indicators, heat stress and water stress indicators. For brevity, the figures analyzed are shown in Appendix II. Projected change in flood-related indicators in Senegal (see Figure A3.1 in Appendix III) shows that the precipitation amount from rainy days is decreasing above 100mm for the period 2014-2070 under both RCP4.5 and RCP8.5. The decline in PRCPTOT is expected to continue beyond the 21st century. Likewise, contributions from heavy rainfall events (R10mm) and consecutive wet days (CWD) are declining across the entire country. In contrast, the contributions from very heavy precipitation (R99PTOT) and maximum 1-day rainfall are declining, especially over the southern parts of the country where lies Velingara and Ziguinchor. This suggests a decrease in the frequency of heavy rainfall events but an increase in the intensity. Similar pattern of PRCPTOT, R10MM and CWD is obtained in Togo (Figure A3.3 – A3.4). The hotspot for the decrease is in the plateau and northern region. The Kara region is likely to receive intense rainfall as indicated by the high values of R99PTOT and RX1day. This signal persists in the end of the century with higher magnitude even in RCP8.5. There is a dipole pattern of PRCPTOT, CWD and R10mm in Guinea (Figures A3.5 – A3.6). These indices decline in the west coast of Guinea and increase inland. Change in heavy rainfall will increase in the mid- and end of the century.

A general warming is expected to dominate the entire land area of the three countries (Figure A3.7 – A3.9). The magnitude of minimum and maximum temperature increase in Senegal are 1.81°C and 3.43°C, respectively, during the 2041-2070 climate. These values are projected to change further and the warm spell during index will exceed 200 days (Figure A3.8). Other indicators like the heatwave duration, magnitude and amplitude are expected to change positively as well. Also, the heat stress indicators show similar pattern in Togo and Guinea, where the gradient of TXX and HWA increase northward.

Senegal is expected to experience severe water stress across the entire country as SPEI, SPI, and CDD intensifies even further into the end of the century. Northern parts of Togo including the Kara region will be the worst hit by the projected change in water stress. Areas prone to severe water stress in Guinea are found in the northeastern region of the country. The findings from this analysis emphasize the potential climate risk that will likely occur in the host countries. The contributions of these signals to vulnerability will be assessed in a later section of this report.

[14]The current and future climate conditions are compared using a two sided student t-test considering unequal variance at 0.05 significance level to determine if the mean values are significantly different between the two climates.

4. VULNERABILITY ASSESSMENT OF SCPZ PROGRAMME INTERVENTION AREAS

Climate change vulnerability assessments are useful tools that can be applied as the first stage of the planning process for adaptation. A climate vulnerability assessment focuses on systems, habitats or assets of interest and aids in determining which of the effects of climate change pose the greatest threats to them. Such assessment identifies stressors not related to climate change, such as changes in land use, habitat fragmentation, pollution, and invasive species, that can impact vulnerability. These stressors include both direct and indirect effects of climate change. The IPCC defines climate change vulnerability as the susceptibility of a system to the adverse effects of climate change and other stressors. Vulnerability assessment helps to improve the understanding of the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change including climate variability and extremes (IPCC 2001). Vulnerability has three components, namely **exposure, sensitivity, and adaptive capacity** (IPCC, 2007; IPCC, 2014). Detailed description of the three vulnerability components is presented in Section 4.1. The current assessment aims to assess the climate change vulnerability of the agricultural and energy sector in the SCPZs of Guinea, Togo, and Senegal. Several studies have used various spatial scales to present agricultural challenges in the context of climate change, for example Kim and Yuei (2019) at global scale, Parker et al. (2019) at regional scale, and Kvalvik et al. (2011) at national to local scale). The degree to which a system, in this case agricultural and energy systems, is susceptible to or unable to withstand the detrimental effects of climate change, including climate change and extreme weather events, is referred to as vulnerability (Hinkel 2011). Although there is no specific method for conducting climate vulnerability assessment for agriculture or any given sector, a commonly used approach is statistical analysis (Wu et al., 2017). This method often employs secondary data, which makes it cheap and less time-consuming. Also, the data can be used and re-used to check different variables. The drawbacks of this approach, however, include the difficulty in considering the adapted capacity and the possibility of misunderstanding the secondary data. Another method is the use of model simulation to focus on the group of factors most sensitive to climate change in the study area of interest. Assessing vulnerability with this method may be difficult due to the lack of biophysical and socio-economic database, especially in developing countries, such as, the host SCPZ countries. A challenge common to performing any vulnerability assessment is unavailability of data. Where data exist, they may either contain missing information or are often available only at country level or in very select locations (Mendelsohn 2008). In this assessment, we adopted the index-based statistical analysis approach, where the exposure indicators (i.e., climate stressors) are derived from regional climate models, and the sensitivity and adaptive capacity parameters from secondary data sources available in the public domain (i.e., from ND-GAIN, WBG, and IRENA). Although the climate stressors are representatives of the selected SCPZs in each of the host countries, a major limitation of this method is that the sensitivity and adaptive capacity indicators used are only available at national scale meaning that the values are kept constant in each country.

4.1 Factors Contributing to Vulnerability

4.1.1 Climate stressors

Climate stressors are factors that can be used to explain the degree of exposure of a system to climate change. The exposure (E) refers to the extent and the characteristics of a system exposed to significant climate variability. This section presents the exposure of the SCPZ agriculture assets and energy sector to potential shock or stress event in the current-near term, mid-century and long term under two emission scenarios (i.e., representative concentration pathways; RCP4.5 and RCP8.5). The climate stressors are represented by extreme climate indices derived from daily rainfall, and minimum and maximum temperature data. These extreme indices were chosen from a list created by the World Meteorological Organization-Commission for Climatology (WMO-CCL)'s Expert Team on Sector-Specific Climate Indices (ET-SCI) (see Table 1).

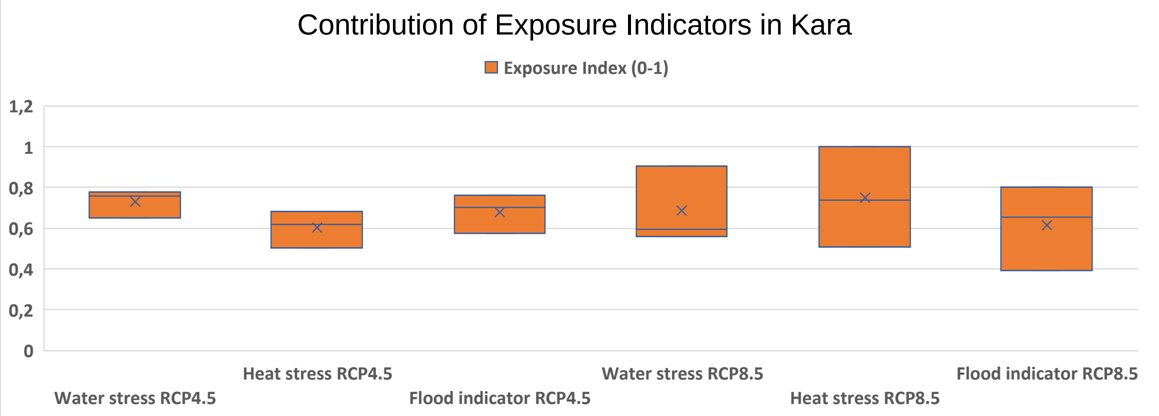
Table 1. List of selected climate stressors defined by the WMO-CCL's Expert Team on Sector-Specific Climate Indices (ET-SCI). The indices were generated using the WMO ET-SCI recommended ClimPACTv2 tool (Alexander & Herold, 2016).

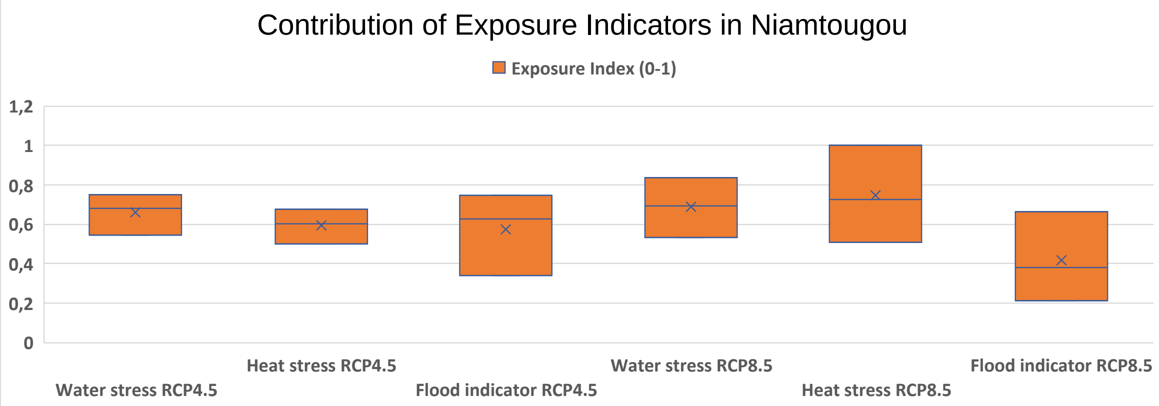
Index Abbr.	Indicator name	Definition	Unit	Group
Prcptot	Total wet day precipitation	Sum of daily PR >= 1mm	mm	Flood indicators
R99ptot	Fraction of annual PR from very heavy rainy days	100* (Annual sum of daily PR > 99th percentile)/Prcptot	%	
Rx1day	Max. 1-day PR	Max. 1-day PR total	mm	
R10mm	Number of heavy rainy days	No. of days for which PR > 10mm/day	Days	
CWD	Consecutive wet days	Maximum length of wet spell: maximum number of consecutive days with RR ≥ 1mm	Days	
WSDI	Warm spell duration indicator	Annual no. of days contributing to events in which 6 or more consecutive days experience Tmax> 90th percentile	Days	Heat stressors
TXx	Annual maximum daily temperature	Annual daily maximum temperature	°C	
TNn	Annual minimum daily temperature	Annual daily minimum temperature	°C	
HWD	Heatwave duration	The length of the longest duration of the heatwave	Days	
HWA	Heatwave amplitude	The peak daily Tmax value in the hottest heatwave	°C	
HWM	Heatwave magnitude	The mean temperature of all heat waves identified by HWN	°C	
SPI	Standardized precipitation index	Standardised Precipitation Index on time scales of 3 months	Unitless	Water (Drought) stressors

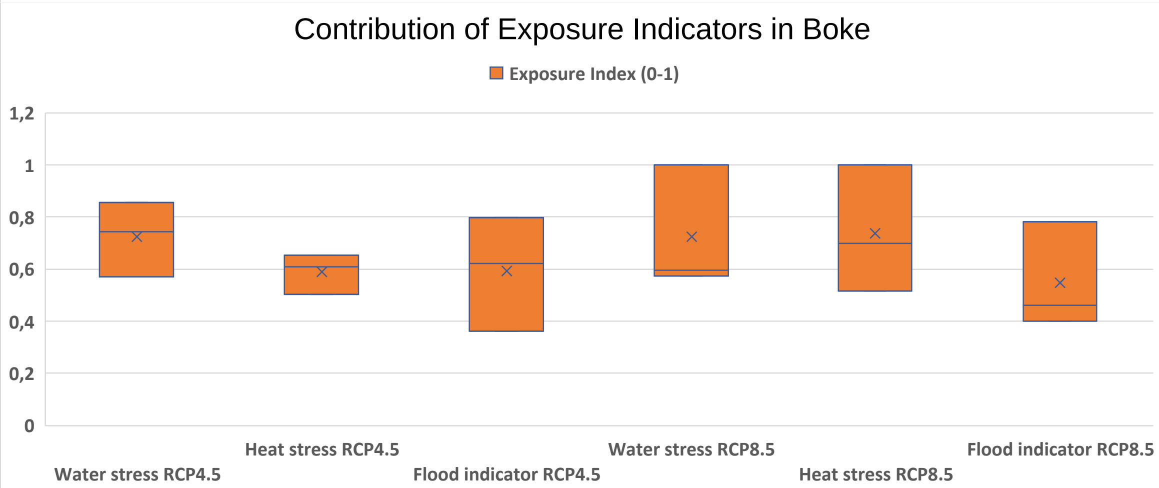
SPEI	Standardized precipitation and evapotranspiration index	Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months	Unitless	
CDD	Consecutive dry days	Maximum length of dry spell: maximum number of consecutive days with RR < 1mm	Days	

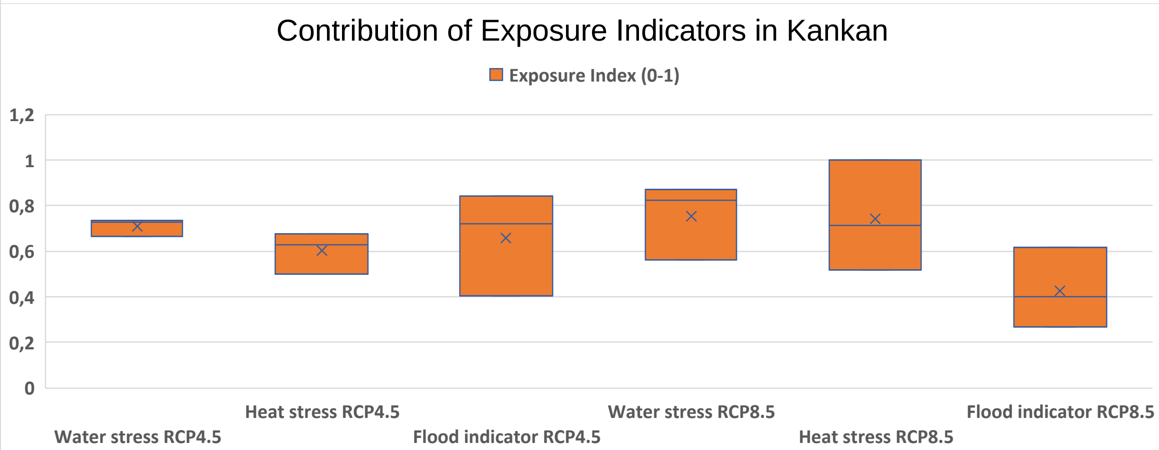
The indices were generated using the WMO ET-SCI recommended ClimPACTv2 tool (Alexander & Herold, 2016). We examine a subset of indices pertinent to agriculture while ClimPACTv2 computes over 60 ET-SCI sector-specific indices. They are further grouped into three classes of exposures; water stress, heat stress and flood indicator to examine the mean annual conditions in present and projected climates.

Projected change in heat stress shows a general increase in all the selected project sites in the SCPZs (see Appendix III) under RCP4.5 and RCP8.5. Annual total precipitation is expected to decrease while heavy precipitation events are expected to be less frequent but intense in Togo. Another potential physical climate risk the Niamtougou and Kara regions are likely to experience is an increase in drought. Similarly, Ziguinchor, Kolda, and Velingara in Senegal and Boke and Kankan in Guinea are exposed to projected increase in heat stress as indicated in the Tables presented in Appendix III. Annual precipitation is likely to reduce while heavy rainfall may decline but become more intense. All the regions will experience water stress due to the projected increase in the frequency of moderate to severe (both 3 months spi and spei < -1.5) drought. The modelled projected change may likely cause negative impacts on crop production by reducing crop yield and livestock rearing by subjecting livestock to heat stress as well as adversely impacting the health of farmers and conditions of the working environment. As expected, contributions of the three groups of climate stressors are higher in RCP8.5 (Figure 7). Water stress contributes the most to the exposure indicators in all regions under RCP4.5. Both heat stress and water stress dominate in RCP8.5.


Contribution of Exposure Indicators in Kara
Exposure Index (0-1)
1,2
1
0,8
0,6
0,4
0,2
0
Water stress RCP4.5
Heat stress RCP4.5
Flood indicator RCP4.5
Water stress RCP8.5
Heat stress RCP8.5
Flood indicator RCP8.5


Contribution of Exposure Indicators in Niamtougou
Exposure Index (0-1)
1,2
1
0,8
0,6
0,4
0,2
0
Water stress RCP4.5
Heat stress RCP4.5
Flood indicator RCP4.5
Water stress RCP8.5
Heat stress RCP8.5
Flood indicator RCP8.5


Contribution of Exposure Indicators in Boke
Exposure Index (0-1)
1,2
1
0,8
0,6
0,4
0,2
0
Water stress RCP4.5
Heat stress RCP4.5
Flood indicator RCP4.5
Water stress RCP8.5
Heat stress RCP8.5
Flood indicator RCP8.5


Contribution of Exposure Indicators in Kankan
Exposure Index (0-1)
1,2
1
0,8
0,6
0,4
0,2
0
Water stress RCP4.5
Heat stress RCP4.5
Flood indicator RCP4.5
Water stress RCP8.5
Heat stress RCP8.5
Flood indicator RCP8.5

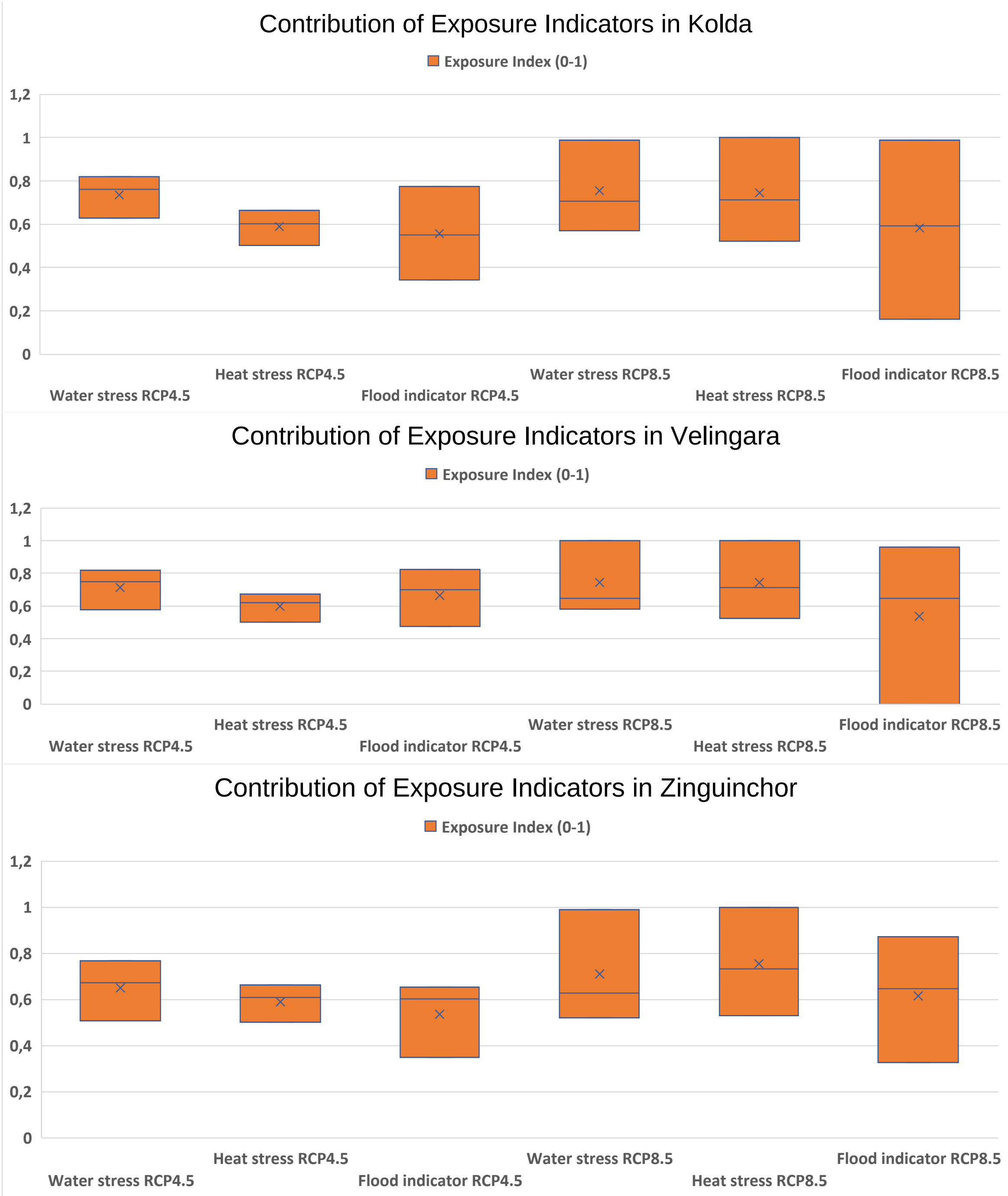


Figure 7. Contribution of Exposure Indicators in the SCPZs

4.1.2 Sensitivity (S)

Sensitivity defines the magnitude of the losses associated with hazard exposure. Therefore, Sensitivity (S) means the degree of influence as a system stimulated by climate-related factors. In this assessment, the sensitivity is investigated relative to the categorized climate extreme presented in Section 4.1.1. Parameters used to represent the sensitivity are derived from the

Notre Dame Global Adaptation Index (ND GAIN) website[15,16,17] and International Renewable Energy Agency (IRENA) energy profile reports. Three indicators relevant to agriculture, including rural population, age dependency ratio and ecological footprint, were selected based on their relevance to agriculture. Similar indicators were considered for the energy, but the age dependency ratio is replaced with dependency on imported energy.

- *Rural population* - The proportion of the total population living in rural areas, defined as the difference between total population and urban population according to national statistical offices.
- *Age dependency ratio* - The proportion of vulnerable populations, including the share of the population above 65 years old and the population under 14 years old.
- *Ecological footprint* - The number of hectares of land and water needed to supply ecosystem services demanded by the average lifestyles of the population in each country. This is compared with the estimated capacity of a country's ecosystems to regenerate and sustain such ecosystem services. This measure uses the surplus or deficit of supply over the demand within each country.
- *Dependency on imported energy* - The proportion of energy use from imports. Energy use refers to use of primary energy before transformation to other end-use fuels, according to WDI, equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

The normalized values of these indices are present in Figure 8. The average of these values was used in the vulnerability calculation.

[15] https://gain-new.crc.nd.edu/country/senegal (accessed 17 April 2023)
[16] https://gain-new.crc.nd.edu/country/togo (accessed 17 April 2023)
[17] https://gain-new.crc.nd.edu/country/guinea (accessed 17 April 2023)

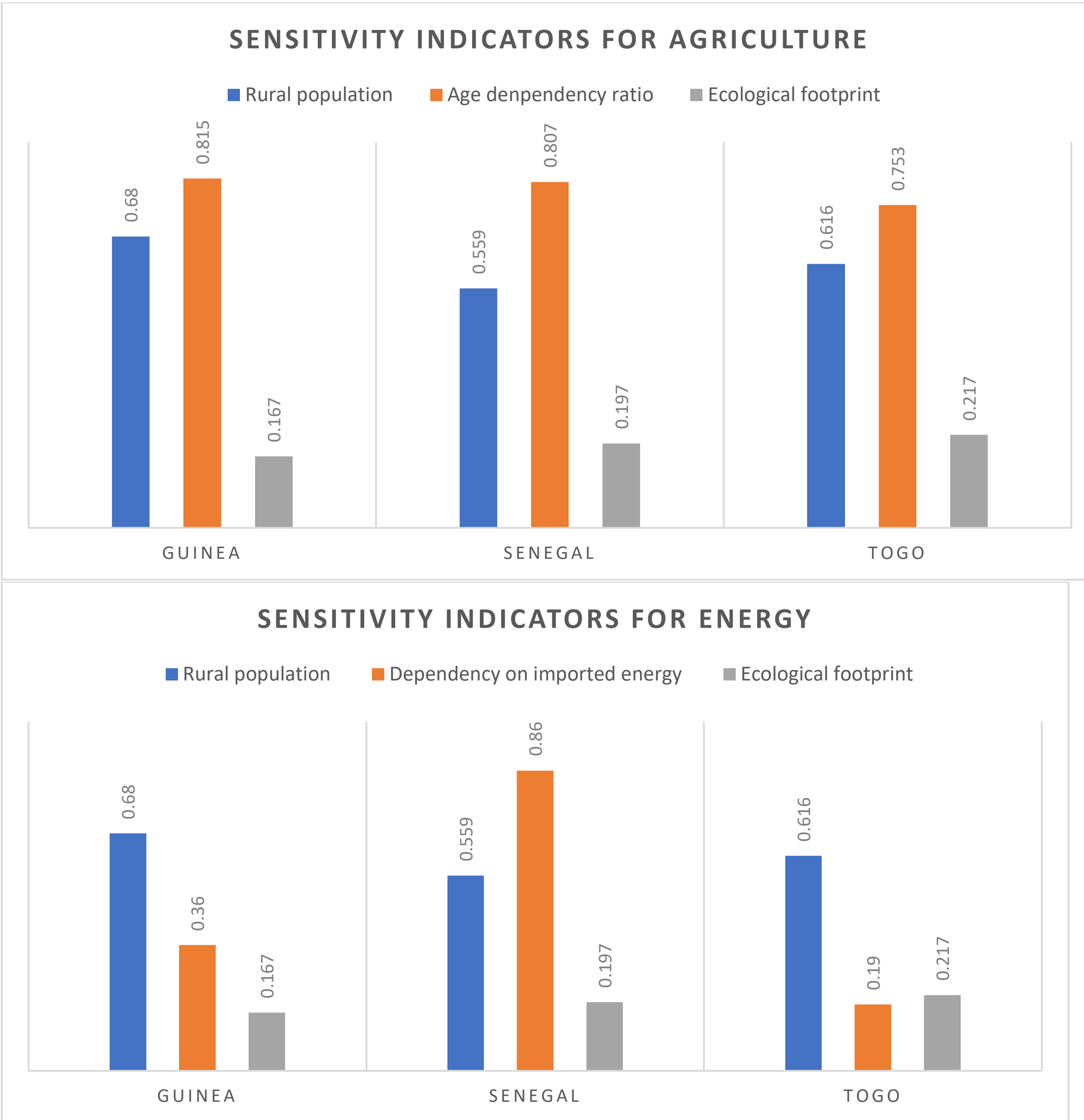


Figure 8. Country level components of sensitivity indicators for agriculture and energy (source ND GAIN[18]). The values are normalized to a range of 0 to 1. Note that the dependency on imported energy data is retrieved from IRENA energy profile reports[19,20,21].

[18] https://gain-new.crc.nd.edu/country

[19] https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Senegal_Africa_RE_SP.pdf (Accessed on 20 April 2023)

[20] https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Guinea_Africa_RE_SP.pdf (Accessed on 20 April 2023)

[21] https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Togo_Africa_RE_SP.pdf (Accessed on 20 April 2023)

Based on the database of the ND GAIN, the rural population is declining, which implies a decrease in the number of workforces participating in agricultural activities leading to high vulnerability. Therefore, a declining rural population will contribute positively to vulnerability assessment. The age dependency ratio defining the populations of 14 years and below are declining and the age 65 and above are increasing. The active workforce population (15-64years) is increasing therefore any adverse climate events on the agricultural sector will negatively impact the labor forces actively working on agriculture and hence, an increase in vulnerability. The ecological footprint defines the fraction of arable land and water needed to supply ecosystem services. An increase in ecological footprint suggests a negative contribution to vulnerability. The imported energy dependency rate demonstrates how much an economy depends on imports to supply its energy requirements. Gross inland energy consumption, which is the total of energy produced and net imports, is used to calculate the percentage of net imports (imports minus exports).

4.1.3 Adaptive capacity (AC)

Adaptive capacity refers to a system's, an institution's, a person's, or another organism's capacity to respond to consequences, capitalize on opportunities, or mitigate potential harm. The ability to profit and prevent loss as natural and artificial systems are impacted negatively by climate change is known as adaptive capacity (AC). In this study, we, as well, selected three indicators relevant to agriculture from the ND GAIN and the World Bank Group (WBG) socio-economic database. The selected indicators include agriculture capacity, quality of trade and transport infrastructure, access to electricity and gross domestic products (GDP) per capita growth.

- *Agriculture capacity* - Measure of agricultural technological capacity as the average of the 2 best scores (lowest vulnerability scores), out of amount of fertilizer use, amount of pesticide use, ability to equip agriculture area with irrigation, and the frequency of tractor use. The indicator reflects a country's capacity to acquire and deploy agricultural technology.
- *Electricity access* - The proportion of the population with access to electricity.
- *Quality of trade and transport infrastructure* - Logistics professionals' perception of quality of trade and transport related infrastructure (e.g., ports, railroads, roads, and information technology)
- *Gross domestic products (GDP) per capita growth* - A metric for measuring the economic output per person in a nation. The GDP per capita is a measure of a country's prosperity based on its rate of economic expansion. A country's GDP is divided by its population to determine its GDP per capita.

Although these indicators are computed at national scale. This means that both the S and AC in the vulnerability assessment will be constant in all regions for each country. However, the indicators provide a good measure to investigate the vulnerability at local scale.

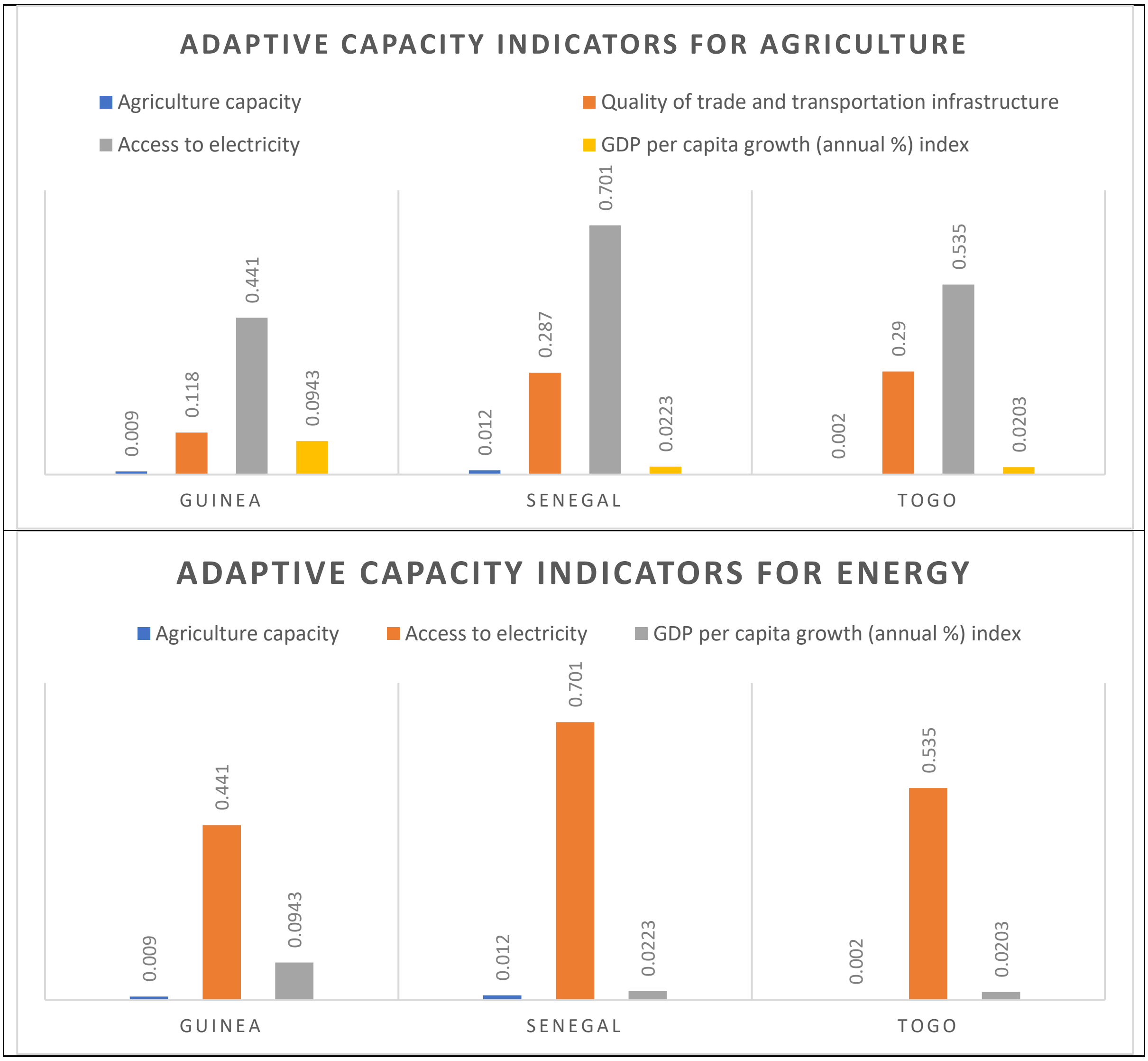


Figure 9. Country-level components of adaptive capacity (source ND GAIN[22]) for agriculture and energy. The values are normalized to a range of 0 to 1. Note that the plotted values are subtracted from unity because higher index values normally denote worst scores, and this could contribute negatively to the vulnerability. Also, the GDP per capita growth is derived from the archive of the World Bank Group socio-economic database[23,24,25].

Agriculture capacity is a measure of agricultural technological capacity including the amount of fertilizer use, amount of pesticide use, ability to equip agriculture areas with irrigation, and the frequency of tractor use. This component is in general low in the three countries (Figure 9), therefore contributing positively to the vulnerability. The quality of trade and transport infrastructure is increasing in Guinea, however, the contribution of critical transport infrastructure to vulnerability is positive. Access to electricity in the SCPZs is still low in all

[22] https://gain-new.crc.nd.edu/country
[23] https://data.worldbank.org/country/togo?view=chart
[24] https://data.worldbank.org/country/guinea?view=chart
[25] https://data.worldbank.org/country/senegal?view=chart

countries therefore causing dire challenges for agriculture activities such as irrigation, lighting, storage, and processing systems that require power supply to function. The decline in access to electricity contributes positively to vulnerability. The GDP per capita growth is a measure of the economic wealth which will determine how much resources a country possesses to invest in building the resilience of climate-sensitive sectors.

4.1.4 Vulnerability assessment framework and data source

The index method is frequently used to determine how vulnerable a population, system or asset is to climate change (Wiréhn et al., 2017; Raúl et al., 2017). The choice of appropriate indicators to measure climate change vulnerability is crucial in this method and is highly dependent on the study area and research objective (Barnett et al., 2008). In this report, we focus on agriculture in seven (7) regions of the SCPZ, including Kolda, Ziguinchor and Velingara in Senegal, Kara and Niamtougou in Togo, and Boke and Kankan in Guinea. Both agriculture, and energy generation and consumption are impacted by biophysical and socio-economic factors at the same time. As a result, both biophysical factors describing heat stress, water stress (drought) and flood indicator, and socio-economic factors describing agriculture capacity (inputs, mechanization, technology, and infrastructure), labor availability, etc., will be taken into consideration as input indicators (Dong et al., 2015; Adger et al., 2004). Given that vulnerability is a theoretical phenomenon that cannot be quantified as an observed phenomenon, it can be said that the index method adopted in this assessment offers a comprehensive approach and is considered appropriate for assessing vulnerability. This assessment considers the three components; exposure (E), sensitivity (S) and adaptive capacity (AC), described in the above Section 4.1.

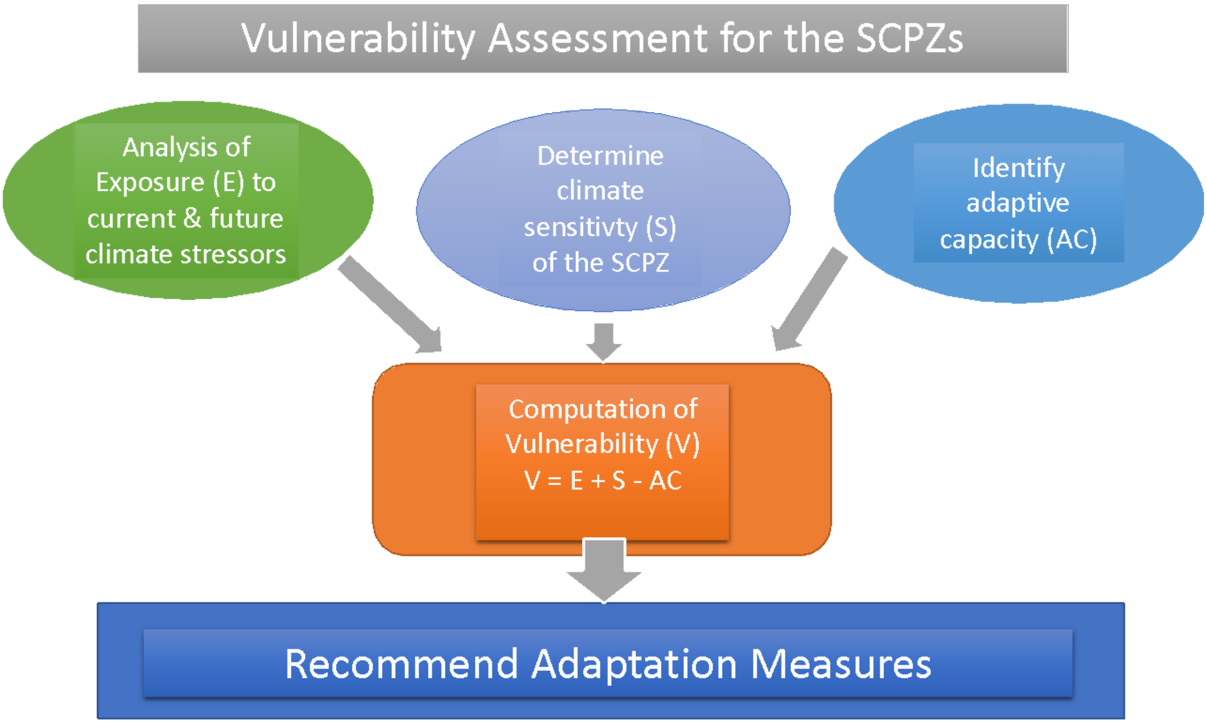


Figure 10. Climate vulnerability framework for SCPZ (adopted from Turner et al., 2003):

For local scale agriculture and for the communities and peoples within the SCPZ sites separately, the broad framework (Figure 10) will be used. This is because the indicators for sensitivity, exposure, and adaptive capacity (Table 1) are each affecting vulnerability in a unique way.

Table 1. Selected indicators contributing the climate exposure, sensitivity, and adaptive capacity. Due to data limitations the best suited sets of indicators relevant to the agriculture and energy sectors were selected for the assessment (e.g., Loi et al., 2022).

Vulnerability Components	Agriculture	Energy
Exposure		
Water stress	✓	✓
Heat stress	✓	✓
Flood indicator	✓	✓
Sensitivity		
Rural population	✓	✓
Age dependency ratio	✓	
Ecological footprint	✓	✓
Dependency on imported energy		✓
Adaptive capacity		
Agriculture capacity	✓	✓
Quality of trade and transportation infrastructure	✓	
Access to electricity	✓	✓
GDP Per capita growth[26]	✓	✓

The data used for the vulnerability assessment is derived from various sources. The climate-related datasets used for the exposure indicators are derived from regional climate model (RCM) ensemble mean as explained in Appendix I. Daily precipitation, and minimum and maximum temperatures were used to derive secondary datasets based on the WMO ET-SCI definitions. These climate indices were further grouped into heat stress, water (drought) stress and flood indicators using the average of their normalized project change values for current-near (2011-2040), mid-century (2041-2070) and long term (2071-2100). Normalization to unitless values ranging from 0 to 1 is necessary because the different climate stressors do not have the same unit. The normalization of the flood indicators was done using the below Equation 1.

$$x_i = \frac{x_i - x_{imin}}{x_{imax} - x_{imin}}$$

Equation 1

Where x_i denotes the value of the climate stressor to be scaled, x_{imin} and x_{imax} are the minimum and maximum values of the range of values for a specific indicator for combined RCP 4.5 and RCP8.5 (i.e., the data from the two scenarios were merged to form the array from which the range is determined). This was done to account for the magnitude of change across the two scenarios.

[26] https://data.worldbank.org/country/guinea?view=chart

For the heat stress and water (drought) stress indicators, normalization was applied such that the values range from 0.5 to 1. This is to avoid damping the contributions from lower values of heat or water stress. Equation 2 expresses how the normalization was done.

$$x_i = \frac{x_i - x_{imin}}{x_{imax} - x_{imin}} \times (r_{max} - r_{min}) + r_{min}$$

Equation 2

Where r_{min} and r_{max} represents the new minimum and maximum range of 0.5 to 1, respectively. Please note that for flood indicators, particularly flood frequency, additional screening constraints are applied when projected changes are negatives in all three climate periods by rescaling the range to minimum of 0.1 and maximum of 0.25. This was done to reflect the diminishing of the flood stress level associated with the declining frequency of heavy precipitation leading to flooding.

Thereafter, the vulnerability (V) for either agriculture or energy is computed using Equation 3 (e.g., Loi et al., 2022):

$$V = E + S - AC$$

Equation 3

The resulting values of V are then divided into four categories of equal intervals, that is, very low – low (0 to 0.35), low – medium (0.35 to 0.7), medium – high (0.7 to 1.05), and high - very high (1.05 to 1.4).

The Notre Dame-Global Adaptation Index (ND-GAIN) Country Index was used to find out how sensitive and adaptable a country is. The ND-GAIN is a free, open-source index that displays a nation's current susceptibility to hazards caused by climate change.
Sensitivity describes how perturbations related to climate change affect people and the industries on which they rely. Increased reliance on climate-sensitive industries and the proportion of people who are vulnerable to its hazards because of topography and demography are among the factors increasing sensitivity.

The term "adaptive capacity" refers to a society's and its supporting sectors' capacity to make changes to lessen potential harm and react to adverse effects of climate events. The ND-GAIN adaptive capacity indicators aim to identify a range of quickly deployable tools for addressing industry-specific climate change impacts.

1.2 **Vulnerability of Agriculture in the SCPZ**

An assessment of the sector's vulnerability for the chosen SCPZ's agriculture will be done in this subsection. So, agriculture and site-specific factors will be the indicators for climate exposure, sensitivity, and adaptive capacity. The three categories of climate stressors that differ depending on the SCPZ site will be used.

4.2.1 Togo

The vulnerability of agriculture to climate change in Kara is projected to lie between medium to high during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-

2100) periods under RCP4.5 (Figure 11a). This is the same situation under RCP8.5 but the vulnerability in the long-term falls within high and very high. Similarly, in Niamtougou the calculated vulnerability is medium to high for all the considered periods (Figure 11b). This highlights the need to make conscious investment towards building the resilience of the agricultural sector to climate change impacts.

(a) Kara

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,81	0,97	1,00
RCP8.5	0,84	0,90	1,10

Vulnerability	
very low - low	0 to 0.35
low - medium	0.35 to 0.7
medium - high	0.7 to 1.05
high -very high	1.05 to 1.4

(b) Niamtougou

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,83	0,98	0,86
RCP8.5	0,84	0,88	1,01

Figure 11. Agriculture vulnerability matrix for (a) Kara and (b) during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

4.2.2 Senegal

Analysis shows that most regions along the southern Agropole in Senegal are currently under medium to high vulnerability to climate change (Figure 12). The severity of the vulnerability in this region varies from the western coast (i.e., Ziguinchor) to the inland eastern part of the southern Agropole (i.e., Velingara). Both water and heat stress contribute equally to the vulnerability in the regions (Figure 7). Ziguinchor region is likely to be highly vulnerable in the end of century (Figure 12c). It is quite important to note that the decrease and increase in the mid-term values in Kolda and Velingara, respectively, is as a result of the low and high frequency in the flood indicator. Flood indicators also contribute across a broad spectrum to the vulnerability. Despite the strategic position of the region in terms of its favorable condition for agriculture production, the level of capacity built in the agriculture sector and investment in the energy sector will in the long term strongly determine the resilience of food security at local and national scale.

(a) Kolda

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,80	0,79	0,89
RCP8.5	0,76	0,97	1,00

Vulnerability	
very low - low	0 to 0.35
low - medium	0.35 to 0.7
medium - high	0.7 to 1.05
high -very high	1.05 to 1.4

(b) Velingara

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,76	0,86	0,84
RCP8.5	0,73	0,89	0,95

(c) Ziguinchor

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,70	0,75	0,89
RCP8.5	0,75	0,92	1,05

Figure 12. Agriculture vulnerability matrix for (a) Kolda, (b) Velingara and (c) Ziguinchor during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

4.2.3 Guinea

In Guinea, the relatively weak adaptive capacity (Figure 9) contributes positively to the vulnerability of agriculture in the current term. The agriculture system in the Boke is projected to be highly vulnerable in the end of the 21st century (Figure 13). For Kankan it is found to be highly vulnerable in the mid- and end of the century. Except for the mid- and long-term period, where the vulnerability is between high to very high under RCP8.5 and in the long-term under RCP4.5, Boke is expected to mostly experience medium to high vulnerability to climate change and variability (Figure 13a). Likewise, Kankan is expected to experience high to very high vulnerability in the long-term under RCP4.5 but this condition is likely to persist from the mid to far century under RCP8.5 (Figure 13b).

(a) Boke

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,91	0,95	1,00
RCP8.5	0,83	1,02	1,20

(b) Kankan

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	1,02	0,98	1,14
RCP8.5	0,84	1,10	1,14

Vulnerability	
very low - low	0 to 0.35
low - medium	0.35 to 0.7
medium - high	0.7 to 1.05
high -very high	1.05 to 1.4

Figure 13. Agriculture vulnerability matrix for Boke and Kankan during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

4.3 Vulnerability of Energy

An assessment of the energy vulnerability for the chosen SCPZ's is presented in this subsection. Relevant energy indicators and site-specific factors are selected and combined as the indicators for climate exposure, sensitivity, and adaptive capacity. Comparable to the agriculture vulnerability assessment, three categories of climate stressors that differ depending on the SCPZ site are used to calculate the vulnerability.

4.3.1 Vulnerability analysis

The vulnerability of the energy sector in Kara and Niamtougou is low to medium in the current-near climate (Figure 14). Thereafter, the vulnerability lies within medium to high in the two countries. Components contributing to the vulnerability is the rural population for sensitivity and access to electricity for adaptive capacity.

(a) Kara

Scenarios	**Current-near term (2011-2040)**	**Mid-term (2041-2070)**	**Long term (2071-2100)**
RCP4.5	0,65	0,81	0,84
RCP8.5	0,68	0,73	0,93

(b) Niamtougou

Scenarios	**Current-near term (2011-2040)**	**Mid-term (2041-2070)**	**Long term (2071-2100)**
RCP4.5	0,67	0,82	0,70
RCP8.5	0,67	0,72	0,84

Vulnerability

very low - low	0 to 0.35	
low - medium	0.35 to 0.7	
medium - high	0.7 to 1.05	
high -very high	1.05 to 1.4	

Figure 14. Energy vulnerability matrix for Kara and Niamtougou during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

Kolda and Velingara are projected to experience medium to high vulnerability in all the three climate periods while Ziguinchor will experience high to very high category in the end of the century under RCP8.5 (Figure 15). Despite the heat stress increasing by end of the century compared to the mid and current term, the flood indicators are decreasing more in the end of century therefore contributing negatively to the vulnerability. Other future periods are expected to pose medium to high vulnerability in all the regions in Senegal.

(a) **Kolda**

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,83	0,82	0,91
RCP8.5	0,79	1,00	1,02

Vulnerability

very low - low	0 to 0.35
low - medium	0.35 to 0.7
medium - high	0.7 to 1.05
high -very high	1.05 to 1.4

(a) **Velingara**

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,79	0,89	0,87
RCP8.5	0,76	0,92	0,98

(c) Ziguinchor

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,73	0,78	0,92
RCP8.5	0,78	0,94	1,08

Figure 15. Energy vulnerability matrix for Kolda, Velingara, and Ziguinchor during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

In Kankan, the current-near term is facing low to medium vulnerability under RCP8.5. This is expected to become medium to high in future climates (Figure 16). In general, the vulnerability is medium to high in Boke.

Boke

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,74	0,78	0,83
RCP8.5	0,66	0,85	1,03

Vulnerability

very low - low	0 to 0.35
low - medium	0.35 to 0.7
medium - high	0.7 to 1.05
high -very high	1.05 to 1.4

(a) **Kankan**

Scenarios	Current-near term (2011-2040)	Mid-term (2041-2070)	Long term (2071-2100)
RCP4.5	0,85	0,81	0,97
RCP8.5	0,67	0,94	0,98

Figure 16. Energy vulnerability matrix for Boke and Kankan during the current-near term (2011-2040), mid-term (2041-2070), and long term (2071-2100) periods under RCP4.5 and RCP8.5

It was found from the energy vulnerability assessment that most of the SCPZs are medium to highly vulnerable to climate change. Some few regions are highly vulnerable especially in the end of 21st century while some have low to medium vulnerability in the near-term climate. This suggests that the production and transmission of energy in the SCPZs will continue to face growing difficulties due to climate change. Production and delivery of energy will be impacted by a gradual rise in heat stress, a rise in the number and severity of water stress (drought) events and shifting precipitation patterns. The production and transmission of thermal and hydropower as well as fossil fuels will all be impacted. Consequently, there is a need for adaptation strategies like using renewable energy.

4.3.2 Solar PV technologies

Solar PV technology can mitigate climate change by reducing greenhouse gas emissions from energy generation. However, the deployment and operation of solar PV systems can also be impacted by climate change-related risks and vulnerabilities as shown in subsection 4.4.1.

Some of the climate-related risks associated with solar PV technology include:

- Physical Risks: Extreme weather events such as storms (including sandstorms), and floods can damage solar PV systems and disrupt their operation. Heatwaves can also reduce the efficiency of solar panels, leading to lower energy yields.
- Resource Risks: Droughts or changes in precipitation patterns can affect the availability of water resources required for cleaning solar panels, which can lead to reduced energy yields.
- Market Risks: Changes in policy or regulations can affect the financial viability of solar PV projects, especially if they are dependent on subsidies or tax incentives.
- Technological Risks: Changes in the availability or cost of materials required for solar PV systems can affect their deployment and operation.

Some of the vulnerabilities associated with solar PV technology include:

- Location: The location of solar PV systems can impact their exposure to physical risks such as extreme weather events and resource risks such as water availability.

- Technology: The efficiency and durability of solar PV systems can impact their resilience to physical and resource risks.

- Financial: The cost of solar PV systems can impact their affordability and the ability of communities to deploy them, especially in low-income areas.

There are several potential adaptation measures that can help reduce climate risks and vulnerabilities for solar PV systems, including:

1. <u>Site selection:</u> Choosing an appropriate location for solar PV systems is crucial to ensure they are less vulnerable to climate risks. The site should be away from areas that are prone to floods, landslides, and other natural disasters.
2. <u>Design:</u> Solar PV systems can be designed to withstand harsh weather conditions, such as strong winds and heavy rainfall. This can be done by reinforcing the PV panel frames, using stronger mounting systems, and designing the system to be more aerodynamic.
3. <u>Maintenance</u>: Regular maintenance of solar PV systems is essential to ensure they remain functional and efficient. Maintenance should include cleaning the panels to remove dirt and debris, checking the wiring for damage, and replacing any worn-out components.
4. <u>Backup power:</u> Installing backup power systems, such as batteries, can help ensure that solar PV systems continue to operate during power outages caused by extreme weather events.

5. Insurance: Having adequate insurance coverage for solar PV systems can help mitigate the financial risks associated with damage or loss due to extreme weather events.
6. Monitoring and early warning systems: Monitoring the performance of solar PV systems can help detect any issues early on, allowing for timely repairs and replacements. Early warning systems can also be put in place to alert system operators of impending extreme weather events.

Overall, a combination of these adaptation measures can help reduce climate risks and vulnerabilities for solar PV systems. It is important to assess the specific risks and vulnerabilities of each system and implement appropriate adaptation measures accordingly.

4.3.3 Bio digestor technologies

Biogas is a renewable energy source generated through the decomposition of organic materials such as animals, food, and agricultural residues. While biogas production can help reduce greenhouse gas emissions and contribute to a sustainable energy transition, it is also subject to various climate-related risks and vulnerabilities.

Some of the climate-related risks associated with the use of biogas include:

- Physical Risks: Extreme weather events such as floods, droughts, and storms can impact the availability and quality of feedstock materials for biogas production. These events can also damage biogas facilities and disrupt their operation.
- Resource Risks: Changes in precipitation patterns and water availability can impact the amount of water required for biogas production. Similarly, changes in temperature and weather patterns can impact the availability and quality of feedstock materials.
- Market Risks: Changes in policy or regulations can impact the economic viability of biogas projects, especially if they are dependent on subsidies or tax incentives.
- Technological Risks: Changes in the availability or cost of biogas equipment, feedstock materials, or other inputs can impact the deployment and operation of biogas facilities.

Some of the vulnerabilities associated with the use of biogas include:

- Location: The location of biogas facilities can impact their exposure to physical risks such as extreme weather events and resource risks such as water availability.
- Technology: The efficiency and durability of biogas facilities can impact their resilience to physical and resource risks.
- Financial: The cost of biogas facilities can impact their affordability and the ability of communities to deploy them, especially in low-income areas.

Some potential adaptation measures that can help reduce climate risks and vulnerabilities for biodigesters include:

1. Diversify feedstock sources: Climate change can affect the availability and quality of feedstock for biodigesters. Diversifying feedstock sources can reduce the vulnerability of the system to changes in climate conditions. This can be achieved by using a mix of several types of organic waste, including agricultural waste, food waste, and animal manure.
2. Improve feedstock quality: Climate change can affect the quality of feedstock for biodigesters, as it can increase the level of contaminants and reduce the nutrient content. Improving feedstock quality through proper storage and handling can help reduce the risk of system failure and improve the efficiency of the biodigester.

3. Increase system resilience: Biodigesters can be made more resilient to climate change by improving system design and operation. This can include increasing the size of the system, adding backup power sources, and improving the insulation to protect the system from extreme weather events.
4. Monitor and manage system performance: Monitoring and managing the performance of biodigesters can help identify potential issues before they become major problems. This can include monitoring the system's temperature and pH, as well as the quality and quantity of biogas produced.

Overall, the adaptation measures for biodigesters can help reduce climate risks and vulnerabilities, while also improving the efficiency and economic viability of the system.

2 SUMMARY AND CONCLUSION

5.1 Major highlights

The findings of this study pointed out several significant difficulties in assessing agricultural and energy vulnerability in seven SCPZs, including Boke and Kankan in Guinea, Kara, and Niamtougou in Togo, and Kolda, Velingara, and Ziguinchor in Senegal. A thorough assessment of agricultural vulnerability is required in many areas. According to the current assessment, the combination of the three IPCC-recommended components—exposure, sensitivity, and adaptive capacity—to assess agricultural and energy vulnerability is quite reliable. The current climate has a significant impact on agriculture in the SCPZs, and this impact will continue to exist in the future, having a detrimental effect on the economy, society, and environment.

The findings also demonstrate that vulnerability and adaptive capacity are inversely correlated, with the latter having a significant impact on the former. Except Boke and Kankan, most of the SCPZ were found to have medium to high agricultural vulnerability in the present and future climate. High to very high vulnerability is found in the end of the century under RCP8.5 in Boke. In Kankan, high to very high vulnerability is found over the long term under RCP4.5, but under RCP8.5, this condition is likely to last well into the next century. Results from Guinea clearly demonstrate the two regions' poor capacity for adaptation. This highlights the need for more adaptive capacity to make the region less vulnerable and more resilient. Ziguinchor in Senegal is found to be highly venerable in the end of the century.

Furthermore, it was found from the energy vulnerability assessment that most of the SCPZs are medium to highly vulnerable to climate change. Some few regions are on the other hand highly vulnerable especially in the end of 21st century while some have low to medium vulnerability in the near-term climate. This suggests that the generation and distribution of energy in the SCPZs will continue to face growing difficulties due to climate change. Also, the SCPZs will like face numerous challenges on the production and delivery of energy due to future projections of rise in heat stress, rise in the number and severity of water stress (drought) events, and shifting precipitation patterns. The production and transmission of thermal and hydropower as well as fossil fuels will all be under stress. Consequently, there is a need for adaptation strategies like using renewable energy.

In order to reduce the harm that climate change will do to the economy—society in general and the agricultural sector in particular—improvement of adaptive capacity, such as improving the agriculture capacity, raising people's levels of education, strengthening the planning capacity of local decision makers, improving critical infrastructure (e.g., irrigation, roads, renewable energy, etc.), and increasing the budget for climate change response, are necessary solutions.

Agriculture in Senegal is more vulnerable to flooding and water stress in the coastal SCPZ (Ziguinchor) than in the other SCPZ. The vulnerability to agriculture is also increased by low agricultural capacity, which is associated with inadequate technological factors like the amount of fertilizer and pesticide use, the ability to irrigate agricultural areas, and the frequency of tractor use.

The primary causes of agricultural and energy vulnerability were determined using a quantitative local scale assessment method. The resulting vulnerability matrix emphasizes the high-risk SPCZs as a result. Despite some limitations, this study adds to the conversation about how to deal with the threat of climate change. The vulnerability assessment's findings have been helpful in developing planning strategies to lessen the harm and adverse effects that climate change will have on the agricultural and energy sector and the socio-economic activities of the SCPZs in general.

5.2 Recommended adaptation measures

Based on the level of vulnerability found in the regions there is the need to make deliberate efforts to adapt to the identified climate exposure, reduce the sensitivity and increase the adaptive capacity of the agriculture and energy systems in the SCPZs. Some recommendations are:

For Agriculture:

- Adoption of climate resilient agriculture practices
- Improvement of the biophysical conditions of the regions
- Promote sustainable use of available water resources through efficient irrigation system
- Wealth creation and access to finance
- Provision of adequate public infrastructure such as roads
- Improve access to access to capital and technology
- Improve access to climate information and climate-informed agro-advisory services
- Government should formulate policies to ensure equitable land distribution
- Promote research and agricultural extension services
- Promote the use of drought resistant varieties of crops, crop diversification, changes in cropping pattern and calendar of planting
- Conservation of soil moisture through appropriate tillage methods
- Promote afforestation and agro-forestry

For Energy:

- Adopt technologies that are suited for the climatic conditions prevailing and are in line with international standards.
- Ensure infrastructure supporting the RE technologies are climate resilient and properly maintained.
- Decrease the reliance on hydropower by switching to other renewable resources that are sensitive to reduction in water availability e.g. to wind and solar

- For biogas energy diversify feedstock sources to reduce the vulnerability of the system to changes in climate conditions.
- Increase capacity of planners to better understand the effect of climate change and streamline adaptation measures in short- and long-term planning.
- Improve access to financing and to technology.
- Conduct wind/solar suitability analysis for future climates to identify suitable regions for the installation of wind and solar farms.

5.3 Proposed GCF project intervention in the SCPZ

The SCPZ programme seeks to build resilience of the critical agriculture value chain and contribute to GHG emission reduction through an integrated approach around two mutually connected components:

- **Component 1: Strengthening of critical SCPZs value chain infrastructure and management governance -** Under this component, the programme will invest in improving the climate resilience of critical infrastructure along the agricultural value chain in the three selected countries. First, at the production stage, the programme will invest in the development of SCPZs access infrastructure and support for agro-industrial parks (AIPS) management governance such as Agro-Processing Hubs (APHs), Agricultural Transformation Centres (ATCs). It will also involve the construction of access facilities such as roads, administrative building and storage warehouses, rehabilitation/upgrading of small-scale agricultural water management (AWM) technologies such as equipped boreholes, wells and small reservoirs/dams including rain water harvesting technologies, while the use of drip irrigation technology powered by solar pumps will be widely promoted especially among the most vulnerable group (women) to increase production of vegetables and fruits. Second, at the processing stage, linkages between farmers and cooperative societies will be established including the rehabilitation and /or establishment of new ones to facilitate cooperatives' cross-border and trans-national activities. Also, at this stage, renewable energy efficient drying, processing and packaging technologies will be introduced to improve post-harvest handling of staple crops to reduce losses after harvest, and add market value especially for cashew, mango, and other cash crops. At each investment stage, women will constitute at least 50% of the target beneficiaries.

- **Component 2: Promotion of climate resilient agricultural practices and technologies adoption among smallholder farmers -** Under this component, the programme will invest in the promotion and use of CRA practices and technology uptake among agricultural value chain actors in the three selected SCPZ countries. At the production stage, the programme will invest in the adoption of CRA practices and technology uptake such as, use of drought resistance or SGC crops, integrated nutrient management, and sustainable agro-forestry practices. It will also involve capacity building of value chains agents/communities’ and development of agricultural processing support infrastructure such as: 1) O&M learning and training, management, business planning, stakeholder engagement, contract negotiation, PPP arrangements, governance, project performance monitoring, reporting and evaluation (M&E), investment mobilization and support, and investment promotion among others; and, 2) training and capacity building of value chain actors in the use of ‘Good Agricultural Practices’ in product quality, standardization and conformity requirements, as well as developing linkages and responding to commodity demand in terms of quality and quantity. Lastly, under this component, the programme will support investment in biogas technologies to improve diversification, value addition, productivity and profitability across the agricultural value chain

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7. APPENDIX

Appendix I – Data and Methods

This section summarizes the key elements of the methodology used for climate analysis. Firstly, the historical climate of the regions of interest is presented. Thereafter, the future climate under different emission scenarios is analyzed. Also, the section describes the Regional Climate Models (RCMs) used for the downscaled simulations including the data used for evaluating the baseline simulations. The baseline climate is taken as the 30-year period from 1976 to 2005 and compared with different climate periods in the current (i.e., 2006 – 2035 and 2011-2040) and future (i.e., 2036-2065, 2041-2070, and 2071-2100). The model evaluation is performed based on annual cycle, climatological mean and trends in annual values of precipitation, minimum and maximum temperatures.

Climate Change Scenario

Basically, two representative concentration pathways (RCPs) were used-RCP4.5 (low-medium emission) and RCP8.5 (high emission). Under RCP 4.5, emissions peak around 2040 before declining and this requires that carbon dioxide (CO2) emissions start declining by approximately 2045 to reach roughly half of the levels of 2050 by 2100. It also requires that methane emissions (CH4) stop increasing by 2050 and decline somewhat to about 75% of the CH4 levels of 2040, and that sulphur dioxide (SO2) emissions decline to approximately 20% of those of 1980–1990[27]. In the RCP4.5 scenario, radiative forcing is expected to stabilize at $4.5\ W\ m^{-2}$ in the year 2100 without ever exceeding that value[28]. RCP8.5 is generally considered as the basis for worst-case (business-as-usual) climate change scenarios, and was based on what proved to be overestimation of projected coal outputs. In RCP 8.5 emissions continue to rise throughout the 21st century thereby stabilizing the radiative forcing at 8.5 Wm^{-2}. The use of the RCPs scenario provides a common platform for the RCMs used, to explore the climate system response to stabilizing the anthropogenic components of radiative forcing. By extending the simulations until 2065, the range in radiative forcing across RCPs is small compared to their dispersion in 2100[29].

Station data

Daily station precipitation, minimum and maximum temperature data from 1981-2010 were analyzed for selected stations within the SCPZs (Table 1). These datasets are extracted from the archives of the National Meteorological Services of the corresponding host countries. The datasets were used to evaluate the performance of the RCMs in terms of their representation of annual trends and variability. Furthermore, the daily series were used to generate project-scale climate indices relevant to agriculture as defined by WMO Expert Team Sector-Specific Climate Indices (ET-SCI)[30]. Analysis of trends in the indices in order to investigate the direction, magnitude and deviation of the index from the climatological mean is also presented.

Table 2. Selected meteorological stations within the SCPZ of the three host countries

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[27] https://ar5-syr.ipcc.ch/topic_futurechanges.php

[28] Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, et al. The next generation of scenarios for climate change research and assessment. Nature. 2010; 463: 747±756. https://doi.org/10.1038/nature08823 PMID: 20148028

[29] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In Stocker T. F., Qin D.,Plattner G.-K., Tignor M., Allen S. K., Boschung J., . . . Midgley P. M. (Eds.) (p. 1535). United Kingdom and New York, NY, USA.: Cambridge University Press.

[30] https://climpact-sci.org/indices/

Country	Region	Station	Latitude	Longitude
Guinea	Boke	Boke	10.93532	-14.28633
	Kankan	Kankan	10.38886	-9.29399
Togo	Kara	Kara	9.62788	1.20357
		Niamtougou	9.8	1.083333
Senegal	Southern Agropole	Zinguinchor	12.5	-16.272
		Kolda	12.888	-14.972
		Velingara	13.15	-14.1

Gridded observation

Station-based gridded rainfall and surface temperature from the Climate Research Unit (CRU)[31] were used for evaluating the downscaled simulations. Specifically, the CRU Time-Series (TS) version 4.02 - CRU TS4.02[32] was used, supplemented with Stations Data from the University of California in Santa Barbara Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)[33]. The CRU station-based gridded dataset is produced by angular-distance weighting interpolation of station observations onto a 0.5° grid[34]. It is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observations. The dataset is available from 1901 to near present on a monthly time scale by the inclusion of additional station observations[35]. CRU temperature is widely used and has also been applied for correcting reanalysis data to apply them to impact modeling[36],[37]. Although CRU is a purely station-based dataset, the reliability of CRU data varies spatially due to station sparsity, especially in the data spare continent like Africa. However, this dataset fulfills most of the IPCC climatological baseline criteria reported in IPCC Technical guidelines for assessing climate change impacts and adaptations (IPCC AR6, 2021[38]):

- It is representative of the present-day or recent average climate in the study regions;
- It is of sufficient duration to encompass a wide range of climatic variations in the regions;
- It sufficiently covers a period for which data on all climatological variables are abundant in the regions, and readily available;
- It is of sufficient quality for use in assessing climate impacts in the regions; and,
- The dataset is consistent with the current WMO recommended period (30 years) adopted in impact assessment.

[31] http://badc.nerc.ac.uk/data/cru/.

[32] Harris, I.C.; Osborne, T.; Jones, P.; Lister, D. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Sci. Data 2020, 7, 2052–4463

[33] Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, et al. The climate hazards infrared precipitation with stations a new environmental record for monitoring extremes. Scientific Data, 2015;2: 150066. https://doi.org/10.1038/sdata.2015.66 PMID: 26646728

[34] Harris, I.; Jones, P.D.; Osborn, T.J.; Lister, D.H. Updated high-resolution grids of monthly climatic observations—The CRU TS3.10 Dataset. Int. J. Climatol. 2014, 34, 623–642.

[35] Ibid 11.

[36] Weedon, G.P.; Balsamo, G.; Bellouin, N.; Gomes, S.; Best, M.J.; Viterbo, P. The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-interim reanalysis data. Water Resour. Res.2014, 50, 7505–7514.

[37] Mitchell, T. D., & P. D. Jones, 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int. J. Climatol. , 25, 693–712

[38] https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

The gridded data analyzed were derived from the area average that represents the region of interest as shown in Figure 1 below.

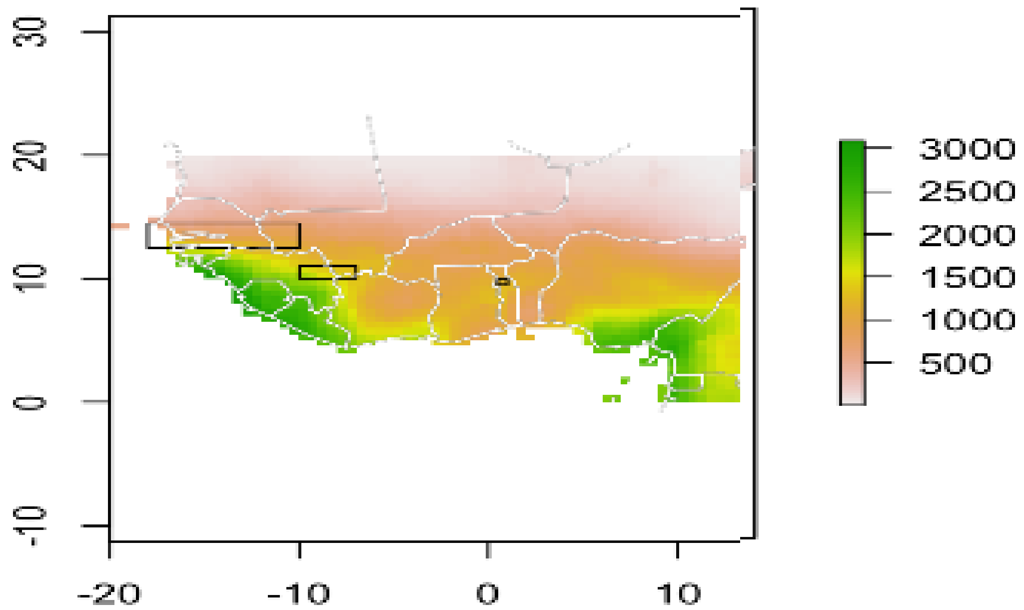

Figure 18. Map showing the outline of the area blocks (black boxes) where data was extracted from and the average annual total rainfall amount derived from CRU for the period 1976–2005

Another useful precipitation data source is the daily rainfall dataset from CHIRPS[39]. It uses TIR imagery and gauge data in addition to a monthly precipitation climatology, CHPClim, and atmospheric model rainfall fields from the NOAA Climate Forecast System, version 2 (CFSv2). CHIRPS is gridded precipitation data created from a blend of high-resolution satellite imagery (at 0.05°) and station-based data to produce a 0.25° horizontal resolution data. The CRU gridded datasets were also compared with the resolution of ERA5 reanalysis daily maximum and minimum temperature fields. ERA-5 is the fifth generation of the European Centre for Medium Range Weather Forecasts (ECMWF) reanalysis produced by combining the Integrated Forecast System with data assimilation[40]. ERA5 reanalysis is produced at a spatial resolution of 0.25° grid and at hourly time intervals.

The Regional Climate Models

The long-term climate simulations carried out in the analyses are produced by three regional climate models (RCMs) participating in the Coordinated Regional Climate Downscaling Experiment (CORDEX) framework[41]. The RCMs include: (i) the Swedish Meteorological and Hydrological Institute, Rossby Centre (SMHI-RCA v4), (ii) the Climate Limited-area Modelling Community (CCLM v4.8.17) and (iii) the Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology (REMO2009). Common to these regional climate models is the global circulation model (i.e., the Maxx Planck's Earth Systems Model low resolution runs) that was used as initial and boundary conditions to force the historical simulations and future projections. These RCMs have been extensively used for

[39] Funk, C. et al. (2015) 'The climate hazards infrared precipitation with stations--a new environmental record for monitoring extremes', Scientific data, 2(1), p. 150066.

[40] Hersbach, H. et al. (2020) 'The ERA5 Global Reanalysis: achieving a detailed record of the climate and weather for the past 70 years'. doi: 10.5194/egusphere-egu2020-10375.

[41] https://cordex.org/data-access/esgf/

weather forecasts, seasonal forecasts, and climate change studies over Africa[42,43, 44, 45,46, 47,48]. The CORDEX RCMs downscale many global climate models (GCMs) from the Coupled Model Intercomparison Project, Phase 5 (Taylor et al., 2012[49]; Sylla *et al.*, 2016[50]). The RCMs are run over the whole of Africa at 44 km resolution. To date, the CORDEX-Africa data constitute the most comprehensive RCMs projections available for the continent.

Owing to the fact that observational data are sparsely distributed over much of the target areas, and even when they exist, most of these datasets are inconsistent (e.g., missing or erroneous data) in many parts of African countries (IPCC 1994[51]; Kalognomou *et al.*, 2013[52]; Sylla *et al.*, 2013[53]; Shongwe *et al.*, 2015[54]; Girvetz et al. 2019[55]), independent observations of the same variable and the model ensemble were used in line with IPCC recommendations as follows:

> *'Although crucial, the evaluation of climate models based on past climate observations has some important limitations. By necessity, it is limited to those variables and phenomena for which observations exist. In many cases, the lack or insufficient quality of long-term observations be it a specific variable, an important process, or a particular region, remains an impediment. In addition, owing to observational uncertainties and the presence of internal variability, the observational record against which models are assessed is 'imperfect'. These limitations can be reduced, but not entirely eliminated, through the use of multiple*

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[42] Fotso-Nguemo, T.C., Vondou, D.A., Pokam, W.M., Djomou, Z.Y., Diallo, I., Haensler, A., Tchotchou, L.A.D., Kamsu-Tamo, P.H., Gaye, A.T. and Tchawoua, C., 2017. On the added value of the regional climate model REMO in the assessment of climate change signal over Central Africa. Climate Dynamics, 49(11), pp.3813-3838.

[43] Akinsanola, A.A., Ogunjobi, K.O., Gbode, I.E. and Ajayi, V.O., 2015. Assessing the capabilities of three regional climate models over CORDEX Africa in simulating West African summer monsoon precipitation. Advances in Meteorology, 2015.

[44] Sawadogo et al. (2020). Current and future potential of solar and wind energy over Africa using the RegCM4 CORDEX-CORE ensemble. *Climate Dynamics*, 1-26.

[45] Dosio et al. (2020). A tale of two futures: contrasting scenarios of future precipitation for West Africa from an ensemble of regional climate models. *Environmental Research Letters*, 15 (6), 064007.

[46] Kebe et al. (2020). Late 21st Century Projected Changes in the Relationship between Precipitation, African Easterly Jet, and African Easterly Waves. *Atmosphere.11 (4), 353.*

[47] Mbaye et al. (2019). Impacts of 1.5 and 2.0 ◦C Global Warming on Water Balance Components over Senegal in West Africa. *Atmosphere* **2019**, *10*(11), 712; https://doi.org/10.3390/atmos10110712.

[48] Gibba et al. (2019). State-of-the-art climate modeling of extreme precipitation over Africa: analysis of CORDEX added-value over CMIP5. *Theoretical and Applied Climatology*, 137 (1), 1041-1057.

[49] Taylor, K.E., Stouffer, R.J. and Meehl, G.A. (2012), "An overview of CMIP5 and the experiment design", Bulletin of the American Meteorological Society, Vol. 93 No. 4, pp. 485-498.

[50] Sylla, M.B., Elguindi, N., Giorgi, F. and Wisser, D. (2016), "Projected robust shift of climate zones over West Africa in response to anthropogenic climate change for the late 21st century", Climatic Change, Vol. 134 Nos 1/2, pp. 241-253.

[51] IPCC (1994). IPCC Technical guidelines for assessing climate change impacts and adaptations. University College London and Center for Global Environmental Research.

[52] Kalognomou E-A, Lennard C, Shongwe M, Pinto I, Favre A, Kent M, Hewitson B, Dosio A, Nikulin G, Panitz H-J, B"chner M. 2013. A diagnostic evaluation of precipitation in CORDEX models over southern Africa. *Journal of Climate* **26**: 9477–9506.

[53] Sylla MB, Giorgi F, Coppola E, Mariotti L. 2013. Uncertainties in daily rainfall over Africa: assessment of gridded observation products and evaluation of a regional climate model simulation. *International Journal of Climatology* **33**: 1805–1817.

[54] Shongwe et al. 2015. An evaluation of CORDEX regional climate models in simulating precipitation over Southern Africa. *Atmos. Sci. Let.* **16**: 199–207 (2015).

[55] Girvetz E. et al. (2019) Future Climate Projections in Africa: Where Are We Headed?. In: Rosenstock T., Nowak A., Girvetz E. (eds) The Climate-Smart Agriculture Papers. Springer, Cham. https://doi.org/10.1007/978-3-319-92798-5_2.

independent observations of the same variable as well as the use of model ensembles' (IPCC, 2013)[56].

Prior to the analysis covering the historical period, spatial correlation was done between the CRU observations and simulated precipitation and mean 2-metre temperature patterns derived from the 3 RCMs and their ensemble mean (Table 2). The spatial correlation between the simulated precipitation pattern by the ENS model, the RCMs and CRU. DJF is the season when the 3 RCMs and the ENS-model precipitation exhibit the highest correlations. Results indicate that the ENS provides added value to the simulations over the three RCMs. In all seasons, the spatial pattern of temperature is better reproduced by the ENS model when compared to the individual model runs. For the highly variable precipitation, the pattern correlation is low and comparable between the CCLM model and ENS. Although the pattern correlation between ENS model simulations and CRU observations are lower for precipitation than for temperature, these correlations are still much higher than with the individual model simulations, except for DJF, MAM, and JJA when the CCLM correlates better with CRU observations.

Table 3. Pattern correlations between the CCLM, SMHI, REMO simulations and observations, and between ENS simulations and observations, for DJF, MAM, JJA, and SON trimesters over the West African Domain.

2-m Temperature					
RCMs/season	DJF	MAM	JJA	SON	Annual
CCLM	0.88	0.82	0.82	0.85	0.84
SMHI	0.87	0.82	0.83	0.85	0.84
REMO	0.81	0.81	0.82	0.9	0.84
ENS	0.9	0.88	0.88	0.93	0.90
Precipitation					
CCLM	0.39	0.32	0.38	0.22	0.33
SMHI	0.38	0.3	0.34	0.23	0.31
REMO	0.38	0.31	0.33	0.22	0.31
ENS	0.38	0.31	0.35	0.23	0.32

DJF = December -January - February; **MAM** = March - April - May; **JJA** = June - July - August; **SON** = September -October - November.

Appendix II

Analysis of projected change in the selected climate extreme in the selected region of the SCPZ. The change in current-near term (2011-2040), mid-century (2041-2070) and long term (2071-2100) are computed relative to the baseline (1976-2005) for the RCMs under RCP4.5 and RCP8.5 emission scenarios.

(a) Togo

[56] IPCC (2013). Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Heat stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Togo	Kara	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase
	Niamtougou	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase

Flood indicators					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Togo	Kara	rx1day_RCP45	Increase	Decrease	Increase
		rx1day_RCP85	Increase	Increase	Increase
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Decrease	Decrease
		r99ptot_RCP45	Increase	Decrease	Increase
		r99ptot_RCP85	Increase	Increase	Increase
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Decrease	Decrease	Decrease
		cwd_RCP85	Decrease	Increase	Decrease
	Niamtougou	rx1day_RCP45	Increase	Increase	Decrease
		rx1day_RCP85	Decrease	Increase	Decrease
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Decrease	Decrease
		r99ptot_RCP45	Increase	Increase	Increase
		r99ptot_RCP85	Increase	Increase	Decrease
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Decrease	Decrease	Decrease
		cwd_RCP85	Decrease	Decrease	Decrease

Water (Drought) stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Togo	Kara	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Increase	Increase	Increase
		cdd_RCP85	Decrease	Increase	Increase
	Niamtougou	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase

		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Increase	Increase	Increase
		cdd_RCP85	Decrease	Increase	Increase

(b) Senegal

Heat stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Senegal	Kolda	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase
	Velingara	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase
	Zinguinchor	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase

		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase

Flood indicators					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Senegal	Kolda	rx1day_RCP45	Increase	Decrease	Increase
		rx1day_RCP85	Increase	Increase	Increase
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Decrease	Decrease
		r99ptot_RCP45	Increase	Decrease	Increase
		r99ptot_RCP85	Increase	Increase	Increase
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Decrease	Decrease	Decrease
		cwd_RCP85	Decrease	Increase	Decrease
	Velingara	rx1day_RCP45	Increase	Increase	Decrease
		rx1day_RCP85	Decrease	Increase	Decrease
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Decrease	Decrease
		r99ptot_RCP45	Increase	Increase	Increase
		r99ptot_RCP85	Increase	Increase	Decrease
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Decrease	Decrease	Decrease
		cwd_RCP85	Decrease	Decrease	Decrease
	Zinguinchor	rx1day_RCP45	Decrease	Decrease	Decrease
		rx1day_RCP85	Decrease	Increase	Decrease
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Decrease	Decrease
		r99ptot_RCP45	Decrease	Decrease	Decrease
		r99ptot_RCP85	Decrease	Increase	Increase
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Increase	Decrease	Decrease
		cwd_RCP85	Increase	Decrease	Decrease

Water (Drought) stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Senegal	Kolda	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Increase	Increase	Increase
		cdd_RCP85	Decrease	Increase	Increase
	Velingara	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Increase	Increase	Increase
		cdd_RCP85	Decrease	Increase	Increase
	Zinguinchor	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Decrease	Increase	Increase
		cdd_RCP85	Decrease	Increase	Increase

(c) Guinea

Heat stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Guinea	Kankan	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase

		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase
	Boke	txx_RCP45	Increase	Increase	Increase
		txx_RCP85	Increase	Increase	Increase
		hwd_RCP45	Increase	Increase	Increase
		hwd_RCP85	Increase	Increase	Increase
		wsdi_RCP45	Increase	Increase	Increase
		wsdi_RCP85	Increase	Increase	Increase
		hwa_RCP45	Increase	Increase	Increase
		hwa_RCP85	Increase	Increase	Increase
		hwm_RCP45	Increase	Increase	Increase
		hwm_RCP85	Increase	Increase	Increase
		tnn_RCP45	Increase	Increase	Increase
		tnn_RCP85	Increase	Increase	Increase

Flood indicators					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Guinea	Kankan	rx1day_RCP45	Increase	Increase	Increase
		rx1day_RCP85	Increase	Increase	Increase
		prcptot_RCP45	Increase	Decrease	Increase
		prcptot_RCP85	Decrease	Increase	Decrease
		r99ptot_RCP45	Increase	Increase	Increase
		r99ptot_RCP85	Increase	Increase	Increase
		r10mm_RCP45	Increase	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Increase	Decrease	Increase
		cwd_RCP85	Decrease	Increase	Decrease
	Boke	rx1day_RCP45	Increase	Decrease	Increase
		rx1day_RCP85	Decrease	Increase	Increase
		prcptot_RCP45	Decrease	Decrease	Decrease
		prcptot_RCP85	Decrease	Increase	Decrease
		r99ptot_RCP45	Increase	Increase	Increase

		r99ptot_RCP85	Increase	Increase	Increase
		r10mm_RCP45	Decrease	Decrease	Decrease
		r10mm_RCP85	Decrease	Decrease	Decrease
		cwd_RCP45	Decrease	Decrease	Decrease
		cwd_RCP85	Decrease	Decrease	Decrease

Water (Drought) stressors					
Country	Region	Indicator	C2011_2040	C2041-2070	C2071_2100
Guinea	Kankan	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Increase	Increase	Increase
		cdd_RCP85	Increase	Increase	Increase
	Boke	spi_RCP45	Increase	Increase	Increase
		spi_RCP85	Increase	Increase	Increase
		spei_RCP45	Increase	Increase	Increase
		spei_RCP85	Increase	Increase	Increase
		cdd_RCP45	Decrease	Increase	Increase
		cdd_RCP85	Decrease	Decrease	Increase

Appendix III
Flood Indicators

Figure A3.1 Projected change in selected flood indicators in Senegal for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005). See Appendix I for the description of regional climate model used and the definition of the climate indices presented in Table 1 of the main document.

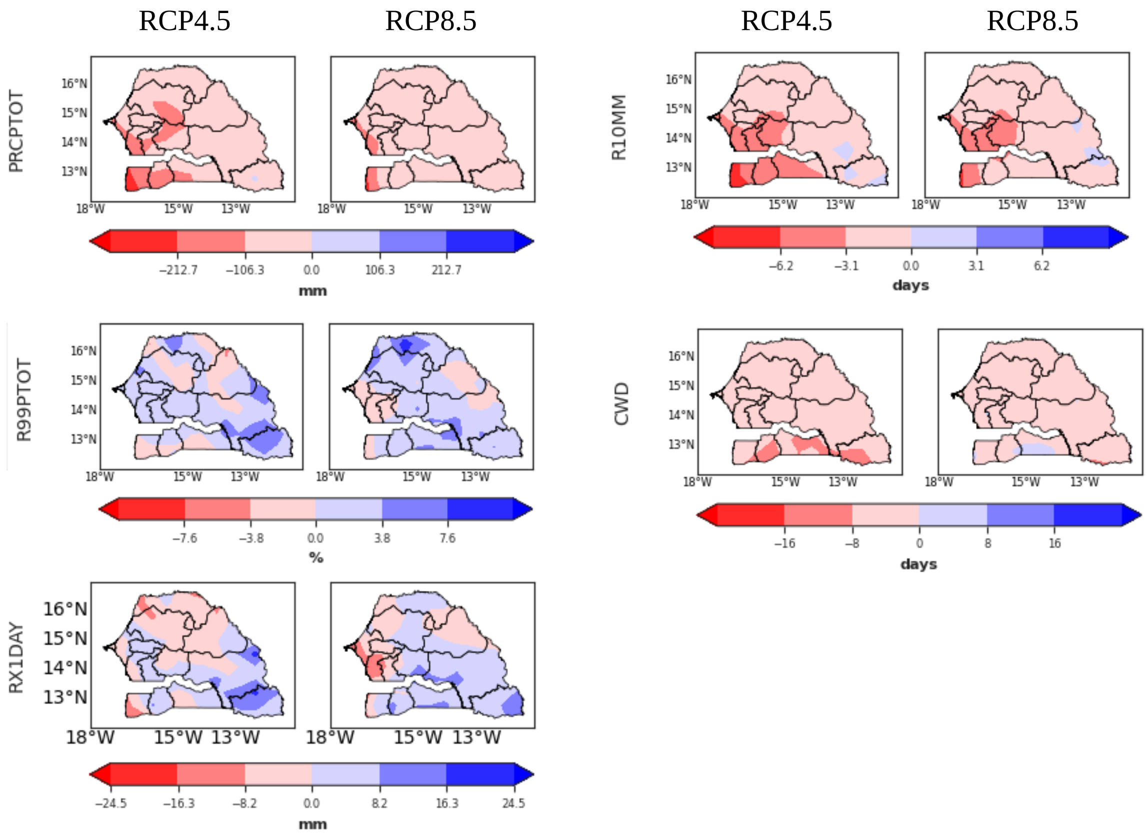


Figure A3.2 Projected change in selected flood indicators in Senegal for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

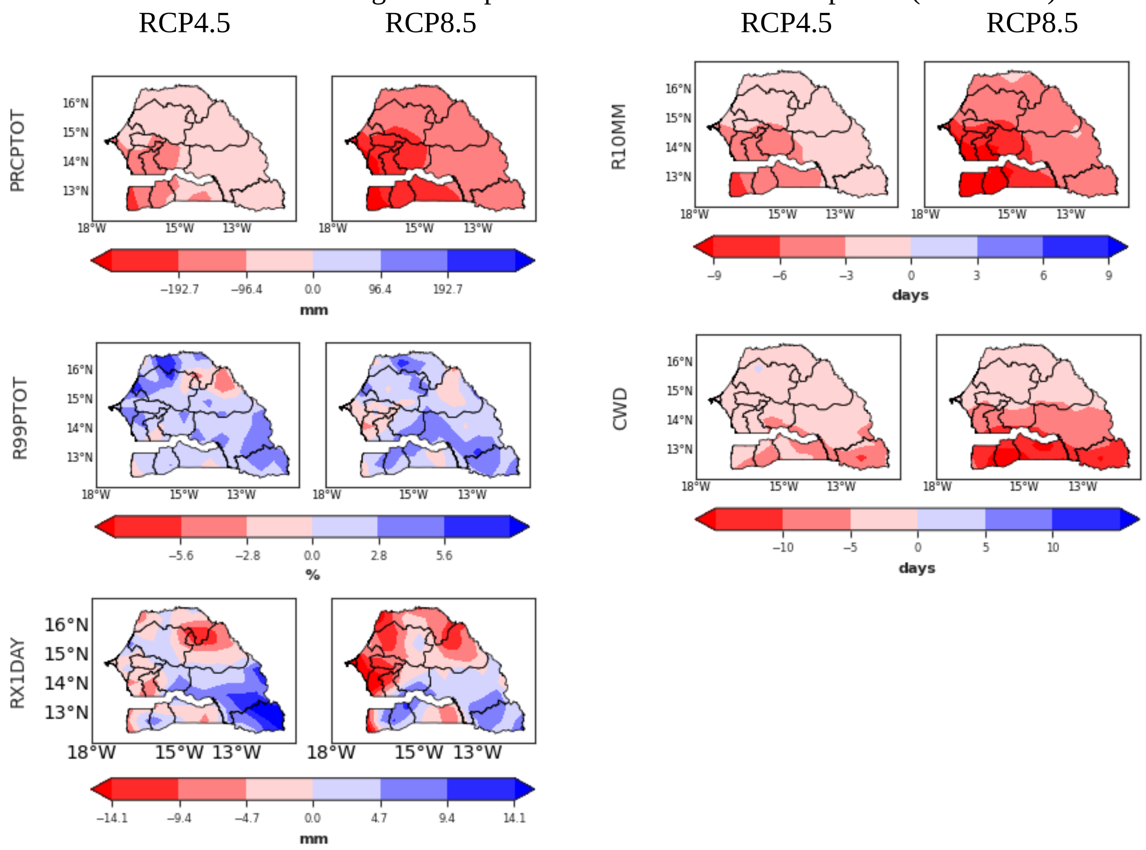


Figure A3.3 Projected change in selected flood indicators in Togo for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

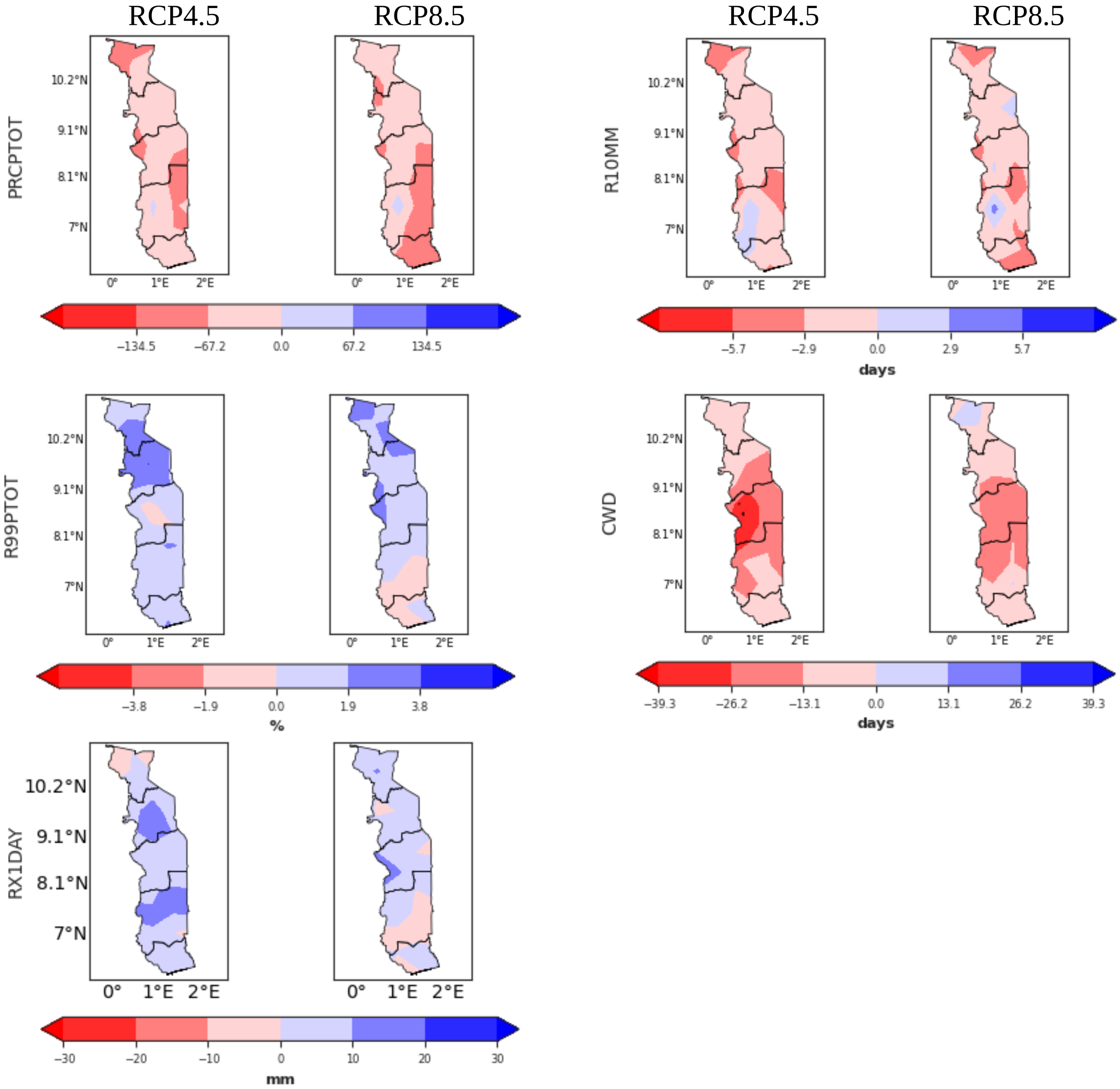


Figure A3.4 Projected change in selected flood indicators in Togo for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

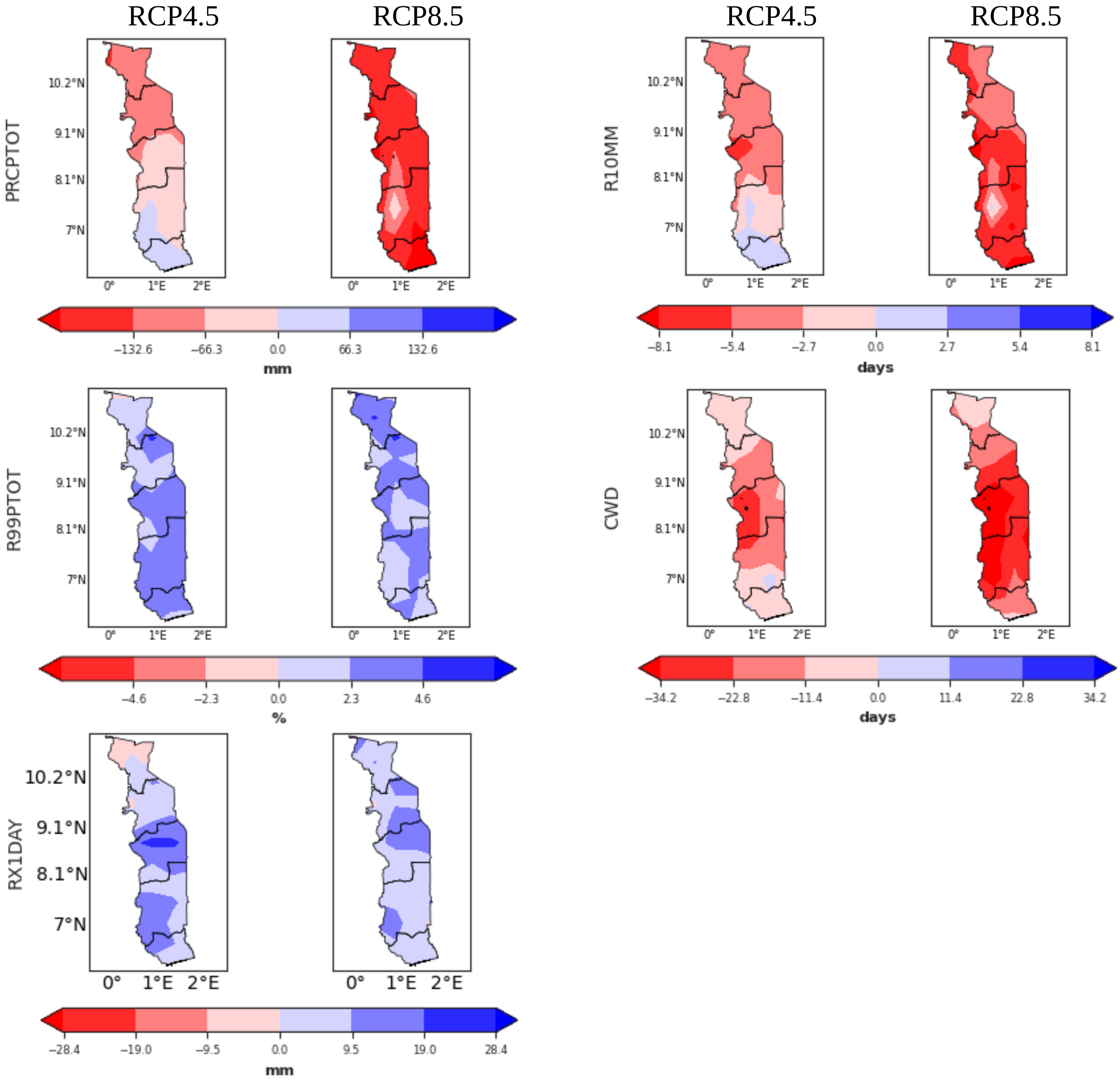


Figure A3.5 Projected change in selected flood indicators in Guinea for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

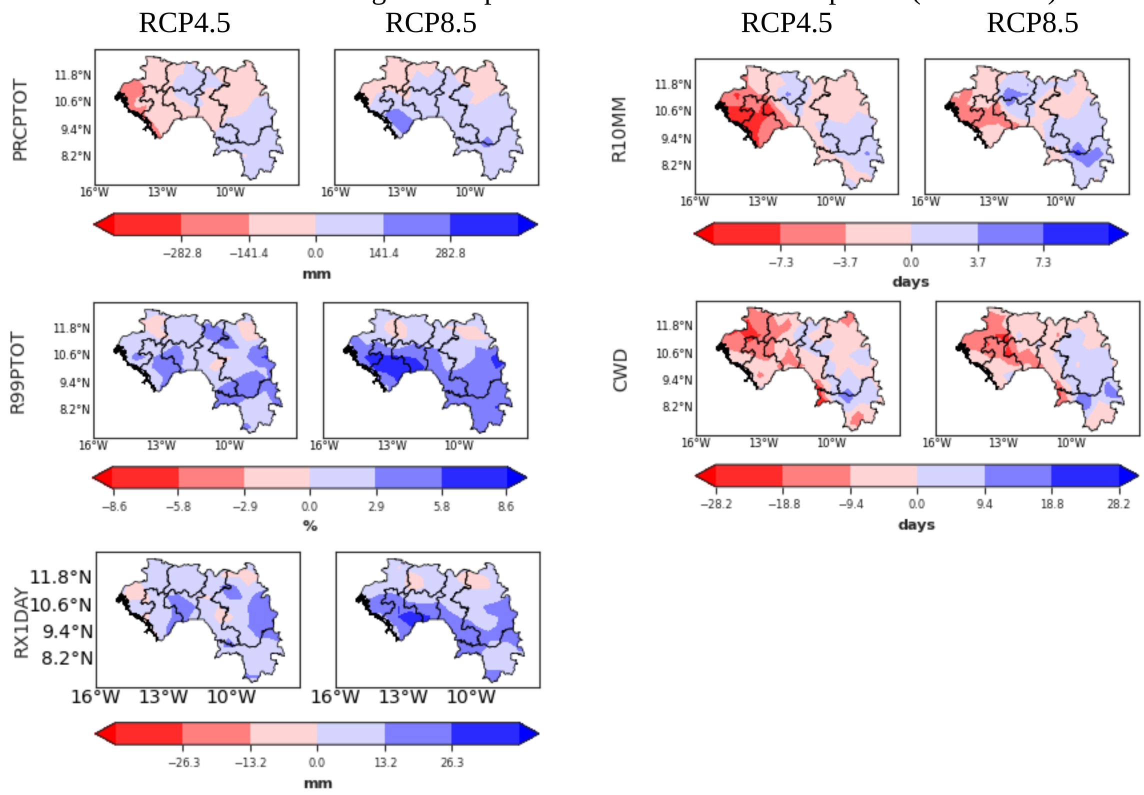
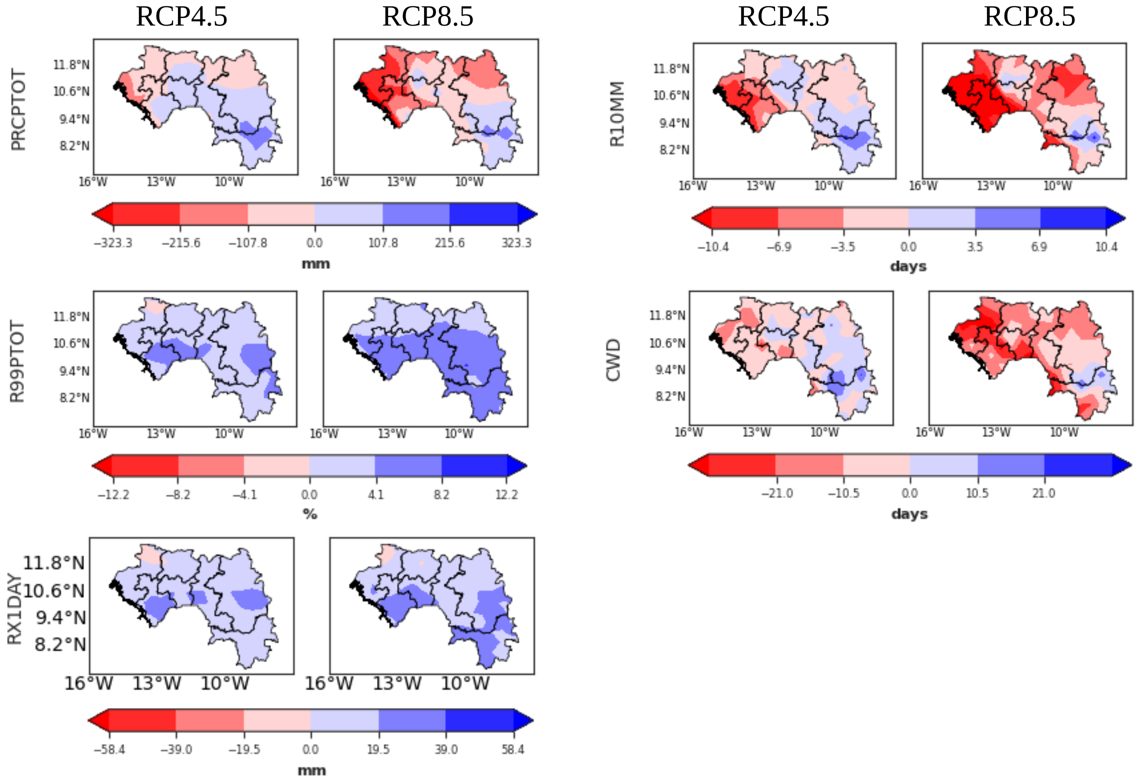


Figure A3.6 Projected change in selected flood indicators in Guinea for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).



Heat stressors

Figure A3.7 Projected change in selected Heat stress indices in Senegal for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

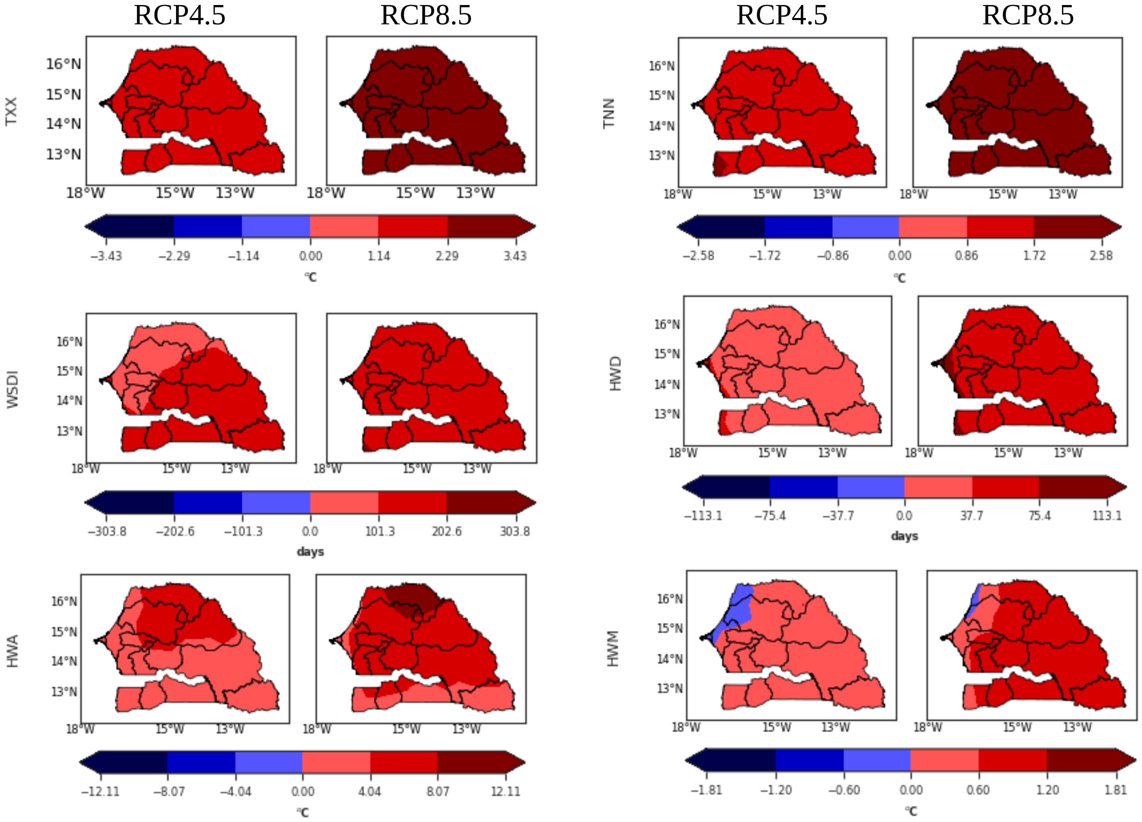


Figure A3.8 Projected change in selected Heat stress indices in Senegal for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

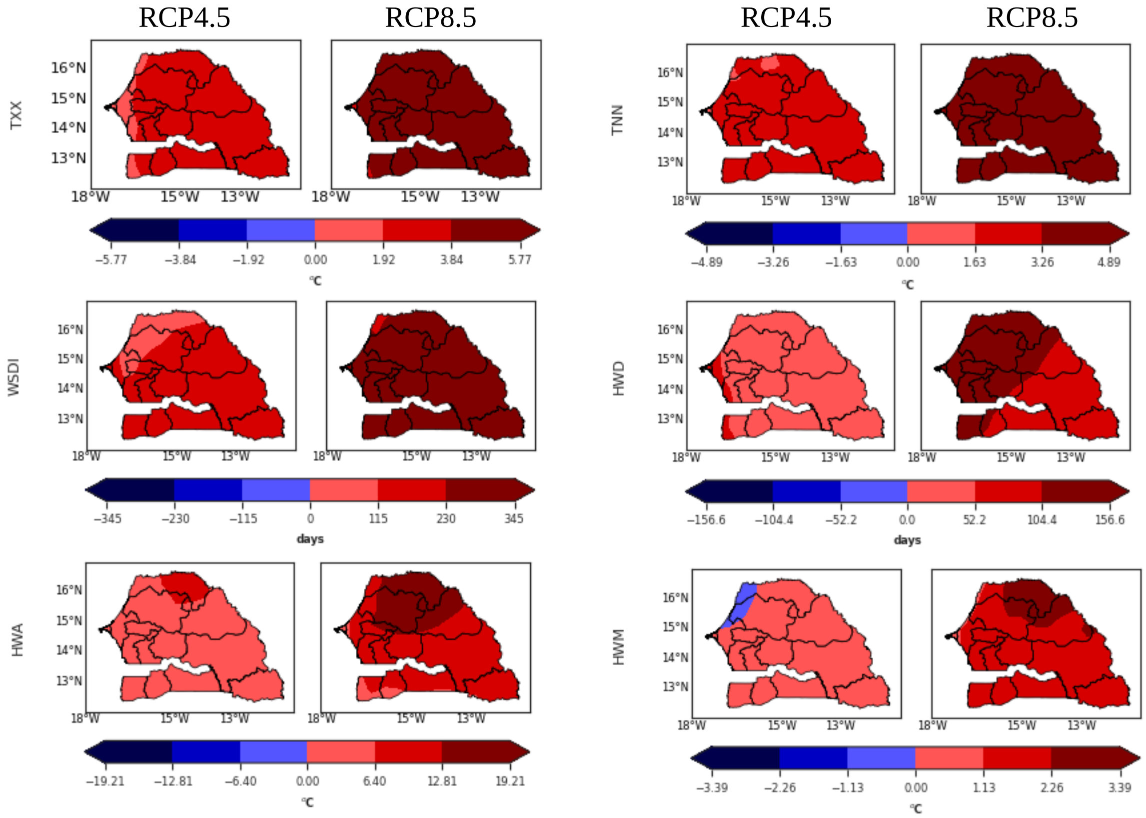


Figure A3.9 Projected change in selected Heat stress indices in Togo for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

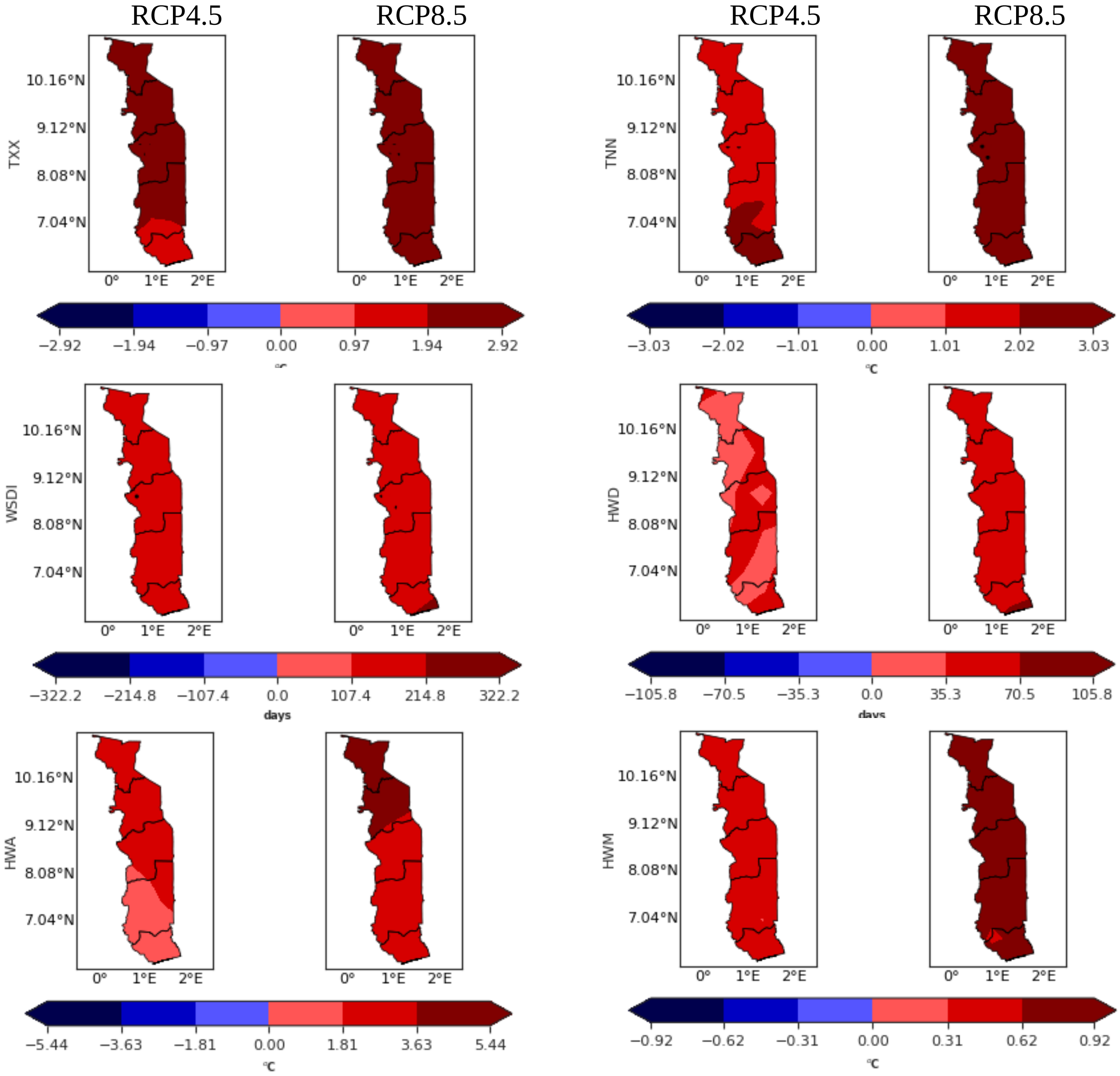
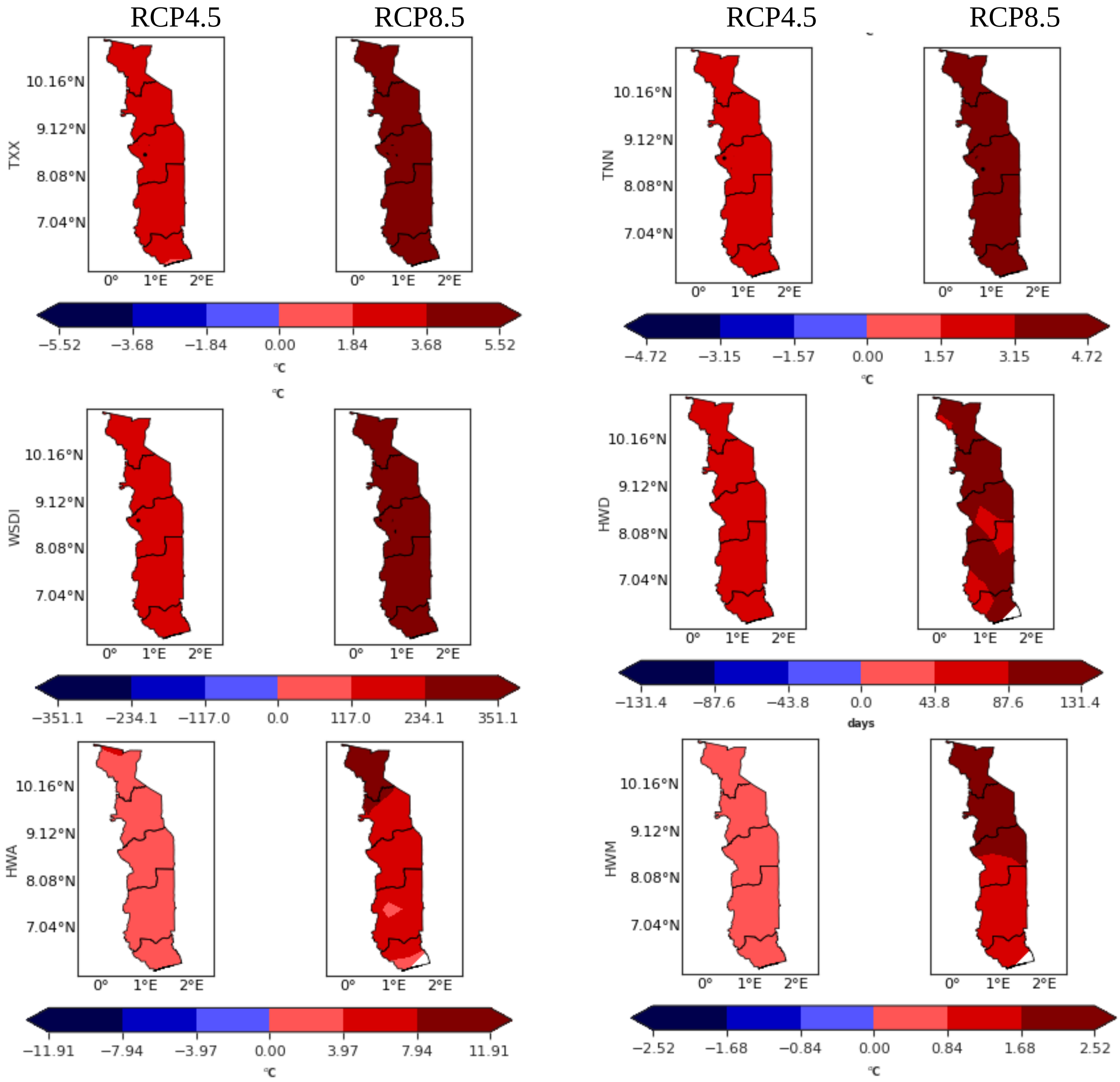


Figure A3.10 Projected change in selected Heat stress indices in Togo for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).



Water stressors

Figure A3.10 Projected change in selected water stress indicators in Senegal for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

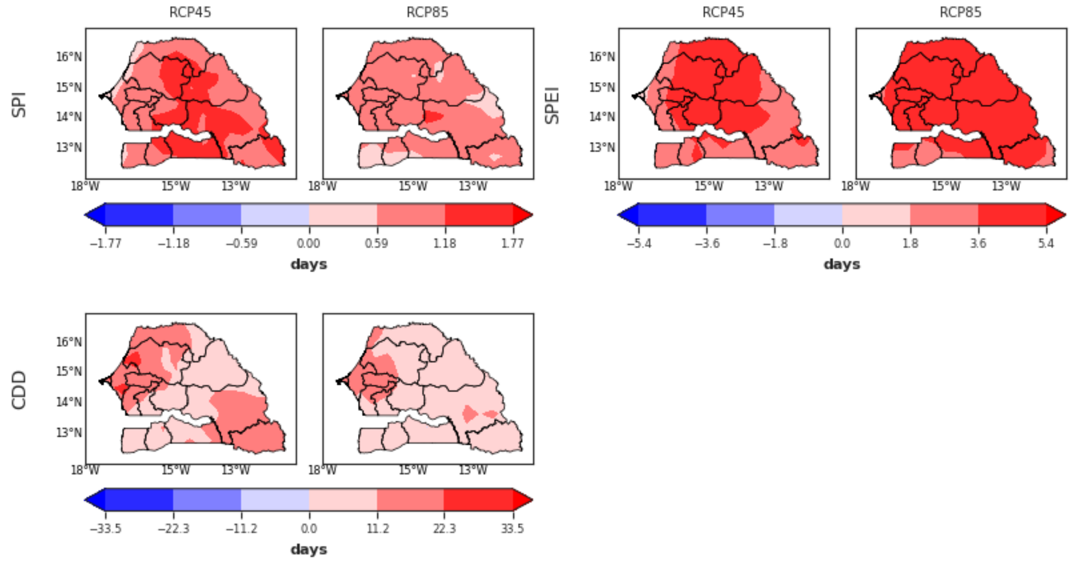


Figure A3.11 Projected change in selected water stress indicators in Senegal for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

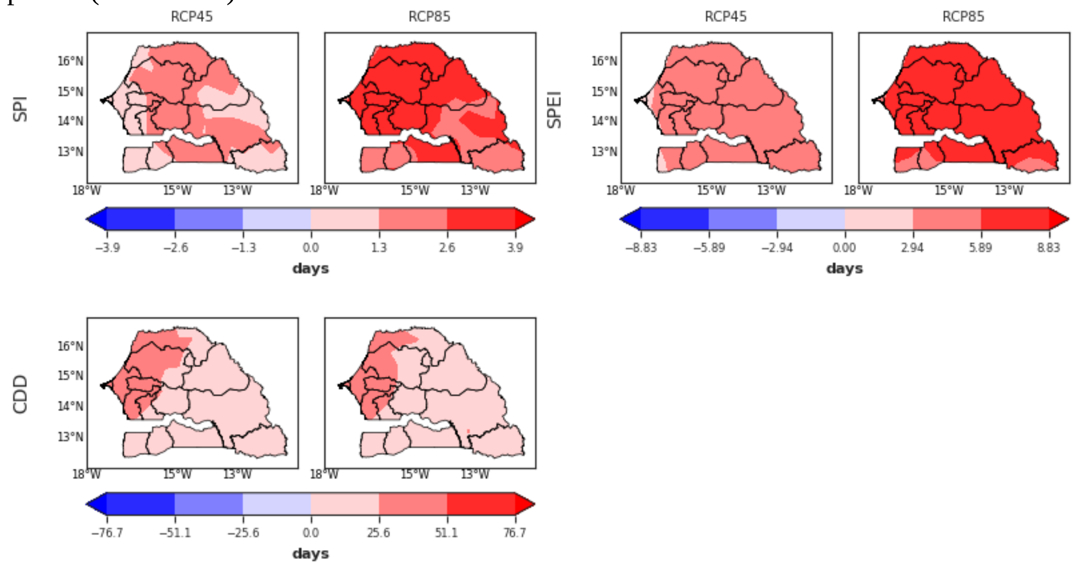


Figure A3.12 Projected change in selected water stress indices in Togo for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

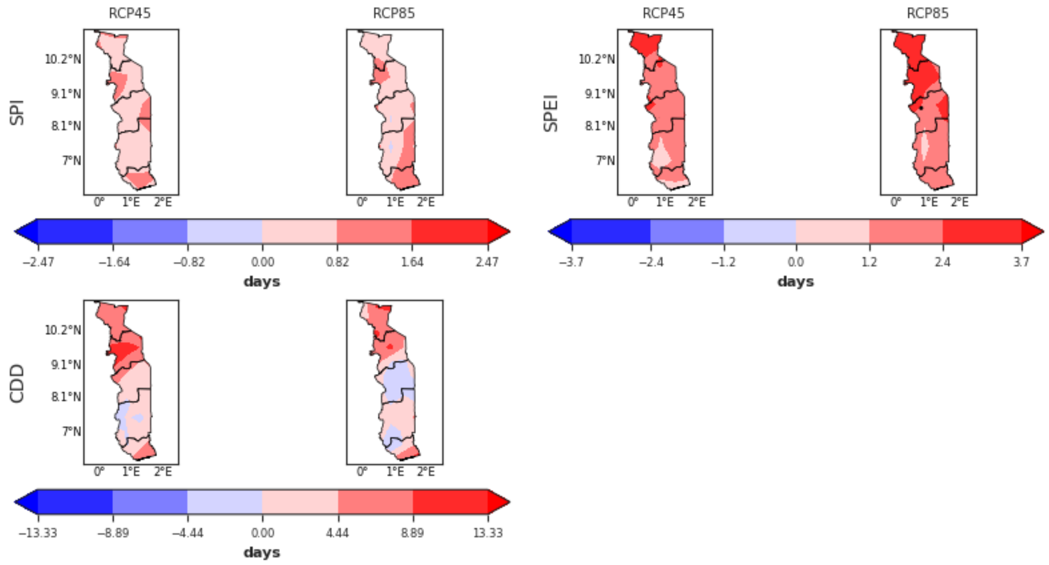


Figure A3.13 Projected change in selected water stress indices in Togo for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

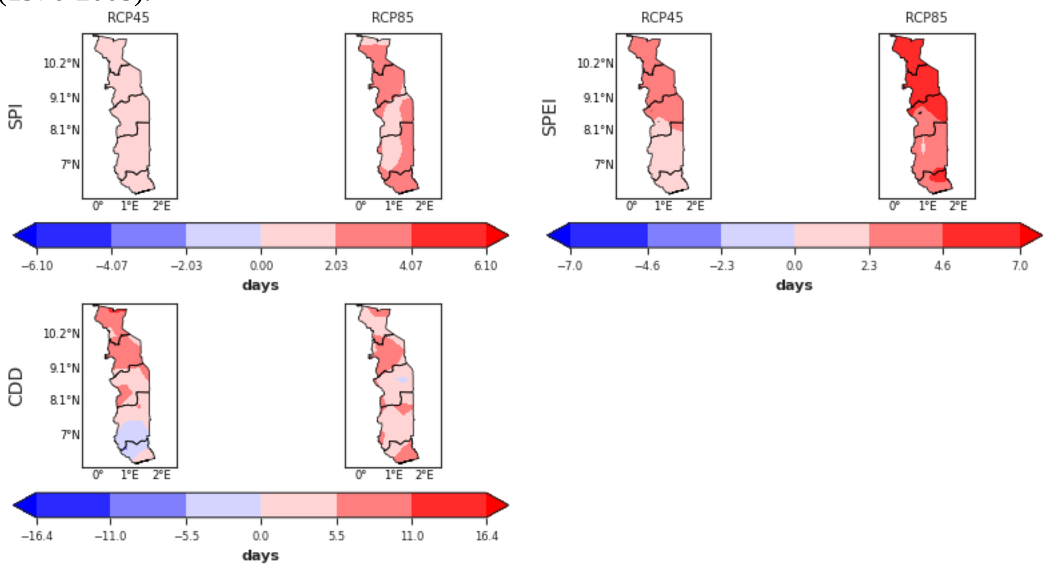


Figure A3.10 Projected change in selected water stress indices in Guinea for the period 2041-2070 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).

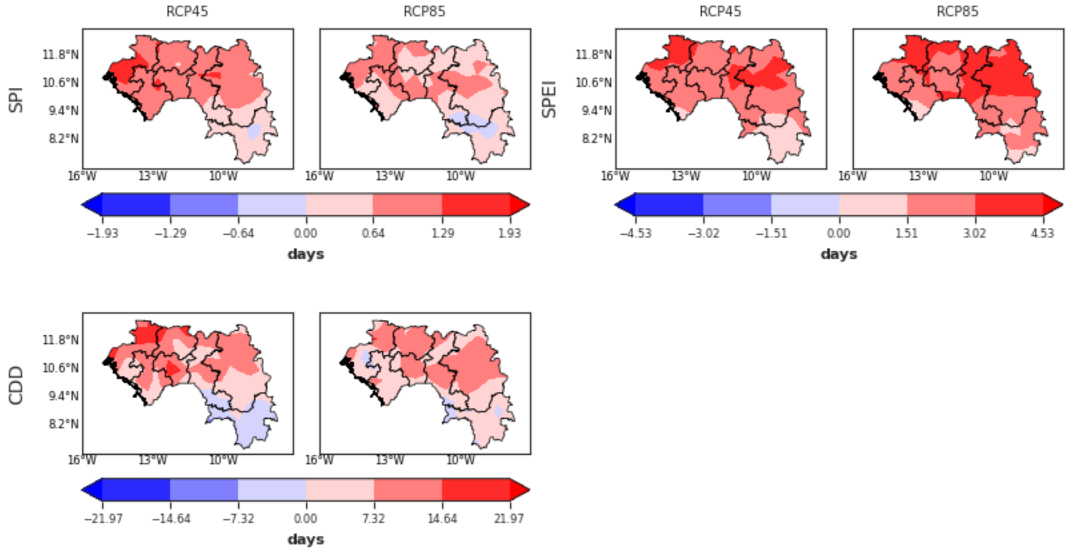


Figure A3.11 Projected change in selected water stress indices in Togo for the period 2071-2100 under RCP4.5 and RCP8.5. The change is computed relative to the baseline period (1976-2005).