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WFP Critical Corporate Initiative: Climate Response Analysis for Adaptation

Guinea-Bissau

Alliance

Bioversity International
CIAT International Center for Tropical Agriculture Since 1967 Science to cultivate change
CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

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Key messages

CONTEXT

Guinea-Bissau is a low-income, food-deficit country with significant development challenges and high vulnerability to climate change. High levels of poverty, political instability, a general absence of employment opportunities, and a lack of basic services especially in rural areas dominate the socioeconomic profile of the country. The adaptive capacity of the largely poor and food-insecure rural population is low, yet climate change impacts already manifest in increasing occurrences of droughts, flooding, and waterlogging. To better respond to and anticipate the needs of the local population under current and future arising climate challenges, the present report provides an assessment of future projections of climate change impacts on food and nutrition security and vulnerability indicators and elaborates recommendations for climate adaptation response programming for World Food Programme (WFP) operations in four livelihood zones (LZs): the eastern highlands (LZ1), northeastern plains (LZ2), northern coastal zone (LZ3), and southern coastal zone (LZ4).

PROJECTED CLIMATE CHANGE IMPACTS THROUGH 2050

- **Although Guinea-Bissau is small, projected climatic changes and recommendations for adaptation responses differ according to the LZ and agroecological conditions.** While climate projections suggest a general warming trend across the whole country, precipitation will likely become more erratic and unpredictable, with some parts receiving more and other parts less precipitation in the future. There is a general precipitation increase projected in the near future (2030) and a subsequent decrease in the medium-term future (2050). The decrease is highest in the northeastern plains and lowest in the southern coastal zone. Accordingly, the flood and waterlogging risk increases in the future particularly in the southern coastal zone and eastern highlands (LZ1 and LZ4), whereas the drought risk increases significantly in the northern part of the country, particularly in the northern coastal zone and northeastern plains (LZ2 and LZ3). With high and increasing temperature levels across the whole country, thermal heat stress is already elevated and will continue to impact human and animal health, being particularly detrimental for livestock productivity.

- **Both coastal zones (LZ3 and LZ4) will also likely be affected by sea level rise in the future.** Sea level rise will impact both the northern and southern coastal zone (LZ3 and LZ4); the southern zone will be most affected, especially around Catió, Cufar, and in estuaries along the border with Guinea. In the north, projections indicate future permanent flooding of a few areas adjacent to estuaries, mainly around Cacheu. Crop production will be impacted by permanent loss of land due to sea encroachment and by increases in flooding and the salinization of fields.

- **Despite projected climatic changes in temperature and precipitation and the related occurrence of droughts and flooding, the suitability of most assessed key crops is projected to remain high throughout Guinea-Bissau.** In particular, the entire country is classified as highly suitable for the cultivation of rice, cashews, and millet in past and future projected scenarios, whereas suitability for cassava is projected to continuously decline from highly suitable to medium-suitable, particularly in eastern parts of Guinea-Bissau towards 2030 and 2050. This trend, however, can be counteracted by adopting heat-tolerant cassava varieties, which will keep suitability in future projections at a high level throughout almost the whole country, except the southern part of the southern coastal zone.

ECONOMETRIC ANALYSIS OF CLIMATE CHANGE IMPACTS OF AVAILABILITY AND STABILITY OF FOOD SUPPLY THROUGH 2050 (IMPACT)

- **According to an economic analysis based on a future scenario involving high global carbon emissions, few mitigation efforts, and improved technology, improvements in agricultural productivity and yield are projected to increase the availability and stability of food supply through 2050.** These increases are likely to decrease levels of hunger and undernourishment by increasing caloric availability and consumption. While these gains are in line with socioeconomic trends, they are due to rapid industrialization, technological innovation, and improving education levels rather than better climatic conditions. On the contrary, agricultural gains will be suppressed by negative climatic trends that prevent the sector from reaching maximum potential productivity. In Guinea-Bissau, the negative climate impact is especially pronounced for groundnuts, and relatively slight for rice, millet, and sorghum. Harvested area, meanwhile, is projected to be considerably higher under climate change (CC) than under the no climate change (No-CC) benchmark, resulting in higher production of these crops under CC despite lower yields. Cassava exhibits considerable resilience, with a projected yield that is higher under CC than under the No-CC benchmark.

- **Additionally, these gains may be distributed unevenly, leading to pockets of entrenched deprivation.** A geospatial hotspot analysis of eight vulnerability dimensions finds different types of vulnerability occurring in tandem across all LZs, with areas facing a high number of overlapping vulnerabilities commonest in the western parts of the northern coastal zone as well as in pockets spread across the remaining LZs, particularly in the northeastern plains and eastern parts of the southern coastal zone. Without effective intervention, current vulnerability indicates a preponderance for future vulnerability, suggesting that national-level gains in agricultural productivity or socioeconomic development may be felt less fully in these areas.

RECOMMENDATIONS AND OPPORTUNITIES FOR FUTURE WORLD FOOD PROGRAMME PROGRAMMING, PARTNERSHIPS, AND FUNDING STREAMS

- **Adaptation recommendations for WFP programming focus on promoting agricultural production measures against droughts, particularly in the northeastern plains and northern coastal zone; against flooding and waterlogging, particularly in southern coastal zone and eastern highlands; and against sea level rise, high tides, and the salinization of crop fields, particularly in coastal areas.** Adaptation measures should be implemented both at household and community level as well as at landscape level. Household- and community-level practices focus on climate-resilient agricultural and livestock production, such as by promoting crop varieties tolerant of droughts or waterlogging, water-saving irrigation, or short-cycle livestock breeds. Landscape-level recommendations, on the other hand, revolve around forest conservation, reforestation, and sustainable use of forest resources. In addition, adaptation recommendations are also given at the policy and institutional level, supporting community- and landscape-level activities with institutional systems and processes including early warning systems, forecast-based finance, mainstreaming of climate change into national and provincial-level policy documents, and improving education and awareness campaigns around climate resilience (Table 2).

- **Adding climate adaptation programming into their portfolio also increases opportunities for WFP to access international climate financing mechanisms for their work in Guinea-Bissau.** Existing climate resilience projects and proposals in the pipeline from other organizations are relatively few yet represent a good indication of suitable funds to approach. These include international funds like the Global Environment Facility, the Green Climate Fund, the Adaptation Fund, the Least Developed Countries Fund, the International Fund for Agricultural Development, the European Union (EU) Global Climate Change Alliance Plus Initiative, and the West African Development Bank. WFP should seek strategic partnerships with organizations to develop joint climate adaptation-focussed project proposals and

Acronyms and abbreviations

AEZ	Agroecological zones
AF	Adaptation Fund
CC / No-CC	Climate Change / No-Climate Change
CGIAR	Consortium of International Agricultural Research Centres
CIAT	International Centre for Tropical Agriculture
CLEAR	Consolidated Livelihood Experience for Analysing Resilience
CSP	Country Strategic Plan
DENPARP II	Second National Poverty Reduction Strategy Paper
EU	European Union
FAO	United Nations Food and Agriculture Organization
FNSMS	Food and Nutrition Security Monitoring System
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HDI	Human Development Index
IFAD	International Fund for Agricultural Development
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INE	Instituto Nacional de Estatistica (National Statistics Institute)
IUCN	International Union for the Conservation of Nature
KIIs	Key Informant Interviews
LDC	Least Developed Country
LDCF	Least Developed Country Fund
LPDA	Letter of Agricultural Development Policy
LZ	Livelihood Zone
NAPA	National Adaptation Program of Action
NGO	Non-Governmental Organization
ODA	Overseas Development Aid
PNIA	National Agricultural Investment Programme
RCP	Representative Concentration Pathway
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDGs	Sustainable Development Goals
SO	Strategic Outcome
SSP	Shared Socio-Economic Pathway
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme
ZHSR	Zero Hunger Strategic Review

Introduction

The recent Zero Hunger Strategic Review of the World Food Programme (WFP) has identified climate change as one of several new and complex drivers of hunger. This novel threat to global nutritional security requires new approaches in terms of both design and resourcing. The international funding mechanisms that provide resources for addressing climate change are often beyond the reach of existing expertise in the specific programme design requirements of such funds. In response, the Critical Corporate Initiative seeks to broaden and enhance WFP programme design capacities through a collaboration between the Programme and Policy Development Department and the Partnerships and Advocacy Department. This effort will support the successful identification and pursuit of diversified financing opportunities to complement WFP's current resources.

As part of the Critical Corporate Initiative, WFP's Climate and Disaster Risk Reduction Programmes Unit, in collaboration with the Research, Assessment and Monitoring Unit, has developed a gap analysis of climate risk management actions with CGIAR and the Alliance of Bioversity and the International Center for Tropical Agriculture (CIAT) to identify thematic funding needs and priority actions. The initiative was conducted in Burundi, Guinea, Guinea-Bissau, Haiti, Myanmar, Nepal, Niger, Pakistan, Somalia, and Tanzania. In close coordination with the national WFP officers, the Alliance of Bioversity and CIAT identified livelihood zones (LZs), key crops, priority outcomes, and key climate and non-climate hazards for each country. Analysis was then conducted using a diverse methodology, including desk review, climate change modelling, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) assessment, stakeholder workshops, and key informant interviews. The results are organized herein; the report begins with an overview of Guinea-Bissau's people, economy, geography, and well-being (Section IV). Section V presents the current and future threats of climate change and its impact on food production, distribution, trade, and broader national outcomes. Section VI examines the enabling and distortionary policy contexts surrounding climate and food in the country. Section VII analyses current WFP activities and how these may be optimized in light of the findings in Sections V and VI. Finally, Section VIII offers recommendations for partnerships that may enable and enhance the opportunities for programmatic optimization.

PART 1.

National context

1.1 Geography

Guinea-Bissau, officially the Republic of Guinea-Bissau, is a small-island developing state in West Africa, bordered by Senegal to the north, Guinea to the south and east, and the Atlantic Ocean to the west. With a total surface area of 36,125 square km, the country is the smallest in the region. Its territory is divided into a continental part and an insular one, the latter consisting of eight islands as well as the Bijagós Archipelago of another 88 islands and islets, of which only 21 are inhabited [1].

The coastal region of Guinea-Bissau is long and forested, bordered by mangrove swamps with estuaries extending far inland, while the hinterland of the country features plains and hills with savannah areas further east. The country has a generally low elevation, with most of the coast lying at around 20 masl on average and several parts well below this average sea level. In the southeast, the foothills of the Fouta Djalon massif form the highlands along the border with Guinea. These hills reach only about 300 masl in altitude, and together with the great plain of the northeast, they form the upper part of the hydrographic basin that feeds the main rivers. The three largest rivers are Rio Cacheu in the north and Rio Gêba and Rio Corubal in the south-central region; both of the latter flow into the largest of the estuaries, where the capital Bissau is located [1], [2].

1.2 Agro-ecological characteristics

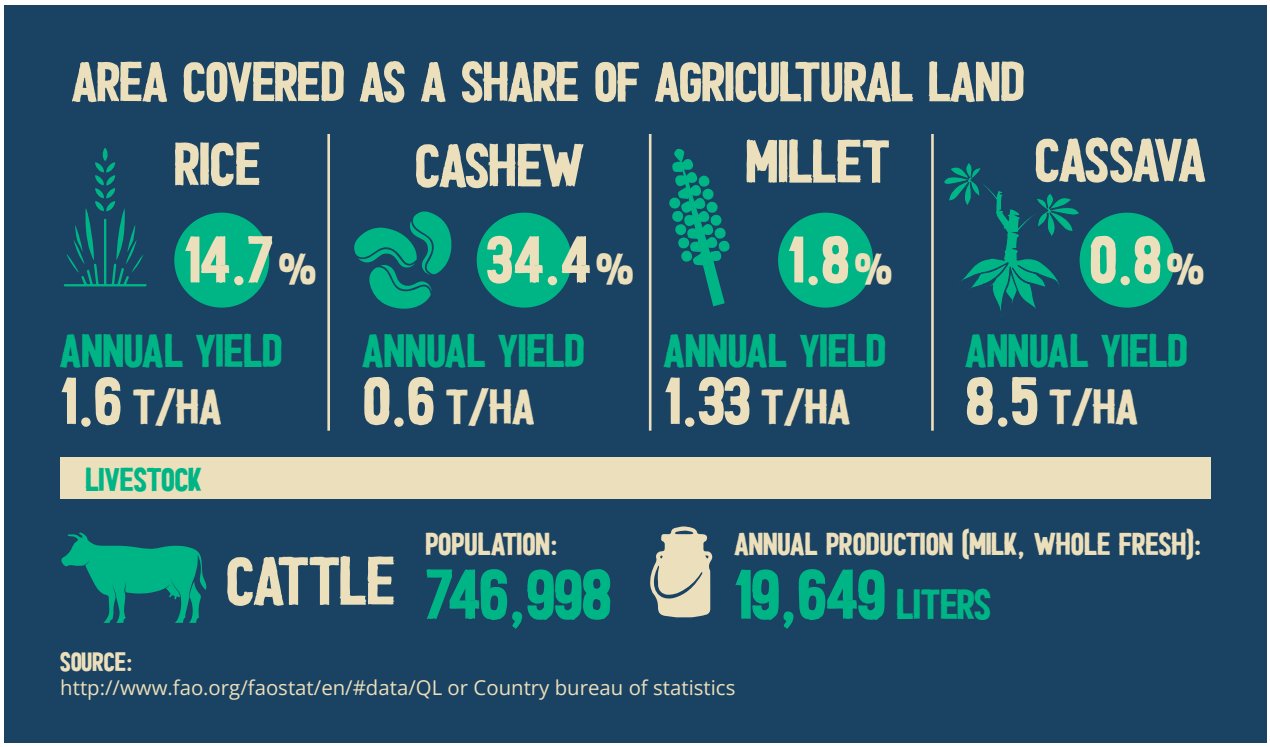
Guinea-Bissau is rich in unique and diverse terrestrial, marine, and coastal ecosystems; the habitat to a vast variety of rare flora and fauna, the country enjoys an important ecological function for migratory bird and fish species. Mangrove forest populates almost 9% of the terrestrial lands in Guinea-Bissau and accounts for almost 3% of global mangrove territory, placing Guinea-Bissau among the top 15 countries in the world with the largest areas of mangroves and second in Africa. Its coastal waters are among the richest in fishery resources and diversity, and the Bijagós Archipelago is classified as a United Nations Educational, Scientific and Cultural Organization Biosphere Reserve [3].

The land suitable for agricultural use covers 58% of the country's total area of 1,630,00 ha. According to Food and Agriculture Organization of the United Nations (FAO) estimates, around 71% of land is under forest cover, while 36.8% is for permanent crops or comprised of arable or other lands. Forest cover, during the last decade, has been degraded at an annual deforestation rate of nearly 4% or 60,000 to 80,000 hectare per year, either due to deforestation for agricultural purposes and for local use in construction, due to illegal logging for export, or due to uncontrolled forest fires. In coastal areas, rice farming is a main driver of deforestation and degradation that led to a decline of mangrove forest cover by 32% since 1940 [4].

There are three main types of agricultural productive ecosystems in Guinea-Bissau: the mangrove ecosystems along the coast; the lowlands freshwater (bas-fonds) ecosystems in the interior, mainly around rivers and freshwater valleys; and the plateau ecosystem. Rice is the main staple crop in the country and is cultivated on approximately 80,000 ha, often under an unsustainable slash-and-burn shifting cultivation practice. Of this land, 45% is on converted mangrove land in the mangrove ecosystem, 18% is on small valley freshwater fields in bas-fonds ecosystems, and 37% is in rain-fed forest and savanna ecosystems within the plateau ecosystem [3]. The area of land suitable for irrigated rice production in mangrove systems

and lowlands is considerably higher at 305,000 ha—200,000 ha of lowlands and 105,000 ha of salty soils—but only 16% of it is actually cultivated [5]. There is thus huge potential to increase rice production by expanding the suitable crop area actually under cultivation, which is also a declared government target [6].

Cashews comprise the single most important cash crop in the country. Cashews cover 34.4% or 521,700 ha of the usable agricultural areas, which measure 1,100,000 ha; the crop occupies 80% of farmers and represents around 90% of the country's total export revenue. It is regarded by the government as a strategic activity for job creation and poverty reduction, given that 75% of cashew producers are small family farmers—750,000 people in total. Other food crops include maize, sorghum, millet, groundnuts, sweet potatoes, cassava, cow peas, tropical fruits like mangoes, bananas, and citrus, and a variety of vegetables and spices [3], [5].

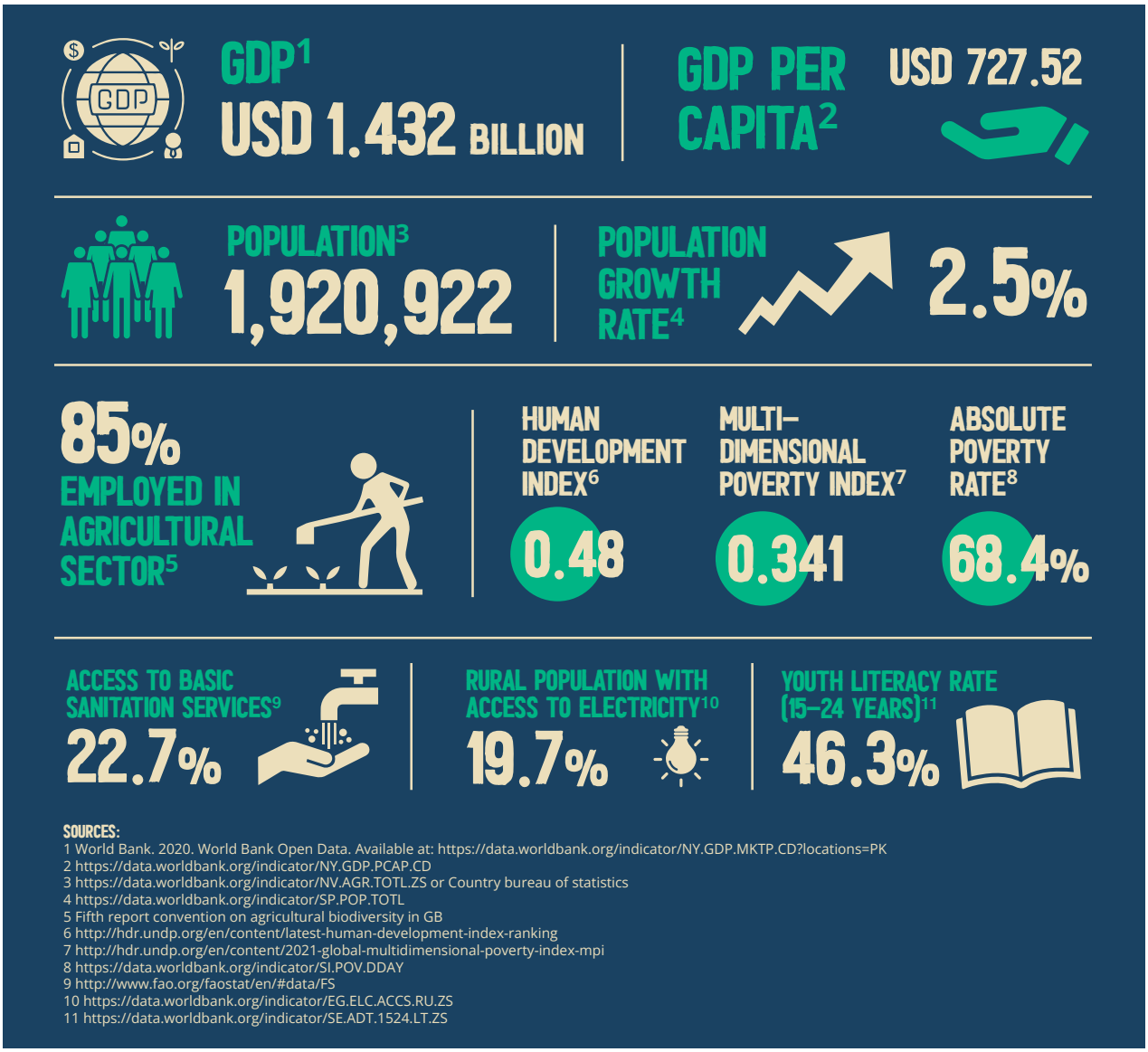


1.3 People and livelihoods

1.31 Socioeconomic characteristics

Guinea-Bissau has a growing and young population of almost 2 million, with a median age of 19 years old and a life expectancy of around 58 years. Around 43% of the population live in urban areas, mainly concentrated in the capital city of Bissau. With a growth rate of almost 3% annually, the population is expected to almost double by 2050 [7], [8].

Agriculture is the backbone of the national economy, accounting for 49% of the gross domestic product (GDP) and employing over 85% of the population. Cashews are the principal source of rural income, while other crops are mostly grown for subsistence purposes [2], [3]. In addition to crops, the livestock and fisheries sectors also make up an important share of the agricultural GDP, with the livestock sector—consisting primarily of 1 and a half million heads of cattle—generating about 17% of the national and 32% of the agricultural GDP. The fisheries sector is dominated by coastal wild capture and accounts for 7% of the national and 13% of the agricultural GDP [3].



1.32 Socioeconomic challenges

Guinea-Bissau is a low-income food-deficit country that faces significant development challenges. High levels of poverty, political instability, a general absence of employment opportunities, and a lack of basic services especially in rural areas dominate the socioeconomic profile of the country. With a Human Development Index of 0.48, it ranks at 175th out of 189 countries [9]. According to World Bank estimates, approximately two thirds of the population or 69% lives below the national poverty line of USD 1.90 per day, and 33% live in extreme poverty [7], [9]. On average, only about 46% of adults and 60% of the youth population are literate [7].

Since independence in 1973, Guinea-Bissau has struggled to secure a stable government and development. During the last two decades, Guinea-Bissau has seen four successful coup d'états—the most recent in 2012—and 16 suspected coup attempts, in addition to political assassinations, a constitutional crisis, and human rights violations that have contributed to deep and persistent political and social instability in the country. Since the 2014 democratic election, the president has dismissed six prime ministers and dissolved five governments for various reasons. As a result, the country suffers from periodic disruptions in basic public services such as those related to health and education, while the frequent reassignment of public offices interrupts efforts to formulate and implement policies and legislations.

The strong economic dependency on cashew nuts as the single most important cash crop makes Guinea-Bissau especially vulnerable to fluctuations in world market prices, subjecting a majority of the population to unstable income and a high risk of food insecurity. A large majority of smallholder farmers lack the skills and knowledge as well as the financial capacity to access adequate processing installations needed for aligning agricultural value chains to markets and commercialization. A recent decline in cashew prices, increasingly adverse weather, and a lack of opportunities are causing a rural exodus especially of the young workforce to urban areas, perpetuating the problems of low productivity and insufficient income opportunities in rural areas. In 2020, unfavourable weather led to cashew production much below expectations, while the global COVID-19 pandemic decreased demand and market prices for the raw nuts. This left large parts of the population acutely food-insecure, with an especially high rate in the northern state of Oio [10].

Gender inequality, discrimination, violence, and the abuse of girls and women are prevalent, especially in rural areas, because the state lacks the capacity to enforce gender-based protection. Customary laws and social, traditional, and religious practices prevent women and girls from obtaining equal access to basic rights such as land ownership, credit, or education. In several rural communities, girls are forced to get married at a young age, leading to early pregnancy, higher school dropout rates, and as a result, an illiteracy rate that is 30% higher for women than for men. Female genital mutilation is another widespread problem affecting almost 45% of women at the national level, while in the east, almost 96% of women are affected [11], [12].

At least 50% of people over 15 years of age are illiterate due to the poor performance of the education system, which suffers from numerous problems such as suboptimal government investments, scarcity of qualified teachers, weak community engagement, delayed enrolment, and repetitive and long strikes. Consequently, school attendance reaches only 61% in rural areas and 84% in urban areas for primary schools, while the primary school completion rate sits at only 27%. Girls are especially affected by early dropout due to early marriage, pregnancy, and domestic chores. Higher education is facing the same problems as primary and secondary education with a quasi-

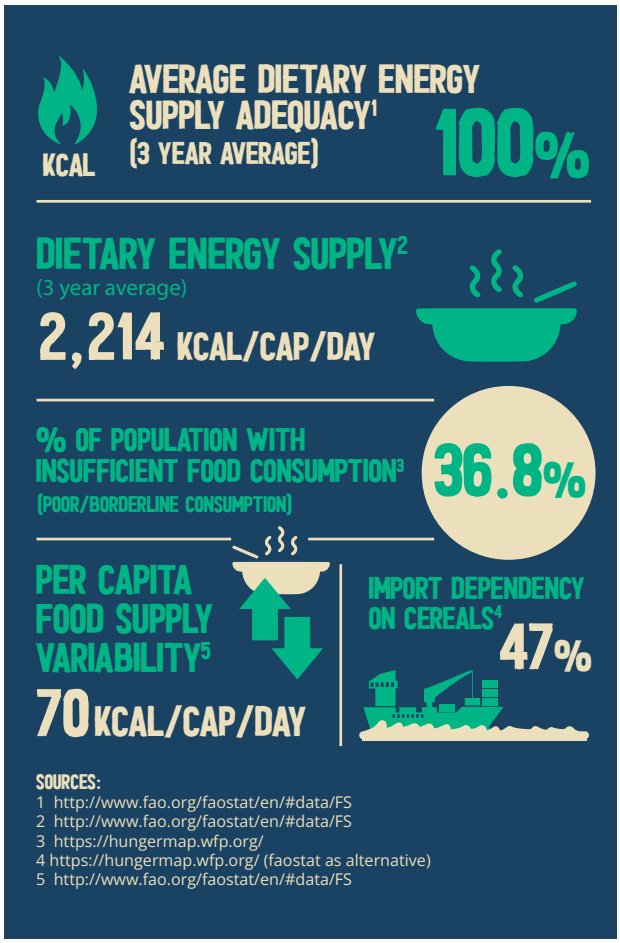
absence of serious universities, which negatively impacts the quality of the human capital in the country [13].

1.33 Food security

Food insecurity in Guinea-Bissau is generally high, with women, girls, and children under 5 years old most vulnerable and most affected by malnutrition. Around one third of the population or 700,000 people experience insufficient food consumption every year [14]. Food intake is dominated by rice with little nutritional diversity, and women often lack knowledge and education about the nutritional needs of children, leading to high levels of stunting. Nationally, approximately 28% of children under 5 years old are stunted on average, reaching over 37% in Oio and 32% in the east of the country. In 2019, about half of households spent more than 65% of their income on food, leaving them with limited resources to access essential non-food items or basic services [10], [13].

The Food Security and Nutrition Monitoring System (FSNMS) jointly run by the Ministry of Agriculture, the National Statistics Institute, the WFP, and government and civil society partners has shown a significant deterioration of the food security situation in recent years [15]. After reaching its peak in September 2019, when food insecurity in rural areas increased to 34% from 20% in October 2017, driven by a plummeting international cashew nut export price, food insecurity increased further in 2020 following the outbreak of the COVID-19 pandemic in the country. Rapid FSNMS assessments conducted in May, July, and October 2020 estimated that 55% of the population was in a situation of severe vulnerability, facing difficulties with accessing food and/or essential non-food needs in health and education and confronted with low food stocks, higher prices for staples, and income losses generated by the failure of the yearly cashew nut marketing campaign.

As farmers in the country have shifted into cashew production over the past decades, own rice production has seen a constant decline. Almost 85% of the population in Guinea-Bissau depends directly or indirectly on cashew nut exports for income. Income from cashew production is used to purchase staples such as rice, which is sometimes obtained by directly exchanging bags of harvested cashews for bags of imported rice. In years of low cashew production or low market prices, it is a common practice for farmers to receive an advance of rice with payment deferred into the coming cashew season, which can cause a dangerous cycle of debt. Price volatility is high, and international cashew prices have been declining over the past years. While the price in 2017 was still at 800 CFAF/kg, it gradually declined to 300 CFAF/kg in 2020. A lack of diversification of production and income sources is leaving many rural households with insufficient earnings and food stocks to cover their needs throughout the year [10].



1.4 National climate profile

The climate in Guinea-Bissau today follows both a north-south and an east-west divide, with two well defined seasons. In the west, the coastal zones have a tropical humid sub-Guinean climate characterised by high temperatures throughout the year and heavy precipitation reaching 1400-1800 mm/year in the northern coastal zone and above 2000 mm/year in the southern coastal zone. The eastern zones of the country—including the eastern highlands and northeastern plains—have a drier, Sudanese climate, which is characterised by lower precipitation from 1000-1500 mm/year, high temperature ranges, high humidity in the rainy season, and low humidity in the dry season.

There is only one rainy season in Guinea-Bissau between May and November, and most rainfall occurs between June and October (Fig. Z, [2], [16], [17]).

Comparison of historical and future projections at the national level indicates that while average temperatures are expected to increase gradually and evenly across all months of the year over the next decades, precipitation is projected to shift and concentrate more towards the peak of the rainy season compared to previous records. The onset of the rainy season in June and its end in October are projected to become drier with less precipitation for both months in the 2030s and 2050s, while we expect a notable increase in precipitation amounts during the months of August and September by 2030, with a subsequent decline towards 2050 (Figure 1).

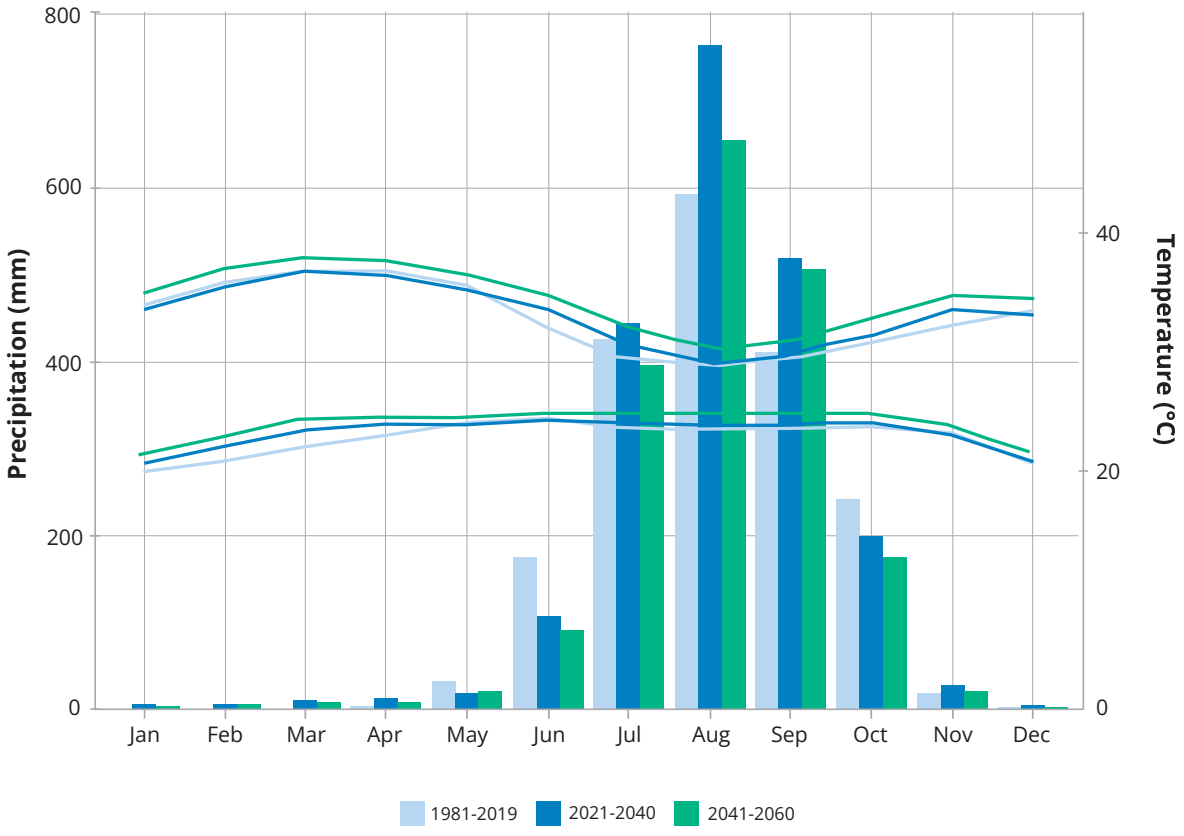


Figure 1: Historical and future projected monthly mean maximum and minimum temperatures and precipitation in Guinea-Bissau

1.5 Economic analysis using the International Model for Policy Analysis of Agricultural Commodities and Trade

The economic analysis presented here uses IMPACT, an exploratory tool for assessing linkages between agricultural policy, climate change, and technologies in agricultural systems. The socioeconomic basis for the results presented in this chapter is Shared Socioeconomic Pathway 5 (SSP5), a policy, population, and GDP trajectory characterized by rapid industrialization, high levels of technological innovation, and improving educational levels, alongside fossil fuel-driven industrialization with little effort to mitigate the impacts of climate change [18].[1] Assumptions regarding future temperature increases due to carbon concentration and radiative forcing are captured in different Representative Concentration Pathways (RCPs), which account for long-term changes in temperature and precipitation, but not for changes in climate variability or in the incidence of extreme weather events [18]. For this study, RCP 8.5 is assumed—the most pessimistic carbon concentration scenario available, which projects a mean global temperature rise of 1.4-2.6 degrees Celsius by 2050 over the 2005 level. Overall, the combination of SSP5 with RCP 8.5 envisions a bleak climate change outlook, exacerbated by increased fossil fuel use, although some of the worst impacts in terms of food availability are partly offset by an optimistic increase in technology and education levels. A "no climate change" (No-CC) scenario is also modelled as a benchmark against which to compare the impacts of climate change.

In IMPACT, yield is modelled as a function of both biophysical and economic factors, meaning that negative climate impacts can be offset by technological improvements related to germplasm and farm management, for example, and by economic incentives for farmers to invest in inputs. Conversely, economic incentives can exacerbate biophysical yield loss if price signals lead investments elsewhere, or if farmers switch to more profitable alternative crops. These relative impacts then translate into a rebalancing of the comparative advantages or disadvantages of commodities with respect to one another, and of the comparative advantages of nations trading in these commodities. This rebalancing, in turn, shapes the price signals driving changes in economic yield and productive decisions at the farm level.

Because IMPACT results are reported at the country level and not disaggregated by LZ or by demographic or economic group, their relevance lies in the context they provide for local-level decision making. Identifying points of climate resilience and vulnerability within Guinea-Bissau's agricultural sector equips policy makers with an inventory of agricultural strengths and weaknesses at the national level. This is critical information that can feed into the formulation of strategies to address climate hazards at the province zone level, which typically involve investments in the infrastructure and institutions required to leverage points of resilience and mitigate points of vulnerability.

1 IMPACT does not account for perturbations resulting from the COVID-19 pandemic.

IMPACT outputs present one possible scenario of future conditions in order to provide general guidance on policy and development interventions. Below, IMPACT climate change projections out to 2050 for supply, demand, and the food availability of key crop and livestock commodities are compared against their respective No-CC benchmark trajectories. This comparison is made to identify points of vulnerability and resilience in Guinea-Bissau's agricultural sector, particularly as regards food production and availability.[2] The commodity focus is chosen by in-country experts based on relevance to the country's diets and farms, especially as regards current and future food and nutritional security.

1.51 Supply-side impacts of climate change

YIELD, HARVESTED AREA, ANIMAL NUMBERS, AND PRODUCTION

Comparison of climate change scenarios against the No-CC benchmark scenario offers insight into how vulnerable or resilient crops are to the effects of climate change. IMPACT allows for farmers to adjust agricultural input levels and/or switch to new crops in response to price signals, thereby altering yield and area levels. Yields and area harvested may thus rise despite climate change-related biophysical setbacks if the corresponding investment in inputs is profitable to the farmer. Conversely, the market forces modelled by IMPACT can also exacerbate biophysical yield losses.

In Guinea-Bissau, yields of most key commodities are projected to be lower under climate change than under the No-CC benchmark (Figure 2). The impact is especially pronounced for groundnuts, and relatively slight for rice, millet, and sorghum. Harvested area, meanwhile, is projected to be considerably higher under climate change than under the No-CC benchmark, resulting in higher production of these crops under climate change despite lower yields. Cassava exhibits considerable resilience, with a projected yield that is higher under climate change than under the No-CC benchmark.

Resilience to climate change may be due to an intrinsic biophysical resilience of the crop, but it may also be because climate change-related damage to alternative crops is severer. The resulting relative scarcity of alternative crops, in turn, places upward pressure on the demand for, and hence the price of, these crops, such that farmers are willing to invest in the inputs necessary to offset the biophysical yield loss resulting from climate change.

1.52 Climate change impacts on diet trajectory

Diet trajectory is represented as the availability of calories from different crops. In future projections, calorie availability is projected to be significantly lower under climate change than under the No-CC benchmark for most key commodities (Figure 3). The projected impact on cereal and potato calorie availability is especially pronounced. Consumption of cassava and other roots and tubers is also impacted, but less so. Consumption of beef and other animal products, on the other hand, exhibits relative resilience in the face of climate change.

2 "Raw" CC trajectories, without comparison to No-CC trajectories, are provided in Annex.

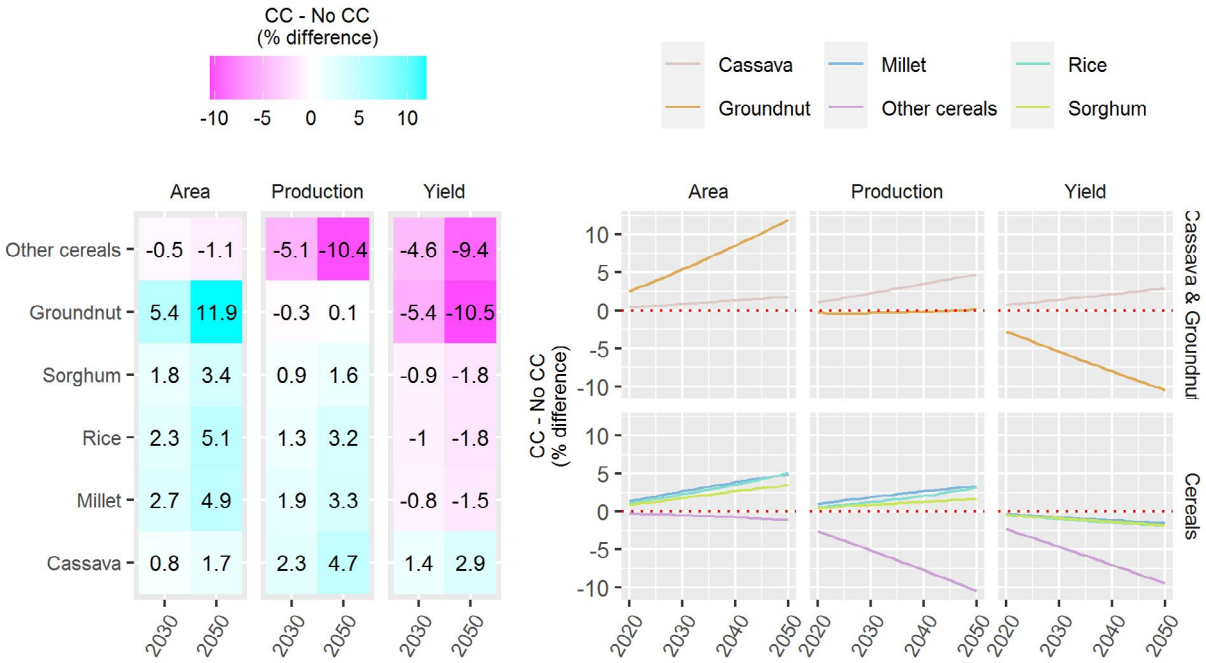


Figure 2: The differences between scenarios characterised by the presence and absence of climate change for the production, area, and yield of major crops. For each year, the difference is calculated as the percentage difference between the climate change value and the "no climate change" value.

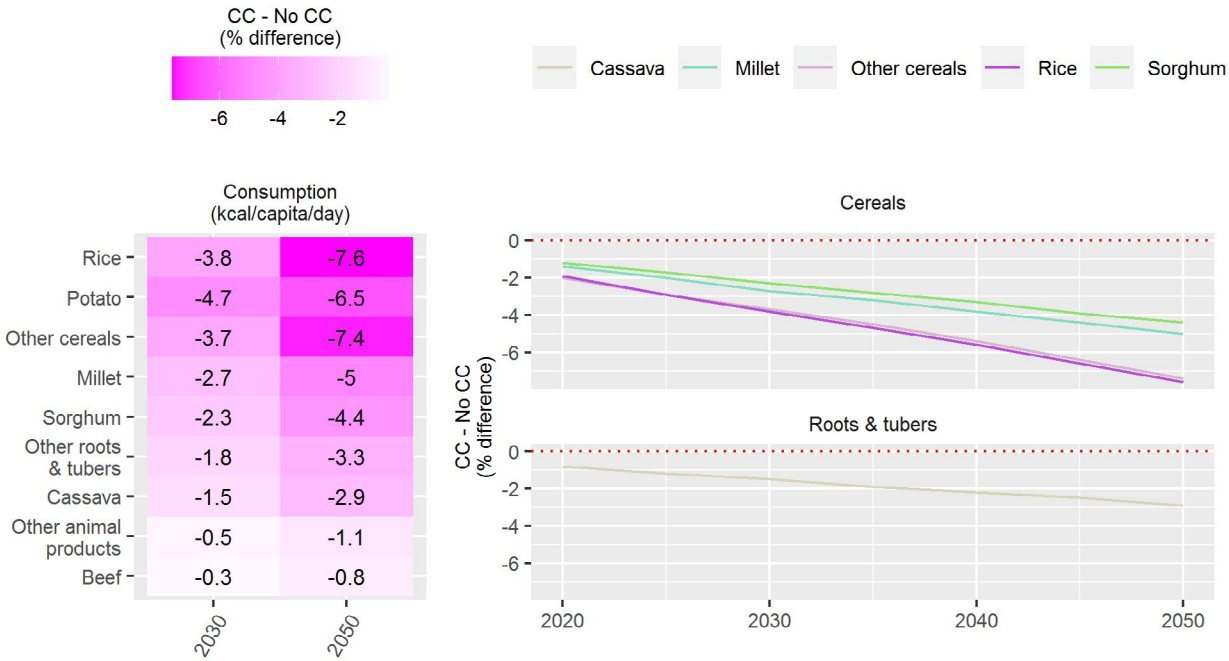


Figure 3: Percentage difference between the expected consumption of key products (kcal/capita/day) with and without climate change. For each year, the difference is calculated as the percentage difference between the values under climate change and without climate change.

1.53 Climate change impacts on the prevalence of hunger and malnourishment

The share of the population at risk of hunger and the number of undernourished children are projected to be higher under climate change than under the No-CC benchmark (Figure 4, left panel). This is consistent with the lower projected calorie intake under climate change seen above. Import dependency for beef and potatoes is projected to be virtually the same under climate change and the No-CC scenarios (right panel). Rice import dependency is projected to be as much as six percentage points lower under climate change by 2030, but to differ little from the No-CC scenario thereafter.

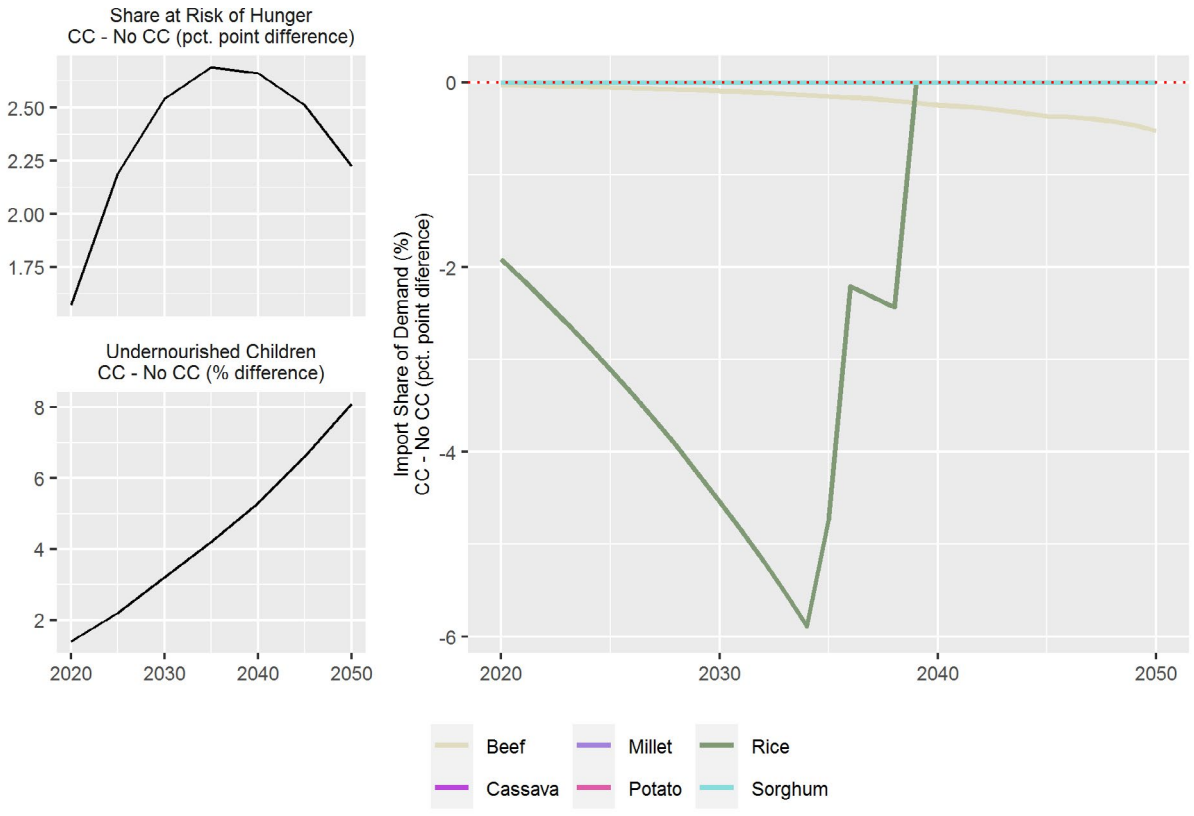


Figure 4: The difference between projected trajectories for key food security indicators and commodities with and without climate change.

1.54 Conclusions and recommendations based on the IMPACT analysis

While peanuts, rice, millet, sorghum, and other cereals exhibit vulnerability to climate change, cassava shows resilience, with projected yields considerably higher under the climate change scenario. Most cereals, including rice, millet, and sorghum, as well as groundnuts, however, are projected to counteract the negative yield effect with more area harvested under the climate change scenario compared to no-CC benchmark, resulting in an overall production increase. This projection indicates that continued investments in rehabilitating degraded lands to expand the production area can go a long way in buffering negative climate change impacts on yields and production. Such investments will be a cornerstone in ensuring future food availability, especially considering the role of rice, millet, and sorghum as key staple crops for food security in Guinea-Bissau.

Overall, calorie availability and the related diet trajectory are projected to be lower under climate change relative to the No-CC benchmark for almost all the crops in this analysis. This finding is partly due to lower relative imports and partly due to lower relative production. It highlights the importance in making investments in research and development for key value chains for food and nutrition security and in improved transport and market infrastructure to allow for availability and access to important food products even and especially in remote rural areas that are highly vulnerable to food and nutrition insecurity.

Negative climate trends such as droughts or summer flooding can disrupt the food supply and reduce incomes from agriculture, which underlines the importance of diversifying livelihoods and income sources in rural areas. This fact is relevant not only for market-oriented and subsistence farmers, but also for landless agricultural wage labourers who risk losing income opportunities if crop production enterprises are destroyed by negative climate events.

1.6 National climate change policies and development strategies

In order to ensure a demand-driven process that ties in with government priorities, a desk review of climate-related and climate-relevant policies and strategies has been conducted to ensure the "enabling" dimension of WFP country programs vis-à-vis national climate ambitions. These policies and strategies have been mapped against current investments by the government, multilateral donors, bilateral donors, International Financial Institutions, and the private sector, in order to highlight gaps and opportunities for WFP programs in alignment with national objectives, such as Sustainable Development Goals (SDGs) 2, 13, and 17. This effort was undertaken through a literature review, discussions with the WFP country offices, and key informant interviews.

1.61 National climate strategies and finance mechanisms

Guinea-Bissau has been a Non-Annex I Party to the United Nations Framework Convention

on Climate Change (UNFCCC) since 1995 and ratified the Kyoto Protocol in 2005 and the Paris Agreement of the Conference of the Parties in 2018. In line with its commitments, the government has published three National Communications on Climate Change in 2000, 2011, and 2018, developed thematic documents on climate change such as the National Adaptation Action Plan (NAPA) in 2006, and submitted their First Nationally Determined Contributions (NDCs) in 2018. Its Second Nationally Determined Contributions are currently being revised and will be published by September 2021 [1], [16], [17], [19], [20], [21].

The country's 2015-2025 National Strategic Plan *Terra Ranka* ("Fresh Start") foresees an approach to environmental and climate challenges that is fully aligned with its commitments to the implementation of the SDGs and the Paris Climate Agreement. Its response is based on four key pillars to be pursued across government policy initiatives: (i) the establishment of a normative and institutional environment for sustainable development and biodiversity protection; (ii) the knowledge, protection, and management of ecosystems; (iii) the regulation of the extraction of renewable natural resources; and (iv) the implementation of a Climate Plan to increase resilience to climate change [6], [21].

Several environmental plans and strategies exist to translate the vision at the sectoral level into concrete programs. Relevant policies include, for example, the National Environmental Management Plan, the National Agricultural Investment Programme (PNIA), the Letter of Agricultural Development Policy (LPDA), Letter of Livestock Development Policy, the National Forestry Master Plan, the National Strategy and Action Plan on Biological Diversity, the Action Plan for the Bolama-Bijagos Archipelago Biosphere Reserve, the Environmental Strategy for Coastal Zone Management, the Water and Sanitation Master Plan, and the Artisanal Fishing Master Plan [21], [22], [23]. In 2021, the national government allocated a budget of 254 billion CFAF (USD 26 million) to the Ministry of Environment and Biodiversity for the implementation of these plans.

Guinea-Bissau to date has not developed a specific national climate change policy. Instead, the government is working together with international partner organizations on integrating climate change adaptation into existing policy plans, a process that has been initiated and largely supported by the international donor community such as the African Development Bank and the International Union for the Conservation of Nature (IUCN). The United Nations Development Program (UNDP) through a Global Environment Facility (GEF)-funded project has been supporting the integration of climate change considerations into the following documents: (i) Letter of Agricultural Development Policy; (ii) Letter of the Livestock Development Policy; (iii) Water and Sanitation Master Plan; and (iv) Gabu Regional Development Plan (Development Plans of Pitche and Pirada Sectors) [22]. Similarly, since 2019 the UNDP has been supporting the government of Guinea-Bissau in initiating the preparation of a National Adaptation Plan (NAP) with funding from the Green Climate Fund (GCF) [23], [24]. The formulation of the NAP is currently ongoing.

In the meantime, the NAPA developed in 2006 remains the guiding document to direct climate change adaptation activities integrated into sectoral policies and national communications to the UNFCCC. It outlines 14 strategic activities to achieve the national goal of climate resilience for food security and to reinforce the rural population's adaptive capacity, reduce pressure on forest and fishing resources, and improve access to potable water for human consumption and livestock. Overall, these activities revolve around the diversification of agricultural production and diets, improved water management such as through irrigation development and the construction of small dams

for water retention, reforestation of mangrove swamps for protection against coastal erosion and salt water intrusion in rice fields from high tides, reforestation of other forest areas to reduce land degradation and desertification, the promotion of short-cycle livestock production, protection and sustainable development of artisanal and coastal fishery resources, and improved education and training about climate impacts and good adaptation practices [1].

In its amended climate change section, the PNIA calls for the development of research into and extension of plant and animal species resistant to the effects of climate change, as well as enhanced education, information, and communication to raise awareness of climate risks and good agricultural practices for adaptation. Specific suggestions for crop cultivation include the development of new and improved varieties like short-cycle drought- or waterlogging-resistant crop varieties for rice, crop rotation, irrigation development, adapting cropping calendars, or the use of Zai techniques in drought-prone areas. In livestock, the focus has been on the promotion and cultivation of improved fodder grasses such as *Brachiaria*, silage preparation, and the creation of watering points and reservoirs for livestock production in drought-prone areas [25].

In its Intended Nationally Determined Contributions (INDCs), the government highlights the need for adaptation actions and underlines that Guinea-Bissau is an absolute carbon sink given its vast forest resources. High deforestation rates and plans for future energy sector development, however, foreshadow a significant increase in future greenhouse gas emissions that the government pledges to counteract with several measures to encourage sustainable forestry management and with an effort to exploit the country's potential renewable energy sources for their final energy mix. More specifically, Guinea-Bissau pledges to increase the percentage of protected areas from 15% to 26%, conduct a nationwide forest inventory, develop a reforestation and sustainable forest management plan including the promotion of climate-resilient tree species, develop new and productive crop varieties with broad-spectrum tolerance of climate stressors, develop an integrated management plan for the coastal zone, cut energy losses by 10%, achieve 80% of universal electricity access, and introduce a number of "climate proofing" activities in its key productive sectors. It estimates that meeting all the adaptation and mitigation targets outlined in its NDC will require USD 200 million by 2020 and USD 500 million in foreign aid between 2020 and 2030 [20].

1.62 National development strategies and finance mechanisms

Guinea-Bissau's turbulent political past involving frequent changes in government meant that over many years the country suffered from significant fluctuation in managerial staff and a lack of continuity in the implementation of public policies. This situation has created many challenges, such as high poverty and food insecurity rates, low economic performance, and an overall lack of income and employment opportunities for the local population. The government in 2010 finally responded to these challenges by drafting the Second National Poverty Reduction Strategy Paper, defining goals such as income generation, better access to social services, and reduced food and nutrition insecurity as national priorities. Accompanied by the adoption of public policies such as the PNIA, the National Health Development Plan, the launch of the school feeding program, and the implementation of a number of development programs and projects

in productive sectors of the country, it marked a turning point towards increased political will to effectively address the country's major challenges [26].

The 2015-2025 National Strategic Plan *"Terra Ranka"* ("Fresh Start") continues these efforts and outlines a comprehensive and integrated plan for the country to become a prosperous and inclusive society by 2025. The vision is to achieve rising living standards, economic opportunities, and a peaceful, united population that enjoys the benefits of the sustainable development of the country's exceptional land and marine biodiversity. For this purpose, the strategic plan outlines 53 programs across six themes: i) Engines of Growth, which promotes growth through agriculture and agribusiness, fishing, and the aquaculture and tourism sectors; ii) Peace and Governance; iii) Biodiversity and Natural Capital; iv) Infrastructure and Urban Development; v) Human Development; and vi) Simplification of the Business Framework and Development of the Private Sector.

Terra Ranka* was further elaborated in 2021 with an updated strategy for economic reforms, summarized under the economic development plan *"Hora Tchiga". The plan suggests concrete investments in key sectors to support the modernization of the state and tackle its socioeconomic challenges considering the COVID-19 pandemic. It specifically pledges to diversify agricultural production and foster national industrialisation, promoting competitiveness and the valorisation of national production along the value chain, with the aim of strengthening and diversifying exports. It thereby has a specific focus on health and education, agriculture and agro-industry, fisheries, tourism, and mining, with a view to increasing the export of national goods and services, youth employment, and the domestic consumption of products of national origin [5].

Strengthening the cashew economy and diversifying agriculture beyond the basic sectors of cashew nuts and rice are important goals of the government of Guinea-Bissau, outlined both under *Hora Tchiga* and *Terra Ranka* [5], [6]. Agricultural diversification plays an important role in sustainable land management through use diversification; it also helps enhance the food security and empowerment of the most deprived populations, especially women, who constitute the majority of the rural population dependent of the agricultural sector for their livelihoods [5]. The development of agricultural, horticultural, and livestock value chains and of artisanal fisheries will be a priority for food security, employment, and the creation of domestic value-addition opportunities in the future.

1.63 International alliances and finance mechanisms

The government of Guinea-Bissau is the primary provider of funds for much-needed investments in infrastructure and social protection programs, yet it registers a huge gap in available financial resources. The local capital market is largely underdeveloped since bond and stock markets are non-existent, and a history of political instability has driven out international investors, who perceive the country as too risky [27]. Guinea-Bissau ranks 174th out of 190 countries assessed in the World Bank's Ease of Doing Business 2020 report, with an overall score of only 44 [28]. In addition, the country has a history of heavy indebtment, which has been restructured by the International Monetary Fund (IMF) through the Enhanced Initiative for Heavily Indebted Poor Countries in 2010 [29]. As a consequence, the country has to receive authorizations from the IMF to incur new debts, which are often declined for high-rate loans even if they are concessional [27]. The ability of the government to implement their development projects thus depends to a large part on external grants or loans with favourable terms.

Since 2017, Guinea-Bissau received on average around USD 137 million annually in gross overseas development aid (ODA). The top ten donors are the International Development Association, EU institutions, Portugal, the Global Fund, the United Nations Children's Fund, the African Development Fund, the International Fund for Agricultural Development (IFAD), UNDP, Japan, and Spain. About 55% of bilateral ODA is directed toward project related to the education sector, 12% toward health and population, and 16% toward other social infrastructure; the remaining 15% is spread across economic infrastructure development, multisector targets, programme assistance, debt relief, and humanitarian and other topics [30].

The majority of financing for climate change-related projects in the country has come from the international donor community [22]. Over the past years, Guinea-Bissau has secured a total of USD 48 million in funding from GEF and the Least Developed Countries Fund (LDCF), and another USD 45 million from IFAD in projects related to climate change, agriculture, and food security development. As of 2021, Guinea-Bissau has received USD 12 million in funding from one approved GCF multi-country project on renewable energy development and submitted three concept notes to the GCF, of which two are directly related to climate-smart agriculture (CSA) and resilient livestock development. A further project on institutional capacity for climate resilience was funded by the EU Global Climate Change Alliance Plus Initiative in the amount of USD 4 million.

UNDP is among the key international players driving the development and implementation of relevant projects on climate change in the country. Approved project proposals from the above-mentioned funds include projects on "Strengthening Climate Information and Early Warning Systems for Climate Resilient Development and Adaptation to Climate Change in Guinea-Bissau" (UNDP/GEF), "Scaling up climate-smart agriculture in East Guinea-Bissau" (West African Development Bank/GEF), "Managing mangroves and production landscapes for climate change mitigation" (IUCN/GEF) and "Strengthening adaptive capacity and resilience to climate change in the agrarian and water resources sectors in Guinea-Bissau" (UNDP/LDCF) [31].

Policy gaps targeting climate change and food and nutrition security often remain at the provincial level. A major problem persists in the lack of human resources with quality education and skills to develop and implement budget plans. There thus exist many opportunities at the provincial level for WFP to support both the integration of climate change considerations into local plans for food and nutrition security and the implementation of these plans.

PART 2.

Context within selected intervention areas

zones and crops of focus with rationale for selections

The present analysis focuses on four selected LZs in Guinea-Bissau (Figure 5). LZs have been defined by the Ministry of Agriculture and Rural Development in Guinea-Bissau as a "geographical area in which households rely on the same means – production systems and access to markets – to meet their living and subsistence needs, including in particular their food and cash income" [2]. There are seven different LZs in total in the country; the four prioritized LZs cover the majority of the continental land area and are thus where most of the rural population lives. For the crop suitability analysis, across the selected LZs we focus on rice, cashews, and cassava – rice is the most important staple crop and cashews are the primary cash crop in the country, and the latter plays an important role for WFP in diversifying production for better nutritional outcomes. The LZs in focus are: (1) the eastern highlands, (2) the northeast plains, (3) the north coastal zone, and (4) the south coastal zone. The following section briefly describes each of these zones in more detail, based on the livelihood zoning reports published by the Government of Guinea-Bissau in 2017 and 2018 [2], [32], and complemented by further literature review and informative interviews with local experts.

THE EASTERN HIGHLANDS

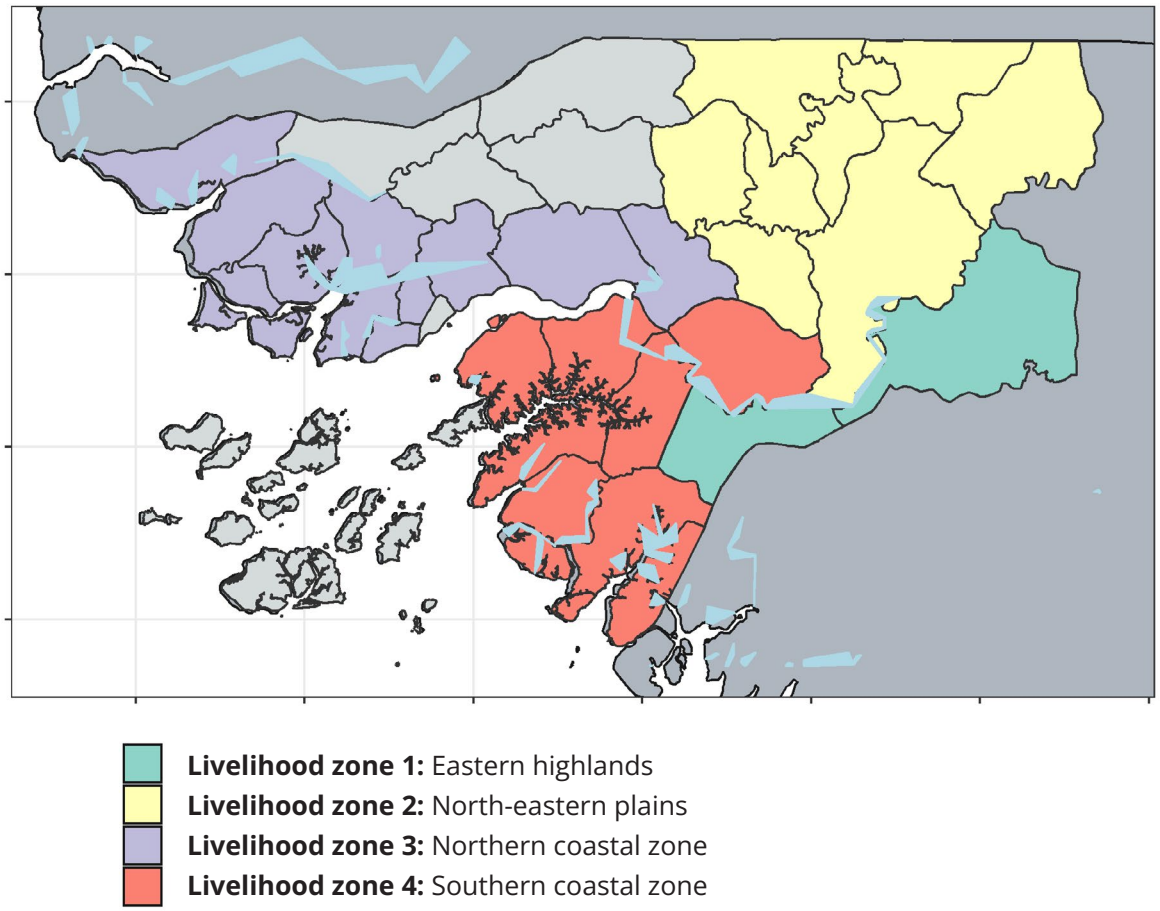


Figure 5: Selected livelihood zones in Guinea-Bissau.

The eastern highlands stretch across the districts of Boé and Quebo in southern Gabú and western Tombali regions along the southern border with Guinea. While the majority of Guinea-Bissau is flat with low elevations below 100 masl, the sparsely populated area in the eastern highlands is characterised by hills that reach up to 300 masl in altitude. A few streams and rivers cross the region, feeding into the main river Rio Corubal to the north. The eastern highlands are defined by a quasi-absence of lowlands, which are the main areas where rice is cultivated in the country. The soils are generally mixed or sandy and of moderate fertility, but the cultivated land, mostly located at moderate, hilly altitudes, suffers from the problem of leaching. The local economy is mainly based on agriculture.

With high temperatures and an average of 1000 mm rainfall per year, water availability is low compared to the rest of the country but supports a wide variety of food crops. Rice production is common and dominated by upland rain-fed rice, so-called "pam-pam" rice, which is produced much more here than elsewhere in Guinea-Bissau. Additional crops grown in the area include cassava, yams, maize, sorghum, and millet, which are often intercropped with beans and pumpkins. Fonio (*Digitaria spp.*) has been introduced recently and is seeing a sharp increase in production and prices that can rise to three or four times the price of rice. However, the area is deficient in cereals, with self-consumption covering only 6-8 months of the year. Hence cash crops are also important, dominated as everywhere in the country by cashews, followed by groundnuts and beans. The environment is favourable for fruit, including a variety of citrus fruits, mangoes, bananas, guavas, and avocados. Market gardening extends into the dry season with the help of watering cans. With regards to livestock, farmers raise cattle, goats, sheep, and poultry including chickens, guinea fowl, ducks. The ruminants are marketed as far away as Bissau.

This LZ suffers from a high incidence of poverty and malnutrition—among the highest in Guinea-Bissau. A suboptimal and largely unpaved road network renders the area largely isolated from the rest of the country, which limits the local population's ability to engage in trade and other cross-regional economic activities. Housing is generally poor, and there is a lack of access to service infrastructure such as quality education, health, and sanitation facilities.

THE NORTHEAST PLAINS

The northeast plains cover the majority of the northern Bafata and Gabu Regions, which are characterised by a relatively dry, Savannah-Sahelian climate with an annual rainfall of about 1250 mm. The local Savannah ecology makes the region conducive to rearing livestock. Trade in cattle and small ruminants thus plays an important role in this part of the country, along with the cultivation of various cereals such as both lowland and upland rice, maize, millet, and sorghum, which are especially common in the north. Next to cashews, which are dominant as elsewhere in Guinea-Bissau, groundnuts are a frequent cash crop. Horticulture is practiced mostly by women yet is low in productivity due to a lack of water and because horticulture is not prioritized, especially during the annual cashew campaign. Cassava is a secondary crop in general, except in Contuboel, where production is high.

Compared to the eastern highlands, this LZ has considerably more commercial and cross-border activities around food and cash products. This situation is made possible by an asphalt road that runs through the northeast plains and links the towns of Bafata and Gabu to Bissau in the west, then continues east through Pitche to the border with the Republic of Guinea. While these activities add important sources of income and livelihoods for the local population, the area still suffers from one of the highest incidences of poverty and malnutrition in the country.

With its dry climate, lack of water, and

sandy soils of moderate fertility, the east is among the least productive regions in the country. Progressive intensification of droughts and dry spells impacts both crop and livestock production. During monsoon season, heavy rains frequently translate into floods around lowlands and riverbeds, which leads to waterlogging and affects crop production during the year's only growing season. Sandy soils and a high rate of deforestation by local communities lead to increasing soil erosion and siltation of waterways, which render irrigation infrastructure development challenging. Limited availability of pastures and water resources forces livestock herders to embark on seasonal migrations in search of feed and water, which often causes intense and sometimes serious disputes between cattle breeders and crop producers.

NORTH COASTAL ZONE

This LZ is characterised not only by the seacoast but also by the large estuaries of the Cacheu River in the north, the Mansôa River in the centre, and especially the Gêba River in the south. A large part of the area is therefore covered by mangroves. With a mix of clay-sandy soils and around 1500 mm of precipitation per year, the area is relatively fertile, which is also reflected in its agricultural production record. The production of saltwater rice, also known as "mangrove rice," is important if not dominant, although there is also significant production of freshwater rice in the lowlands, especially in the interior, for example towards Canchungo and São Domingos, and of some upland "pam pam" rice. With its low elevation, the cultivated land near the coast is subject to frequent flooding during heavy rains or strong winds, negatively affecting crop production. Next to rice, millet constitutes an important cereal, while maize is less important. The primary cash crop in the area is cashews. As a cashew production hotspot, the north coastal zone, together with the northern central region, yields over 55% of the national cashew production. **Apart from the coastline and mangrove swamps, there are dense forests and extensive savannahs.** The north coastal zone is endowed with important fisheries resources. Artisanal traditional maritime and continental fishing is widespread in the area and brings in significant income for those involved. Many communities also rely heavily on timber and non-timber forest products for livelihood generation. The population density is at about 95 inhabitants/m2m, which is high compared to other areas of the country. An exodus for work, whether seasonal or permanent, is typical for this area.

SOUTH COASTAL ZONE

As a coastal zone, this LZ shares many physical characteristics with the north coastal zone: the coastline, the long estuaries, the large expanses of mangroves, the floodplains, the dense and clear forest, and the savannah areas. As a result, its staple food and cash crops are similar, as are its fishery resources and their use. At the same time, there are two main factors that differentiate this zone from its northern neighbour. On the one hand, the south coastal zone features higher production of rice and lower production of other cereals. On the other hand, proper marketing of this produce is hindered by a lack of a viable road network. Its relative isolation is comparable to that of LZ1 and is characteristic of the entire southern part of the country, where road networks are generally poor.

In the 2020 rainy season, significant flooding affected rice fields in this zone, which drastically reduced the rice harvest despite an overall positive trend in rainfall occurrence over the past five years. As in the north, saltwater intrusion into rice fields is frequent in this zone and is exacerbated by deforestation of mangroves and by coastal erosion. The number of water bodies and rice fields in lowlands and mangrove areas make flooding consequences often serious. Despite its important natural resources, the food insecurity rate is generally high in this zone; however, the malnutrition rate

remains low, due to the practice of fishing.

2.2 Climate risks by livelihood zones

This section has several key goals. First, it furnishes an understanding of current and future climate trends and hazards for Guinea-Bissau, including droughts, waterlogging, and heat stress. Next, it assesses climate change impacts through a crop suitability approach for selected crop commodities like rice, cashews, and cassava. Finally, it discusses potential climate risks to food security, taking into consideration nutrition, poverty, gender, market access, education, and other variables of interest to WFP by identifying hotspots of co-occurrence of climate hazards, climate impacts, and these variables of interest.

We assessed climate change in Guinea-Bissau by analysing historical and future changes in climatological mean temperatures and precipitation. The historical analysis focuses on the period from 1981 to 2020. To assess future climate trends and hazards, we focus on the near-term future (2021–2040 or the "2030s") and the medium-term future (2041–2060 or "2050s"). We utilise Representative Concentration Pathway (RCP) 8.5 – Shared Socioeconomic Pathway (SSP) 5, a high-emissions and high adaptation-mitigation challenge trajectory. This RCP–SSP combination is the closest to the world's current emissions trajectory. We focus on 2030 because of the short-term utility of 2030 for planning purposes, but extend the analysis to 2050 so as to assess post-2030 trends, and because by 2030 the difference between RCPs is not substantial [15].

2.21 Mean climate projections

Generally, the findings reported here indicate that Guinea-Bissau is becoming warmer and will experience both wetter and drier episodes in the future. Temperatures will increase continuously and uniformly across the country, while projections of the amount and distribution of precipitation vary.

Future projections of annual mean temperature show a steadily increasing trend throughout all livelihood zones (see Figure 6). Compared to the historical baseline year 2000 (1981 – 2019), the country's average annual mean temperature will increase continuously towards 2030 and 2050. The highest temperatures and strongest increase will likely be registered in the northeastern plains.

Total annual rainfall is projected to grow in the near future across all livelihood zones (see Figure 7). Temperatures in 2030 are highest in the southern coastal zone and lowest in the

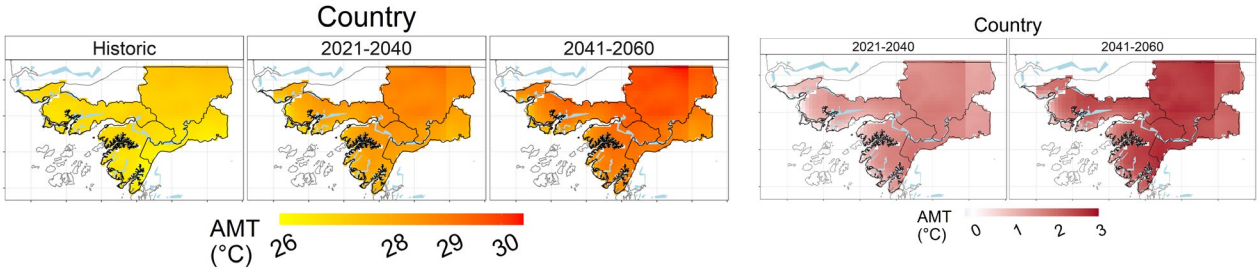


Figure 6: Historical trends and future projections of annual mean temperature (left graphic) and change in annual mean temperature (right graphic) across selected livelihood zones by 2030 and 2050.

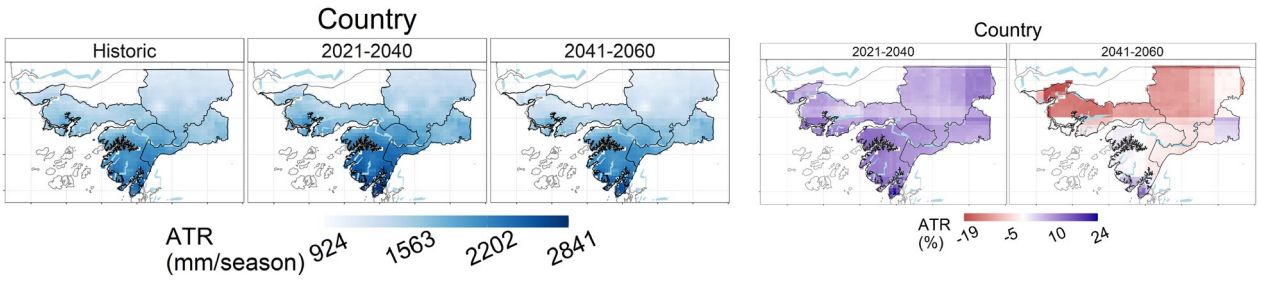


Figure 7: Historical trends and future projections of annual total rainfall (left graphic) and change in annual total rainfall (right graphic) across selected livelihood zones by 2030 and 2050.

northeastern plains. The climate models project a drier midterm future with less rainfall in the northern coastal zone and northeastern plains. Only the eastern highlands and small parts of the southern coastal zone are projected to receive more rainfall beyond 2050.

While climate models agree with regards to future temperatures, the projections for future rainfall are subject to high uncertainty and are especially problematic in the West African Sahel. Different climate models anticipate different trends, with some models indicating a drier future and other models indicating a wetter future. The initial increase in precipitation by the 2030s and subsequent decrease towards the 2050s exemplify the highly complex interplay of factors that determine West African climate patterns. With continued warming, global climate models suggest a rapid melting of the Greenland ice sheet that could lead to high amounts of freshwater discharge and a complex cascade of changing ocean circulations. These events would cause a sudden weakening of the West African monsoon after the 2030s, and therefore a sudden decrease in annual precipitation amounts in the Sahel [33]. This means that policy makers need to prepare for both wetter and drier future scenarios.

Even if precipitation increases in the near future, the simultaneous increase in annual mean and daily maximum and minimum temperatures will lead to higher levels of evapotranspiration. This will be particularly pronounced in the 2050s, when temperatures are projected to increase and precipitation is projected to decrease. This situation will likely have a substantial negative impact on water resources in the country, particularly affecting the eastern zones that are already experiencing severe limitations in water availability for the agricultural and livestock sectors. This negative impact poses a threat to the livelihoods and food security of a significant part of the population.

2.22 Analysis of selected climate hazards

The climate hazards that are most detrimental to agricultural production in Guinea-Bissau include flooding and waterlogging, droughts, variability in precipitation onset and intensity, heat stress, and rising sea levels. These hazards affect crops and livestock as well as the human ability to work productively, and therefore hinder agricultural production and development. The climate hazards analysed here have varying effects across Guinea-Bissau.

DROUGHT RISK

The northern and eastern parts of the country are experiencing increasing droughts that result from changing characteristics of the rainy season [34]. In particular, stakeholders report high irregularity in the spatiotemporal

distribution of rains, an overall decrease in rainfall, a shifting in the onset of the rainy season, and an earlier end to the rainy season. The rainy season used to begin in May and end in November. Now, the rains often begin in June and end in October. The eastern highlands and northeastern plains, which experience a considerably drier climate than the rest of the country, experience significant shortages of water during the dry season while the sandy and unstable soil structure makes the development of irrigation infrastructure challenging. Frequently, the community wells collapse due to insufficiently adapted materials and inadequate building techniques for the unstable grounds. The lack of water also causes regular disputes and sometimes severe conflicts between livestock herders and sedentary crop farmers in the east, as livestock herders practice transhumance in search for feed and water and can find themselves rivalling with crop farmers for scarce resources [35], [36].

The drought risk map below highlights the areas that will be most affected by drought risk in the future. Areas in the south, including the eastern highlands and southern costal zone, that have been historically largely unaffected by drought risk will become increasingly affected in the near and midterm future, yet will remain at moderate risk. Parts of the northern coastal zone and northeastern highlands, however, will likely experience strong drought risk in the near future and extreme drought risk in the mid-future (see Figure 8).

Looking at the seasonal variation of moisture

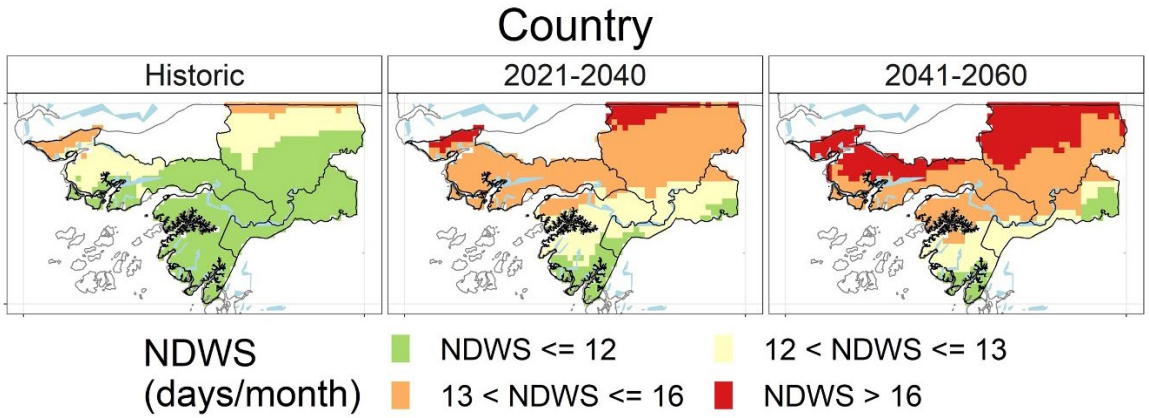


Figure 8: Historic and future drought risk in Guinea-Bissau, expressed as projected number of days per month with water stress (NDWS). Green implies low risk and red implies extreme risk of drought.

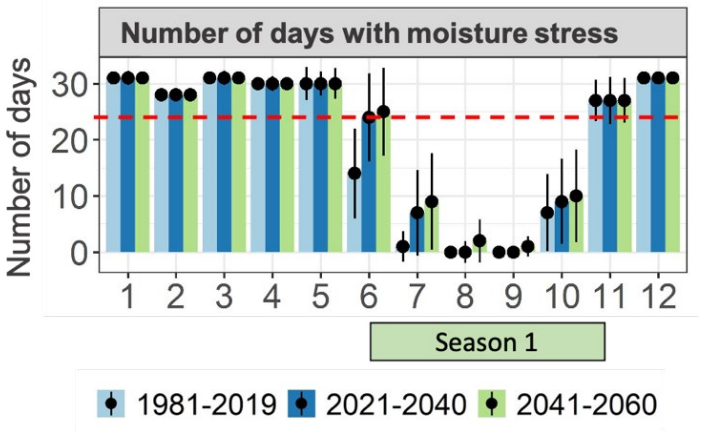


Figure 9: Seasonal variation of moisture stress throughout the year. The red line represents the threshold at which moisture stress becomes critical for crop production.

stress throughout the year, projections indicate that the dry months between November to May will remain unchanged while the number of days with moisture stress during the months of June, July, and October will increase (see Figure 9). This prediction highlights a possible variation in the rainy season's onset and duration. This variation can significantly affect the ability to grow crops, as moisture stress increasingly appears during key crop growth stages. Similarly, a later and shorter rainy season impacts water availability and pasture productivity for livestock, putting further stress on an already struggling sector.

WATERLOGGING AND FLOODING

Flooding and waterlogging is one of the biggest threats to agricultural production in Guinea-Bissau. It frequently affects production, especially in the agricultural lowlands, across all livelihood zones [34]. The low altitude of most parts of the country increases the risk of flood events near watercourses and coastal areas, particularly during and following the rainy season, which is the main rice production season of the year. As precipitation becomes more unpredictable, reports of high-intensity rainfall increase. In 2020, government reports estimated that flooding affected some 26 ha of land, directly damaging over 9000 rural households and leading to a production loss of an estimated 64,000 tons of

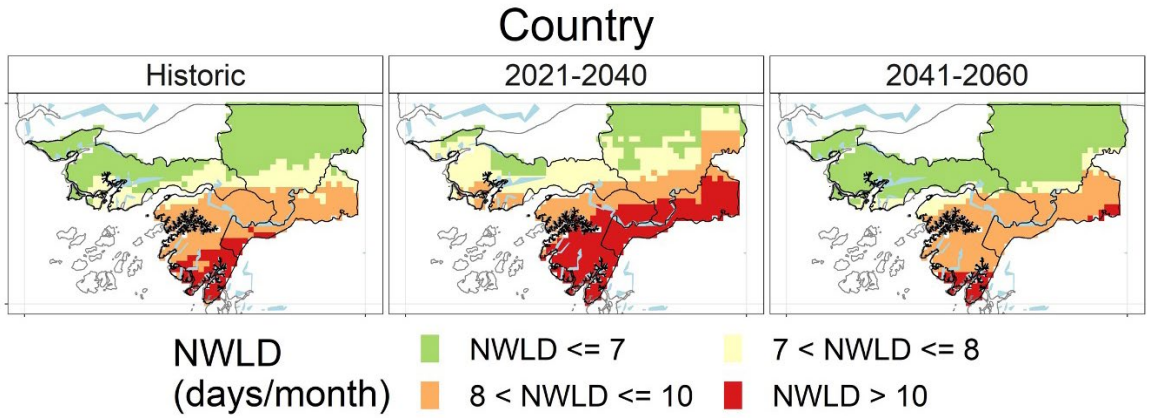


Figure 10: Historic and risk of waterlogging in Guinea-Bissau, expressed as projected number of days per month with waterlogging (NWLD). Green implies low risk and red implies extreme risk of waterlogging.

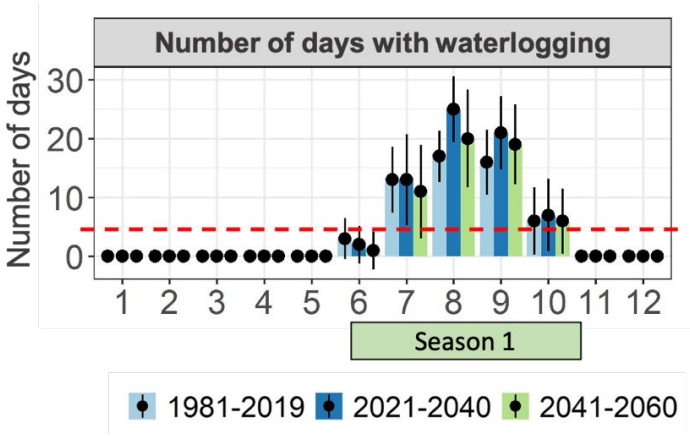


Figure 11: Seasonal variation of waterlogging risk throughout the year. The red line represents the threshold at which waterlogging becomes critical for crop production.

paddy rice despite efforts to contain flood damage with dikes and other protective infrastructure [37]. Flooding does not only cause direct yield loss to crops due to waterlogging, it also causes erosion of fertile soils and sedimentation of fields, riverways, and irrigation channels, putting further pressure on crop production [38]. Drainage in the interior of the country is problematic due to the limited permeability of many soils. Limited drainage exacerbates the impacts of floods.

As shown in Figure 10 below, risk of waterlogging will increase and concentrate around the southern coastal zone and eastern highlands in the future. Risk will be more prominent during the 2030s and reduce by the 2050s. This prediction mirrors the projected future precipitation trajectory. Only the eastern highlands are likely to continue to experience elevated waterlogging risk after the 2030s.

The seasonal variation of waterlogging throughout the year follows a pattern that mirrors rainfall projections, indicating a high correlation between the two phenomena (see Figure 11). While waterlogging risk is likely to decrease slightly during the months of June and July, it will develop a new peak around August and September. There are no major changes expected with regards to the impact of this hazard on crop production, as the hazard is already posing a major challenge to crop production throughout the country. Yet, an increase in the absolute amount of waterlogged days per month may pose additional challenges to adaptation by reducing the effectiveness of available coping strategies, as increased water amounts may cause more severe flooding that potentially destroys protective dikes and overstretches the tolerance level of waterlogging-tolerant crop varieties.

HEAT STRESS

The level of heat stress on animals is assessed by a THI or Thermal Humidity Index. The index captures the coinciding levels of temperature and humidity in shaded areas. Research has shown that crossing a certain THI threshold has a direct impact on livestock productivity and mortality [39]. Spatial trends of the probability of severe or extreme heat stress show that all LZs will continue to experience very high levels of heat stress, leading to lower livestock productivity and increasing mortality beyond 2030 and 2050 (see Figure 12).

Projected seasonal variations indicate that, in the future, heat stress levels will remain high throughout the year. These levels may cross the productivity threshold by 2030 and 2050 even during December and January, the only months that have historically seen fewer days of heat stress (see Figure 13).

SEA LEVEL RISE

Low-elevation coastal zones stand out

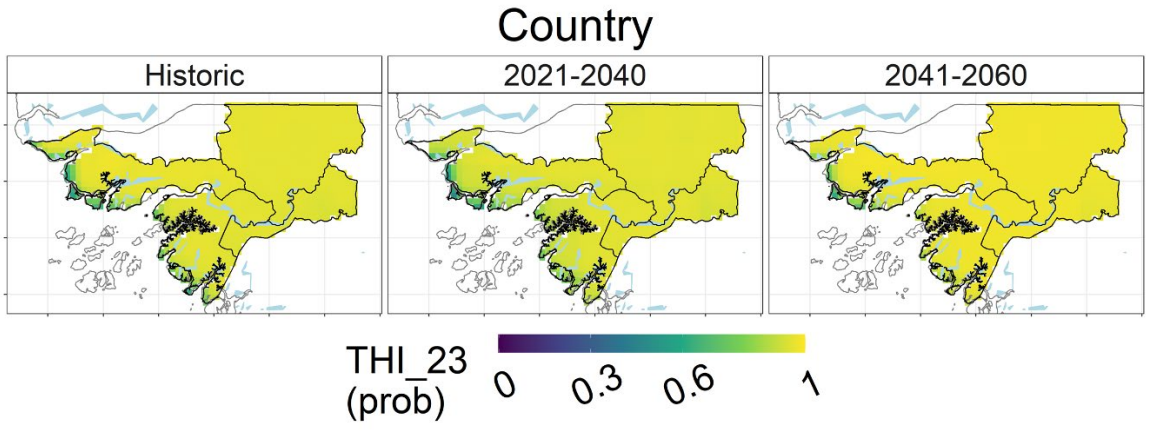


Figure 12: Historic and future probabilities of severe or extreme heat stress in Guinea-Bissau.

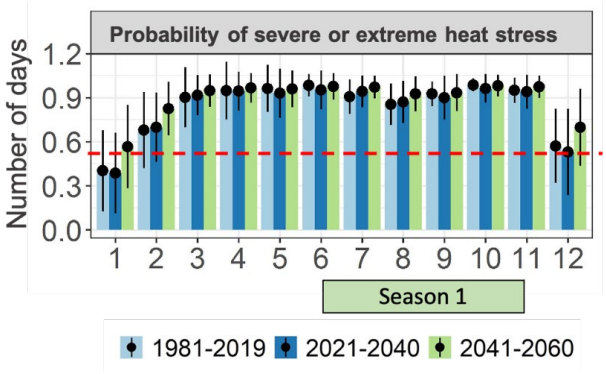


Figure 13: Historic and future seasonal variation in the occurence of severe or extreme heat stress throughout the year. The red line represents the threshold, represented in number of days per month, that presents a detrimental impact on livestock production and mortality.

as one of Guinea-Bissau's indicators of physical vulnerability. Most of Guinea-Bissau's continental terrain consists of costal swamps and mangroves, and over 19% of its land area is less than 10 meters above sea level [40]. Coastal mangrove zones provide some of the most important rice production areas in the country, where farmers clear mangroves to expose lands to precipitation that naturally washes salts from the soils and provides fertile lands for rice production. Farmers traditionally use dikes to prevent coastal tides from coming into the rice fields. Climate change has begun to affect coastal famers, as increasing tides have led to increasing occurrences of saltwater intruding on their rice paddies. This is forcing many farmers to abandon rice cultivation and shift into cashew production [37], [41], [42]. Even today, high tides can cause saline intrusion into aquifers of up to 175 km inland. This intrusion causes problems during the dry season if groundwater extraction exceeds recharge rates. As there are very few perennial water courses available in the country, the majority of the population relies on groundwater resources during the dry season.

Given its vast and largely low-lying coastal area, rising sea levels are projected to be a major concern for Guinea-Bissau. Sea level rise will impact both the northern and southern coastal zone. The southern zone will be most affected, especially around Catió and Cufar and in estuaries along the border with Guinea (see Figure 14). In the north, projections indicate permanent flooding of a few areas that are adjacent to estuaries, mainly around Cacheu. Crop production will be impacted by permanent loss of land due to sea encroachment, increases in flooding, and the salinization of fields. Farmers already report the destruction of swamp rice field dykes by unusually high tidal waves.

CO-OCCURRENCE OF HAZARDS

Drought and waterlogging are important to agricultural livelihoods. In Guinea-Bissau, they often co-occur with heat stress. Drought and heat stress have historically occurred together. This relationship will remain unchanged in the future. The co-occurrence of waterlogging and heat stress has been historically moderate in most of the country and high in the southern coastal zone (see Figure 15, top graphic). Co-occurring heat stress and waterlogging may move inwards towards the northern coastal zone and to parts of the eastern highlands and northeastern plains by 2030. By 2050, we expect a slight reduction in the areas that experience elevated waterlogging risk (see Figure 15, bottom graphic).

2.3 Current

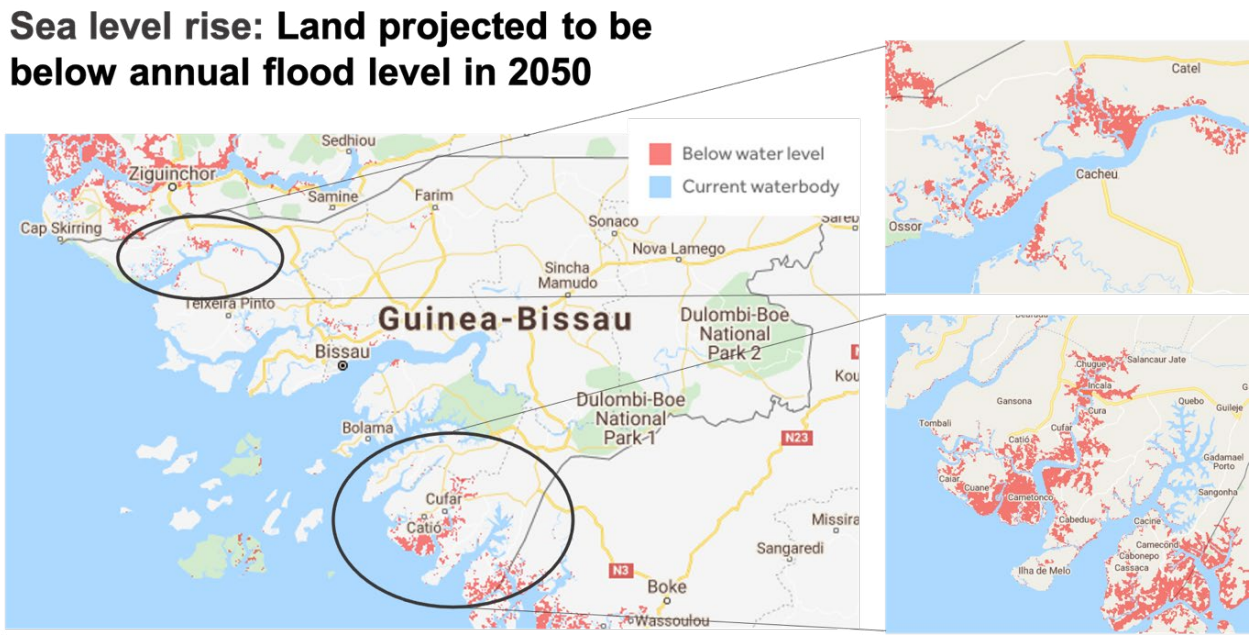


Figure 14: Projected sea level rise in Guinea-Bissau by 2050 for RCP8.5. Results from https://coastal.climatecentral.org/.

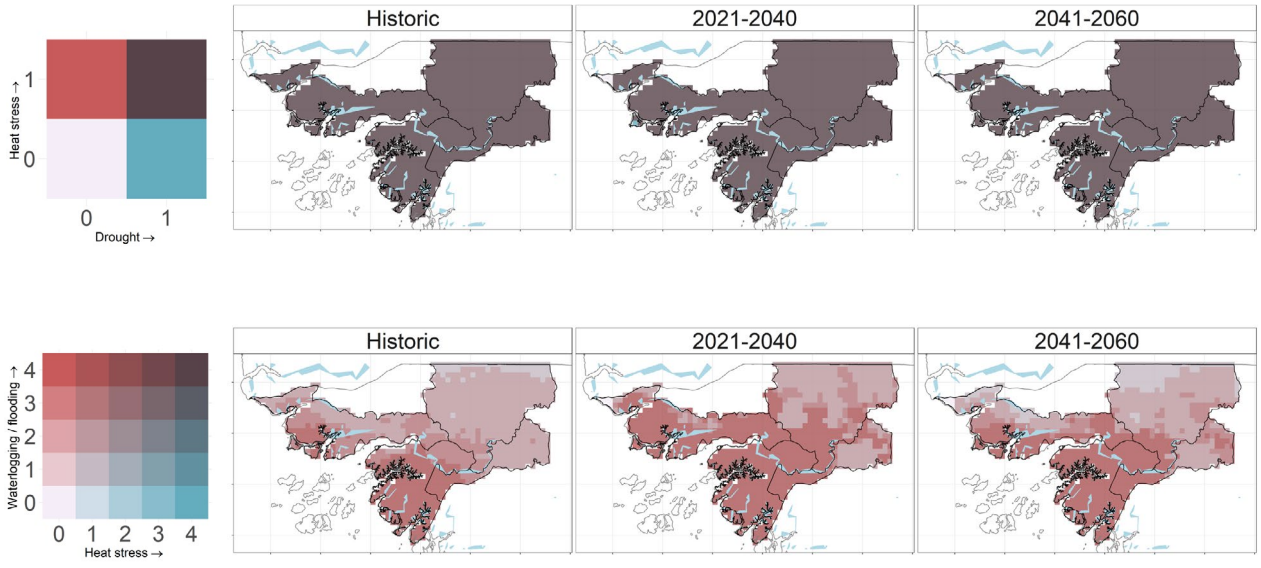


Figure 15: Historic and future spatial projections of the co-occurrence of drought and heat stress (top graphic) and waterlogging and heat stress (bottom graphic) in Guinea-Bissau. The darker the color, the more common the occurrence of the specific hazard.

and future crop suitability

The EcoCrop model [43] was used to find the areas that are suitable for crop production under current and future climate conditions in Guinea-Bissau. The EcoCrop model has been used in numerous research projects to conduct suitability assessments and to understand the impacts of climate change on a large number of different crops. The model uses crop-specific parameters such as minimum, maximum, and average temperature and cumulative precipitation during the growing season. These parameters are estimated across a spatial resolution of 5 by 5 km. Guinea-Bissau's suitability analysis was carried out for the staple crops of rice, cassava, millet, and cashew.

RICE AND CASHEW

The suitability of rice and cashew has historically been high throughout the country and is projected to remain unchanged in the future. All areas are regarded as highly suitable for both crops, as indicated by Figure 16 below.

CASSAVA

Cassava has historically been highly suitable

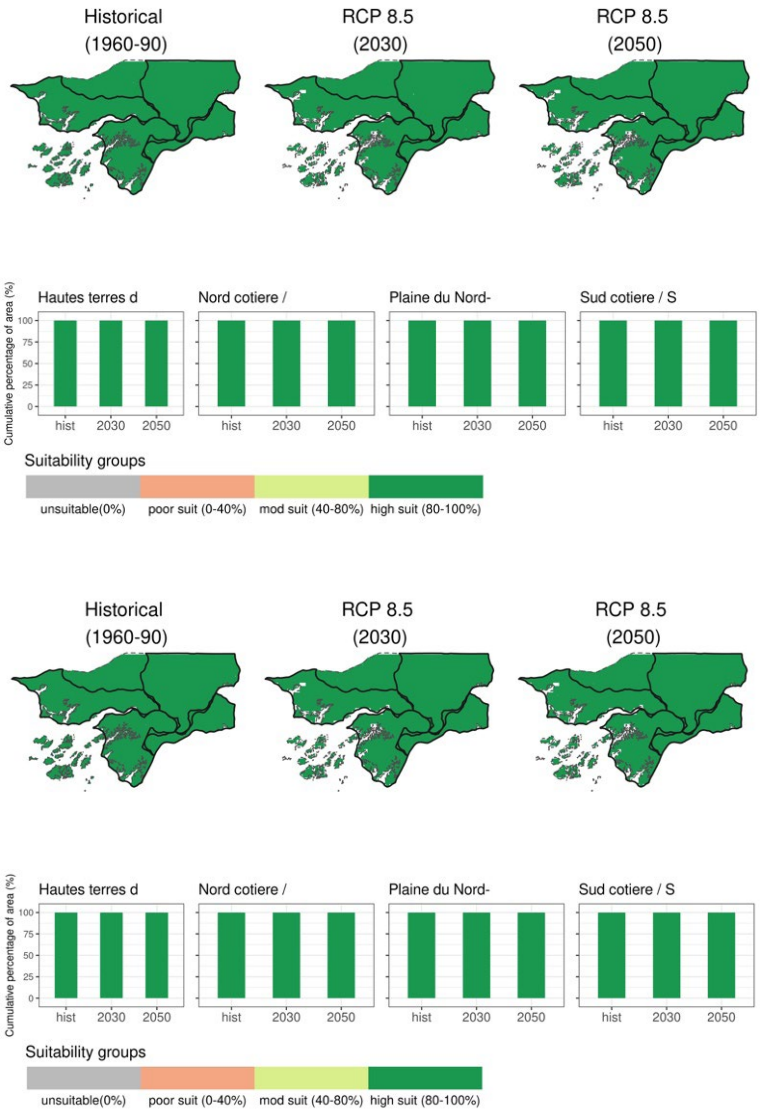


Figure 16: Historic and future suitability of rice (top) and cashew (bottom) in Guinea-Bissau.

across the northern coastal zone and much of the northeastern plains and moderately suitable in the southern coastal zone, as well as in large parts of the eastern highlands (see Figure 17, left graphic). In future climate projections, cassava's suitability is likely to decrease to moderate levels across most of the country, with the exception of some parts of the northern coastal zone. This decline in suitability can be avoided by switching to heat-tolerant cassava varieties (see Figure 17, right graphic). The heat-tolerant variety's suitability will likely increase in the future in all areas except for parts of the south coastal zone, where its suitability will remain moderate.

MILLET

Similarly to that of rice and cashew, the suitability of millet has historically been high and is projected to remain unchanged in the future throughout the entire country. All areas are regarded as highly suitable for millet, as indicated by Figure 18.

2.4

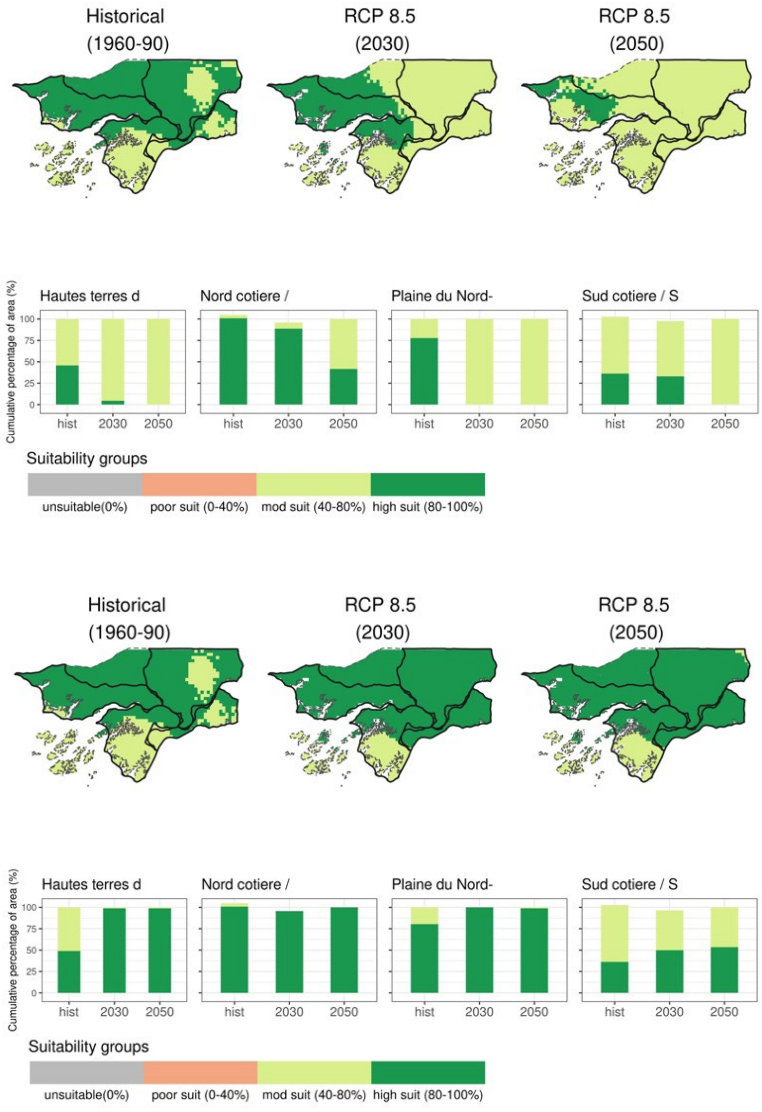


Figure 17: Historic and future suitability of common cassava (top graphic) and heat-tolerant cassava (bottom graphic) in Guinea-Bissau.

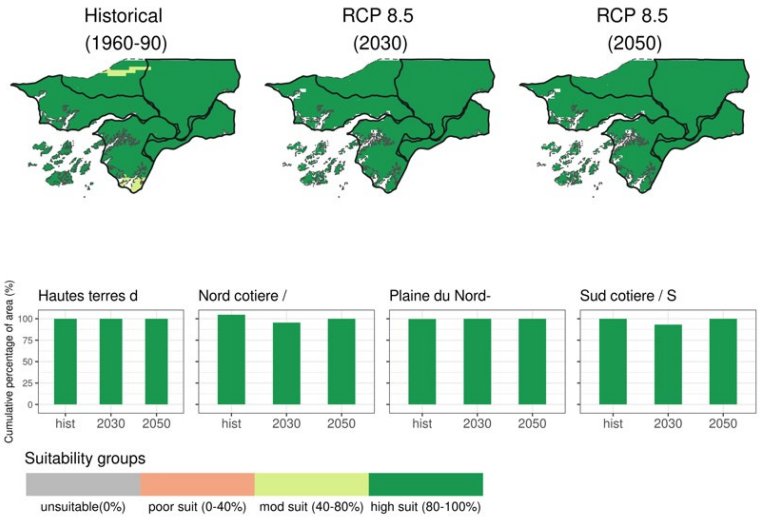


Figure 18: Historic and future suitability of millet in Guinea-Bissau.

Co-occurrence hotspots

Below, we assess the spatial distribution of vulnerabilities across selected provinces and identify areas prone to the co-occurrence of vulnerabilities. For this purpose, data was compiled on a set of vulnerability indicators in Guinea-Bissau and then mapped. A group of indicators was selected to best represent the three primary pillars of vulnerability as shown in Table 1. These indicators are food insecurity and nutrition, inequality, and poor health. Food security and nutrition was based on either direct estimations of food insecurity or food consumption scores alongside estimates on child development and nutrition. Inequality was represented by education-based gender indicators. Nutrition and health was represented by a combination of disease prevalence and mortality rates. The indicators were then tested to determine if they showed sufficient spatial variability to meaningfully contribute to the vulnerability hotspots map.

The variables that did meet these criteria were binarized. A threshold was used to separate values demonstrating "high" vulnerability from those that did not meet the criteria. The resulting binary layers were then summed up to show the prevalence of indicators that display high vulnerability (see Figure 19, top graphic) and aggregated at the variable-grouping level to show the combinations of food and nutrition insecurity, gender based educational inequality, and poor health that contribute to societal vulnerability. A similar process was used to produce maps that show vulnerability hotspots using the additional indicators in our analysis, although these indicators were not aggregated into variable groupings due to their diverse nature. In both figures below, "no areas of high vulnerability" indicates that the indicator values in this area did not exceed the predetermined threshold that represents "high" vulnerability. All variables used in the spatial analysis are classified as "included" in Table 1. Further methodological explanation is detailed in Annex 1.

RESULTS

Table 1: Indicators that were considered in creating the vulnerability hotspot maps. All included indicators are identified as such, and the reasons for any exclusions are noted.

Variable specificity	Variable grouping	Variable	Inclusion status
Primary	Food insecurity & nutrition	Food insecurity	Included
		Wasting prevalence	Excluded (insufficient variation)
		Stunting prevalence	Excluded (insufficient variation)
		Underweight prevalence	Excluded (insufficient variation)
	Gender and educational inequality	Male years of schooling	Included
		Female years of schooling	Included
		Gender education gap	Included
	Health	Plasmodium falciparum incidence rate	Included
		Plasmodium vivax incidence rate	Excluded (insufficient variation)
		Mortality of children under 5 per 1000 live births	Included
		Diarrhea prevalence	Included
Additional	N/A	Net migration	Included
		Accessibility to cities	Excluded (insufficient variation)
		Active fires	Included
		Predominant ethnic group	Excluded (insufficient variation)

The western region of the north coastal zone displays the highest number of "high" vulnerability variables by quite some margin. This contrasts starkly with the substantial areas of the eastern region of the north coastal zone and parts of the remaining three livelihood zones that have no such variables. The only region to show high food insecurity combined with both high inequality and poor health is the western region of the north coastal zone. In addition to the western region of the north coastal zone, high inequality is prevalent across the majority of the eastern highlands, the northern region of the northeastern plain, and smaller areas in the southern region of the northeastern plain and the western part of the south coastal zone. Poor health is concentrated in a diagonal corridor that runs from the northern region of the northeast plain to the southwestern region of the south coastal zone. Poor health is also concentrated in the western region of the north coastal zone. Food insecurity, on the other hand, is only classified as "high" within the western region of the north coastal zone.

Of the additional vulnerability indicators, only outmigration is relevant to Guinea-Bissau. According to the analysis, outmigration is estimated to have taken place across the eastern part of the north coastal zone, stretching through the eastern region of the south coastal zone and into the western part of the eastern highlands. Net outmigration was highest in the north coastal zone with an estimated -5,061 net migrant flow, followed by the south coastal zone, which had an estimated net migrant flow of -4,576 (see Annex 2).

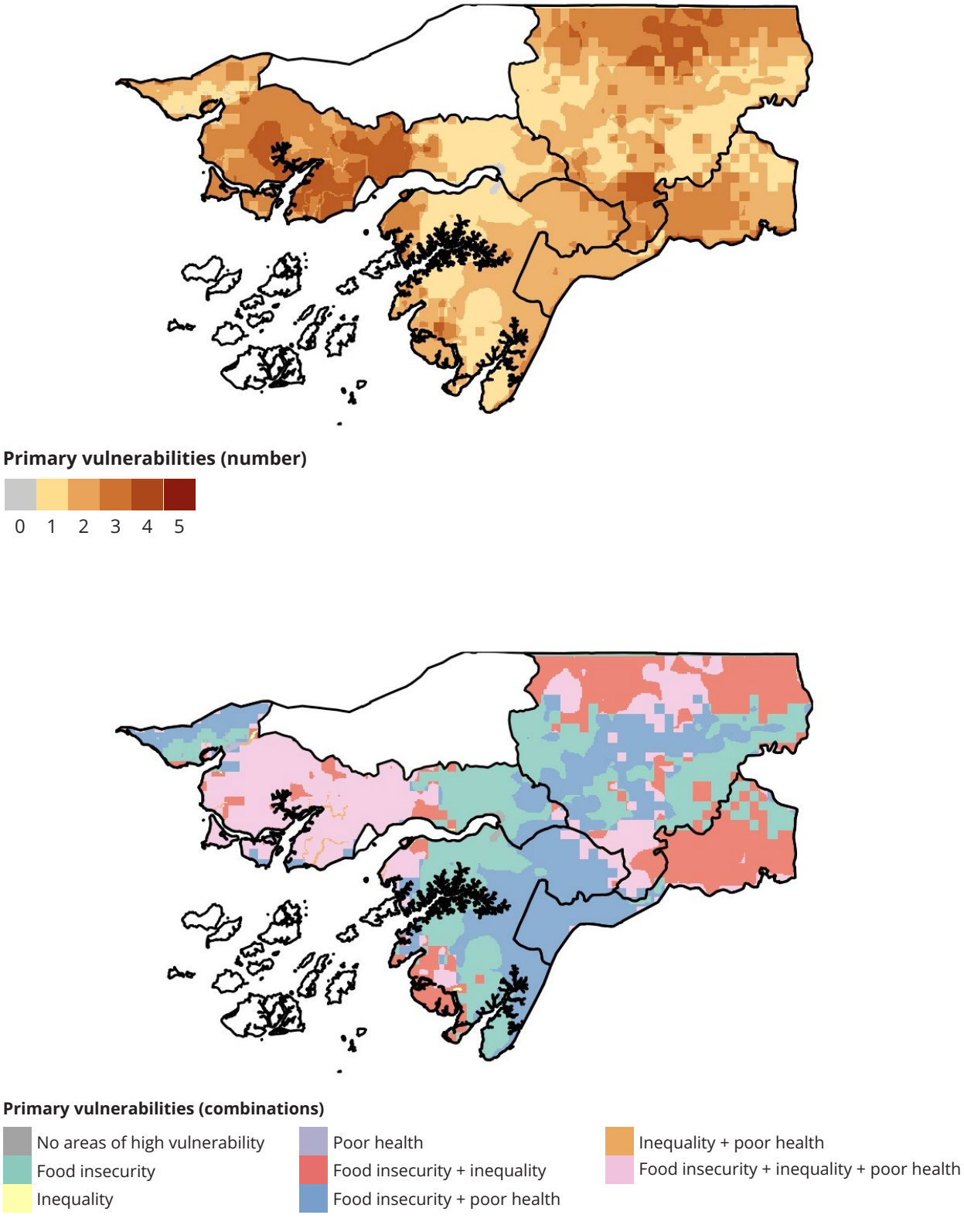
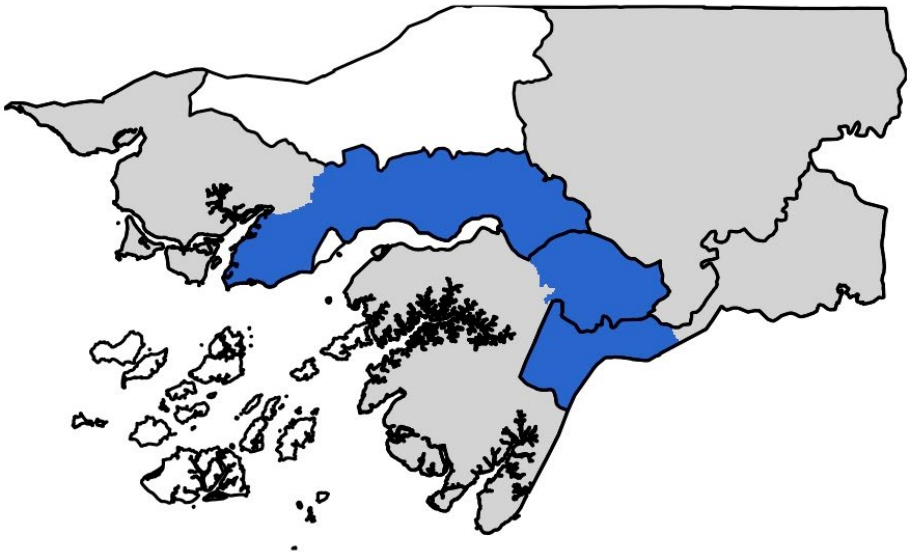
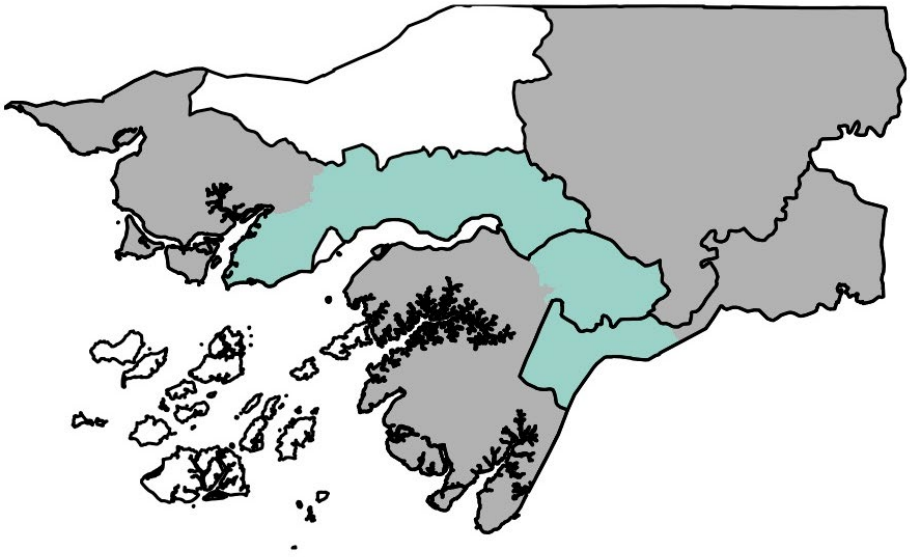


Figure 19: Total number of high vulnerability metrics which span food security and nutrition, health, and inequality (top graphic) and food security and nutrition, inequality, and health hotspots across the livelihood zones, shown as combinations of vulnerability metrics (bottom graphic).



Additional vulnerabilities

0 1



Additional vulnerabilities (combinations)

no areas of high vulnerability

out-migration

Figure 20: Total number of additional vulnerability metrics classified as "high" in a given area (top graphic) and combinations of additional vulnerability hotspots across selected livelihood zones (bottom graphic).

2.5 Summary by livelihood zone

EASTERN HIGHLANDS

- Guinea-Bissau's eastern highlands may experience more days with extreme rainfall during the monsoon season by 2050, leading to higher risk of flooding and waterlogging during summer. However, the change in the growing season's duration from between May and November to between June and October will translate into an overall lack of water during key crop growth stages, affecting the production of rice and other crops.
- Temperatures are gradually increasing across the zone. Thermal heat stress is already high and will remain high, causing stress and suboptimal productivity conditions for livestock.
- Drought risk will increase moderately towards 2030 and decrease slightly towards 2050.
- Rice, cashew, and millet cultivation has been and is projected to remain highly suitable in this zone. Cassava will likely downgrade from moderate to highly suitable to only moderately suitable.
- The area is prone to high food insecurity and inequality as a main vulnerability hotspot.

NORTHEASTERN PLAINS

- Drought risk will increase significantly in the northeast, which can impact the suitability of rice production and decrease overall crop yields. Farmers already experience lower crop yields due to rainfall variability and longer dry spells. The change in the growing season's duration from between May and November to between June and October will translate into an overall lack of water during key crop growth stages, which especially affects rice production.
- The combination of increased drought risk and continued thermal heat stress will likely impact livestock herders, who will find fewer water and feed sources. This situation will trigger more seasonal migration in the east and potential conflicts over resources.
- Risk of waterlogging in the northeast will increase slightly towards 2030 and then decrease to levels lower than today's towards 2050. Adaptation planning should focus on midterm solutions.
- Vulnerability hotspots in this zone are concentrated along the border with Senegal in the north, which is particularly prone to food insecurity, inequality and – in some areas – poor health.
- Rice, cashew, and millet cultivation has been and is projected to remain highly suitable in this zone. Cassava will likely downgrade from highly to moderately suitable to only moderately suitable.

NORTH COASTAL ZONE

- Drought risk has historically been moderate in northern coastal zones but will likely increase towards 2030 and become especially pronounced towards 2050.
- The combination of drought risk, a shorter rainy season, and higher temperatures can lead to fewer growing season days. This will translate into an overall lack of water during key crop growth stages, which especially affects rice production.
- Waterlogging will increase moderately towards 2030 and decrease again towards 2050, potentially disrupting crop production in the coming decades.
- Rising sea levels will likely impact a few estuaries around the Cacheu area and lead to permanent loss of land due to sea encroachment. The sea encroachment will also likely spill over to adjacent areas of coastal mangrove rice fields, increasing the flooding and salinization of these fields. The severity of this encroachment's impacts will depend on the status of coastal mangrove forests.
- The north coastal zone is home to the country's

highest levels of vulnerability in terms of food and nutrition insecurity, poor health, and inequality.

- The cultivation of rice, cashew, millet, and cassava has been and will continue to be highly suitable in this zone throughout the 2050s.

SOUTH COASTAL ZONE

- The risk of waterlogging and flooding will increase significantly around the southern coastal zone. It will be prominent during the 2030s and decrease by the 2050s.
- Drought risk will increase from low to moderate across the southern coastal zone. The change in the growing season's duration from between May and November to between June and October will translate into an overall lack of water during key crop growth stages, which especially affects rice production.
- Higher temperatures and an increase in waterlogging can lead to more pests and diseases, which are already observed by farmers in the region.
- Rising sea levels will likely impact the southern coastal zone, especially around Catió and Cufar and in estuaries along the border with Guinea. Crop production will be impacted by permanent loss of land due to sea encroachment and increases in flooding and the salinization of fields. Farmers already report the destruction of swamp rice field dykes by unusually high tidal waves. The severity of these events' impacts will depend on the status of coastal mangrove forests.
- The zone has pockets of food insecurity and poor health but is generally less vulnerable than the rest of the country.
- The cultivation of rice, cashew, and millet has been and will continue to be highly suitable in this zone throughout the 2050s. Cassava is only moderately suitable in large parts of the zone. Overall cassava suitability will decline slightly across the zone but remain moderately suitable.

PART 3.

Review of World Food Programme activities and recommendations for optimization

In light of the aforementioned climate risks, climate impacts, current policies, and funding mechanisms, we reviewed several high-potential food security interventions in alignment with WFP mandates. These interventions were validated through key informant interviews and an online workshop. The interventions offer insight into the most impactful potential next steps for WFP activities.

3.1 Review of current relevant WFP activities and recommendations for programmatic responses

WFP has established itself as a trusted partner of the government of Guinea-Bissau by providing the government with technical and financial assistance in its efforts towards developing human capital through better education, health services, and social protection. In its 2019 – 2024 Country Strategic Plan (CSP), WFP pursues five strategic outcomes (SOs) that are implemented through different activities that target nutrition, school meals, institutional support for food security and nutrition monitoring, emergency preparedness, and crisis response. WFP emphasizes gender-transformative approaches, education for the empowerment of the rural poor, and the inclusion of people with disabilities (see Figure 21) [11].

While the CSP has no strategic outcome that explicitly focuses on climate resilience building, it has ample room to integrate climate resilience activities into most SOs (see Figure 21). Within current activities, SO1 – Activity 1 and SO4 – Activity 4 already support a number of measures that enhance climate resilience. However, these measures are usually short-term in nature or complement a set of other activities with no specific climate angle. Based on results from the climate risk analysis, programmatic recommendations for climate-adaptation mainstreaming in WFP's activities include the adjustment of current activities as well as the integration of new ones. These programmatic recommendations are described in more detail below.

WFP Guinea-Bissau Country Strategic Plan 2019-2023	
Strategic outcome 1: Crisis-affected populations in Guinea-Bissau are able to meet their basic food and nutrition requirements in the aftermath of shocks.	**Activity 1:** Provide food and nutrition assistance to crisis-affected populations and strengthen the capacity of and coordination among national partners in responding to crises as a contingency measure.
Strategic outcome 2: School-age children in Guinea-Bissau have access to nutritious meals during the school year.	**Activity 2:** Provide nutritious school meals to pre- and primary school children and take-home rations for girls in years 5 and 6 and strengthen the capacities of the government and partners at the central and local levels to implement and monitor a nutrition-sensitive and gender-transformative school feeding programme.
Strategic outcome 3: Populations at risk of malnutrition in Guinea-Bissau, particularly children, women and girls of reproductive age and people living with HIV, have improved nutrition status in line with national targets by 2024.	**Activity 3:** Support the implementation of the national nutrition policy and the protocol for the integrated prevention of stunting and treatment of moderate acute malnutrition focusing on the provision of support for policy design and gender and age-informed implementation, technical assistance and capacity strengthening to the Ministry of Public Heath, Family and Social Cohesion; social and behaviour change communication, the prevention of stunting among children aged 6-23 months, the treatment of moderate acute malnutrition among children aged 6-59 months, and food and nutrition assistance to people living with HIV and their households.
Strategic outcome 4: Smallholder farmers in Guinea-Bissau, particularly women and young people, have improved livelihoods and increased household incomes by 2024.	**Activity 4:** Provide an integrated package of assistance interventions to associations of women and young smallholder farmers that comprises nutrition and literacy education, training in basic business skills, sensitization to their rights to adequate food and nutrition, market access through the school feeding programme and the transfer of knowledge on the optimization of agricultural value chains.
Strategic outcome 5: National institutions and legislators in Guinea-Bissau have enhanced capacity in and are accountable for the development, implementation and monitoring of evidence-based food security and nutrition policies and programmes by 2030.	**Activity 5:** Provide national institutions with support for policies, technical assistance and the transfer of knowledge and advocate for the effective formulation and implementation of gender-transformative social safety nets, food security and nutrition programmes (including data collection and analysis, evidence generation and monitoring systems) and emergency preparedness and response mechanisms.

Figure 21: Overview of WFP's Country Strategic Plan 2019 – 2024 for Guinea-Bissau

3.2 Programmatic recommendations for climate adaptation response based on WFP's existing activities

Effective adaptation to climate change involves "both building adaptive capacity, thereby increasing the ability of individuals, groups, or organisations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action" [44]. Various intervention options can reduce the risk of, impact of, and vulnerability to climate change on the

livelihood, community, landscape, institutional, and policy levels and across supply chains. Activities can target either structural, physical, social, or institutional adaptation and can either focus on specific hazards or strengthen adaptive capacity in general.

In Guinea-Bissau, discussions with stakeholders revealed that effective adaptation planning and implementation is in its infancy because institutional and adaptive capacity is weak, awareness of climate risk and adaptation options is low, and financial resources are largely inexistent [22], [45], [46]. Adaptation actions should therefore take a holistic approach that embrace activities across all levels of intervention, strengthen the institutional and policy level, and support the individual, community, and landscape level with concrete adaptation interventions.

The climate risk analysis highlighted that risk management for agricultural production and food security in Guinea-Bissau mostly evolves around the effective management of water. Risks are often related to a lack of water because of droughts, dry spells, changing onsets and durations of the rainy season, and increased evapotranspiration, humidity, and heat stress from increasing temperatures. Risks also often relate to an excess of water because of heavy precipitation or high tides that lead to flooding and waterlogging, and the intrusion of coastal salt water into agricultural fields and groundwater aquifers that leads to the sedimentation and siltation of waterways and the salinization of agricultural land. The risk of high tides in coastal areas is aggravated by projected rise in sea level over the coming decades with expected permanent inundations and loss of land, especially in coastal estuaries in both the northern and southern coastal zones.

While there are structural, socio-economic, and biophysical differences between the four selected livelihood zones, exposure to the previously mentioned climate hazards is relevant across all LZs, albeit with different degrees of intensity and occurring in different ecological systems. Accordingly, the lists of adaptation options that were identified by local stakeholders and in national plans are also often similar across the LZs. With this in mind, we can describe in more detail how effective adaptation planning can be streamlined into WFP programming based on existing CSP activities. We present below selected adaptation options that have been identified as the most relevant and suitable for Guinea-Bissau from discussions with local experts and stakeholders from government entities and non-governmental and international organizations. These options are grouped by climate hazard and by different levels of interventions. These options are also summarized in Table 2, at the end of this section.

STRATEGIC OUTCOME 1

Under the current program, the emergency relief focus of SO1 – Activity 1 includes asset creating activities like distributing cash or vouchers to support farmers that are frequently affected by fast-onset climate hazards. Supported measures include rehabilitating salinated agricultural fields, learning techniques to protect agricultural fields from future damage, and acquiring knowledge about value chain enhancement and basic business skills. SO1's activities last between 6 months to a year and focus on communities that are prone to flood, soil erosion, and salinization. These communities are mostly situated along the Geba River in Oio, Bafata, and Gabu, and cross LZ2 and LZ3.

Food For Asset (FFA) and Disaster Risk Reduction (DRR) activities could be refocused from relief to resilience building and targeting vulnerable communities in areas where current- and future-projected climate risks are most pronounced. The FFA stakeholders should add anticipatory and preparatory resilience efforts that keep providing short-term relief, while also building up long-term resilience to projected future climate hazards. For example, FFA efforts

can be amended in the following ways:

a. Increase the availability of water through the improvement and construction of micro-dams, small water reservoirs, community ponds, and irrigation channels, and the development of deep boreholes

b. Implement land and soil management techniques like the use of zai pits, infiltration basins, and stone bunds for water harvesting and improved efficiency

c. Protect catchments of drinking and irrigation water and reduce the erosion, siltation, and sedimentation of cropland, waterways, and riverbanks through community-based forest plantation activities

d. Improve the protection of mangrove rice and lowland rice fields along estuaries and rivers from high tides, salt water intrusion, and flooding through mangrove replanting in coastal areas, reforestation inland, and the construction of improved dikes, canals, and drainage systems

e. Construct improved flood-protected houses, community buildings, and livestock sheds at strategic sites for storage, health posts, and markets

With regards to the geographic area and overall scope of FFA activities, WFP should prioritize measures against flooding among vulnerable communities in LZ1 and LZ4 and measures against drought among vulnerable communities in LZ2 and LZ3. Furthermore, FFA activities can be used in integrating resilience-building measures to protect vulnerable communities from rising sea levels and high tides in LZ3 and LZ4 - specifically around Cacheu, Catió, Cufar, and in estuaries along the border with Guinea.

STRATEGIC OUTCOME 2 AND STRATEGIC OUTCOME 3

The school meal program under SO2 – Activity 2 and the nutrition and health program under SO3 – Activity 3 represent unique opportunities for streamlining awareness raising and education campaigns on best behavior for climate resilience and adaptation for the country's most vulnerable communities. The upcoming Social Behavior Change Communication program provides great opportunities for adding training modules that build awareness of climate risks and adaptation behavior at the individual and household level. This program is an opportunity to build the adaptive capacity of the most vulnerable population and entrench education and awareness on climate risks and best behavior into the education program of children, who can act as multipliers by bringing this knowledge into their families. Education modules should focus on resilient nutrition choices, health risks from climate change and how to cope, and good agricultural practices in drought or flood risk zones - including choosing climate resilient and highly nutritious crops for local cultivation.

STRATEGIC OUTCOME 4

In SO4 – Activity 4, WFP is working with smallholder farmers and especially women-led producer groups that supply food for school meals to strengthen their production capacity. SO4's activities are therefore strongly linked with the school meal program in SO2. The activities promote training that includes techniques for improving the production, storage, and transformation of cereals, pulses, and horticultural crops, all of which are already building adaptive capacity to address the impacts of climate hazards. WFP also provides literacy and nutrition classes together with follow-up practice sessions. Resilience building is further supported through asset creation activities that help improve the management of natural resources, enhance household assets and livelihoods, and reduce overall vulnerability to flooding. In collaboration with the Ministry of Agriculture and Rural Development, WFP is also exploring the dissemination of weather information to smallholder farmers to inform agricultural planning. However, the current infrastructure and capacity of the National Meteorological Service is limited, making the realization of this program

difficult.

SO4 represents the ideal venue for introducing more targeted climate adaptation programs into WFP's portfolio of activities. The existing trainings for farmers should be enhanced with specific modules on climate risk awareness and technical training on selecting and implementing climate-smart agricultural (CSA) practices for local contexts. These modules can be disseminated through farmer field schools or the establishment of climate-smart villages as demonstration sites, and should offer practice sessions to train farmers and producer groups on the correct installment and maintenance of CSA practices. The focus of these training modules should be tailored to local risk contexts, responses to increased flood risk in LZ1 and LZ4, protection from coastal tides and sea level rise in LZ3 and LZ4, and responses to increased drought risk in LZ2 and LZ3.

STRATEGIC OUTCOME 5

Under SO5, WFP provides policy support, technical assistance, and capacity strengthening to national institutions, and advocates for the effective formulation and implementation of gender-transformative social protection, food security and nutrition programmes, and emergency preparedness and response mechanisms. WFP has an opportunity to streamline climate risk management in its ongoing efforts to strengthen the capacities of national institutions to take effective legislative action and formulate and implement equitable public policies that support social safety nets, food security and nutrition programs, and emergency preparedness and response mechanisms. Building on its operationalization of a Food and Nutrition Security Monitoring System (FNSMS) for Guinea-Bissau, WFP can develop a climate risk and vulnerability monitoring system and integrate its operationalization into the existing FNSMS. Streamlining climate vulnerability monitoring into the FNSMS is an opportunity to align the redesign with the EU's 2018 evaluation recommendations , which suggested improving the quality of data collection through greater involvement of the National Institute of Statistics (Instituto Nacional de Estatistica, or INE) and to redesign the FSNMS to better reflect partners' needs and local conditions. WFP can further integrate climate vulnerability and adaptation planning into the development and operationalization of national policies and plans that are receiving support from WFP and other partners such as the Social Protection Policy or the National Nutrition Plan 2015 – 2019.

In addition, WFP and its international partner organizations have great potential to support the government in developing new capacities and accessing resources for enhanced climate preparedness at the national and provincial levels. Opportunities exist in providing capacity development, organizing training and awareness activities for key stakeholders around a number of specialized topics related to adaptation planning and effectiveness, accessing international climate finance, and further integrating scientific insights into national plans and objectives. One means of engagement could be employing multi-stakeholder coordination platforms to align and train the various stakeholders who are active in policy on climate risk management and effective adaptation planning and implementation. It is urgent to provide rapid responses that mitigate vulnerability to the effects of climate change by improving access to essential services for vulnerable populations and by strengthening their resilience.

Although leading the development of new policies may be outside the scope of WFP Guinea-Bissau's CSP, WFP can collaborate with other UN agencies to ensure that issues which lie at the intersection of climate resilience and food security are adequately reflected in emerging policy documents and implementation plans. Development of the National Adaptation Plan (NAP) kicked off in 2019, while Guinea-Bissau's INDC are currently in the process of being revised [31]. While UNDP is leading the policy formulation processes, WFP can work with UNDP to shape the text or subsequent implementation frameworks. In addition to

ensuring that issues facing climate-vulnerable communities are addressed, WFP's involvement will also improve its positioning when tendering adaptation-oriented proposals with donors.

WFP, together with national partner governments, developed the Zero Hunger Strategic Review (ZHSR) in preparation for their new country strategic plans. In Guinea-Bissau, the ZHSR highlights areas where the government needs support to implement its sectoral plans on food security and nutrition. There is currently neither assessment nor mention of climate change as a factor that potentially influences the country's ability to reach their national food security and social policy goals. Therefore, WFP should consider updating their approach to conducting ZHSRs and similar baseline studies in preparation for their in-country strategic engagements. This would allow WFP to integrate a climate risk angle in order to identify opportunities where addressing government needs on food and nutrition policy goals can go hand in hand with and benefit from addressing needs in climate risk management.

Table 3: Adaptation measures for selected hazards

Climate Hazard	Intervention Level	Adaptation Options	Link to WFP Programming
Eastern Highlands (LZ1) and Northeastern Plains (LZ2)			
Flood and waterlogging	**Household and community level**	• Train farmers on **climate smart technologies and management practices** in flood prone areas through farmer field schools and climate smart village demonstration sites, stimulate learning and exchange between communities from different areas, focus on the following actions: - Promote access to and use of **waterlogging and salt-water tolerant crop varieties** and implement **modern cultivation techniques like sustainable rice intensification** - Intensify the **construction of dikes** and protection of the most vulnerable areas to flooding and flood-caused sedimentation, improve **canals and drainage systems** that reduce waterlogging in fields • Promote the uptake of **aquaculture, especially in coastal areas, and consider integrated approaches such as rice-fish farming** • **Raise awareness and support education activities** for communities to avoid deforestation and illegal logging in mangroves, create community forest management groups to build ownership and responsibility for sustainable use	SO1 – Act 01 SO4 – Act 04
	Landscape level	• Promote **reforestation and reduce deforestation** in **forest areas** to reduce landslides and the sedimentation of waterways • **Map groundwater** to identify suitable sites for **deep borehole** development, protect water points from salt water intrusion	SO1 – Act 01 SO4 – Act 04

Climate Hazard	Intervention Level	Adaptation Options	Link to WFP Programming
Northern Coastal Zone (LZ3) and Southern Coastal Zone (LZ4)			
Flood and waterlogging	**Household and community level**	• Train farmers on **climate smart technologies and management practices** in flood prone areas across lowlands and near riverbeds through farmer field schools and climate smart village demonstration sites, stimulate learning and exchange between communities from different areas, focus on the following actions: - Promote access to and use of **waterlogging-tolerant crop varieties** and implement **modern cultivation techniques** - Intensify the **construction of dikes** and protection of the most vulnerable areas to flooding and flood-caused sedimentation, improve **canals and drainage systems** that reduce waterlogging in fields - **Provide early warning of heavy rains to allow for early harvesting and improved storage** to avoid harvest and nutrient value loss from excess moisture - **Improve livestock sheds** to avoid disease, promote short cycle livestock breeds - **Plant fodder trees and fodder banks,** make **silage** to provide alternative livestock feed resources - Promote the uptake of **aquaculture, especially in coastal areas, and consider integrated approaches such as rice-fish farming** • **Raise awareness and support education activities** for communities to avoid deforestation and illegal logging, create community forest management groups to build ownership and responsibility for sustainable use - Farmer training in construction techniques and the use of improved stoves to alleviate pressure on forests for firewood to cook food	SO1 – Act 01 SO4 – Act 04
	Landscape level	• Promote **reforestation and reduce deforestation** in the highlands, around communities and crop production areas, and in **coastal mangroves** to avoid landslides, sedimentation, and siltation in the lowlands, reduce flooding and salt water intrusion in crop fields, protect against coastal erosion • **Map groundwater** to identify suitable sites for **deep borehole** development, protect water points from salt water intrusion	SO1 – Act 01 SO4 – Act 04

Climate Hazard	Intervention Level	Adaptation Options	Link to WFP Programming
Northeastern Plains (LZ2) and Northern Coastal Zone (LZ3)			
Drought risk and heat stress	**Household and community level**	• Promote **climate smart agricultural practices through farmer field schools** and **climate smart village** demonstration sites, focus on the following actions: - Integrate zai pits, infiltration basins, conservation agriculture, mulching, compost and manure, water saving irrigation or drip, agroforestry intercropping with annual crops for shade, leaf mulch, erosion control, diversification, short-cycle and drought-tolerant varieties, rainwater harvesting, small irrigation systems, greenhouses for horticulture, and organic soil fertility management - Introduce the planting of Leucaena leucocephala for animal feeding, soil fertilizer and its resistance to drought. - Promote **short-cycle livestock breeds, plant fodder trees and fodder banks, support the development of pasture through introducing forage grasses** like *Brachiaria*, promote silage making and improved storage capacity for feed during the dry season • Develop on-site agricultural and water-management adaptation actions, where the precise adaptation strategy choice will be made by the communities themselves with indigenous knowledge	SO1 – Act 01 SO4 – Act 04
	Landscape level	• Develop and implement **programs for water management, increase storage capacity** at the local level by constructing micro dams, reservoirs, and irrigation infrastructure • **Map groundwater** to identify suitable sites for **deep borehole** development for irrigation and drinking water • Promote **reforestation** for shade and improved micro-climates, control wind erosion that affects cashews and crops • Promote **pasture production and rehabilitation** to favor soil fixation, keep a permanent biomass cover to protect against dust and erosion • Sensitization about the importance of crop diversification for food security • Training beneficiaries on the preparation and use of natural pesticides to protect plants against pests and preparation of organic compounds to fertilize the soil, thus avoiding the use of chemical pesticides and fertilizers.	SO1 – Act 01 SO4 – Act 04

Climate Hazard	Intervention Level	Adaptation Options	Link to WFP Programming
All Livelihood Zones and the National Level			
Cross cutting, all hazards	**Household level**	• **Streamline resilience and adaptation planning into Social Behavior Change Communication,** add modules on resilient nutrition choices, health risks from climate change and how to cope, and good agricultural practices including choosing climate-resilient and highly nutritious crops for local cultivation	SO2 – Act 02 SO3 – Act 03
Flooding and waterlogging	**Policy and institutional level**	• Develop flood and high tide **early warning systems and weather information services** for farmers and communities, link early warning systems to forecast-based action, train farmers on DRR and anticipatory preventive actions before disaster occurs • Support local and provincial government in **developing climate-risk management plans that incorporate flood-sensitive areas,** train effective implementation and monitoring • Develop the **institutional capacity of agricultural research for development** such as crop and livestock breeding and pest and disease management • Support **market development for agricultural diversification** towards climate-resilient and highly nutritious crops and livestock, including local production, the marketing and dissemination of seeds, farmers' inputs, and training for proper management • Develop and **enforce forest protection laws,** build a national forestry inventory, and train government technicians in forestry management for flood and erosion control	SO5 – Act 05
Drought risk and heat stress	**Policy and institutional level**	• **Develop the institutional capacity of agricultural research** for breeding, developing, and disseminating improved and short cycle varieties, e.g. **short-cycle drought- and heat-tolerant varieties** • Support local production, marketing, and dissemination of seeds and inputs to farmers, train farmers on proper management • Support the **integration of climate risk and adaptation into local livestock management plans** including transhumance corridors, construct strategic drinking water points, introduce stress-tolerant livestock breeds • **Build capacity and awareness among provincial and municipal level stakeholders** around climate risks and effective adaptation planning and implementation	SO5 – Act 05

Climate Hazard	Intervention Level	Adaptation Options	Link to WFP Programming
Cross cutting, all hazards	**Policy and institutional level**	• **Contribute to the development of NAP and the revision of NDCs** and similar policy documents, ensure that climate change is streamlined across existing and new policy documents including the next ZHSR • **Employ multi-stakeholder coordination platforms** to provide training and capacity development on accessing resources for enhanced climate preparedness at the national and provincial levels	SO5 – Act 05

3.3 Programmatic recommendations for introducing new activities

WFP efforts to explore the use of weather forecasts represents an opportunity to debut one of their flagship global climate anticipatory action programs on forecast-based finance (FBF). FBF is widely used by WFP. In FBF programs, anticipatory actions at the community and government levels are predefined, triggered, and implemented before a climate shock occurs. The key principle of FBF is that humanitarian responders, disaster management authorities, and communities agree on a set of anticipatory actions that are implemented to mitigate the impact of a shock once a forecast predicts that a certain threshold of risk probability will be exceeded. A humanitarian return on investment analysis of WFP's FBF flood response programming in Nepal found that FBF programming can limit natural disaster damages to vulnerable people by 75% and to assets like crops and cattle by 50%. FBF programming can thus "save a significant amount of money in the immediate response (USD 34 per dollar invested), but it also further decreases long-term recovery needs and costs" [47].

In Guinea-Bissau, introducing FBF programming will depend on the capacity of the national meteorological institute in monitoring and

forecasting weather. At present, there are huge gaps in both physical infrastructure for weather monitoring and technical skills among staff. Introducing climate information services and early warning measures like FBF programming would thus require WFP to partner with other international organizations that have expertise in building up weather-monitoring infrastructure and capacity development for national stakeholders. In 2019, UNDP was approved for USD 6 million funding from the GEF, with USD 33 million co-financing, to begin a project called "Strengthening Climate Information and Early Warning Systems for Climate Resilient Development and Adaptation to Climate Change in Guinea-Bissau". The project represents an opportunity for WFP to join forces with UNDP, collaborate on the rollout of early warning and agricultural advisory, and to gradually introduce FBF programming once the forecasting service is up and running.

It is also recommended that WFP pursue a follow-up, in-depth study of climate vulnerability and resilience mapping at the livelihood level in order to tailor the exact geographic scope of additional climate adaptation interventions. WFP can refer to their in-house Consolidated Livelihood Exercise for Analysing Resilience (CLEAR) approach, an analytical exercise that assesses climate impacts on food security at the livelihood level. The CLEAR approach's collaborative nature also represents a valuable opportunity for raising awareness and for capacity development related to climate risks, impacts, and opportunities for response. For example, WFP activities under SO5 can directly benefit from the CLEAR approach by integrating livelihood and resilience maps into the existing online food security monitoring system.

PART 4.

Scoping WFP programmatic partnership opportunities

Based on the programmatic recommendations above, several potential partnerships may prove particularly promising for WFP activities that address the root causes of climate impact at a meaningful scale.

4.1 Potential programmatic partnerships

Given that WFP in Guinea-Bissau has limited in-house expertise and experience in climate adaptation programming, creating a stronger response will require WFP to enter new strategic partnerships that merge required core expertise on climate change into existing and upcoming activities. Some of the most important partnerships to pursue and establish are partnerships with the other Rome-based UN agencies (RBAs) that work on agriculture and rural development. FAO and IFAD both boast a wealth of expertise and knowledge on designing, implementing, and financing practices and technologies across different interventions levels and for different climate risk contexts. Strengthening strategic partnerships with both organizations, and specifically with FAO, will be a necessity if WFP is to enhance their training modules for smallholder farmers and producer groups. A strategic partnership with FAO is also necessary for WFP to be able to amend some of their activities towards reforestation efforts. Unlike WFP, FAO holds a UN mandate to engage in reforestation activities in Guinea-Bissau. Any activities related to reforestation, such as integrating reforestation into FFA, can thus not be implemented by WFP alone. It is therefore strongly recommended to enter negotiations with FAO to discuss opportunities for collaboration.

Another recommended partnership is with UNDP, given their strong presence, engagement, and experience in the climate policy landscape of Guinea-Bissau. Partnering with UNDP on matters related to climate policy design and implementation, food, and nutrition security would allow WFP to enhance their activities and would also strategically position WFP to gain credibility when developing proposals that target international climate finance. Partnerships with well-established organizations in climate resilience building such as UNDP could develop into multi-year funding opportunities for community-based adaptation activities on a national scale.

4.2 Potential funding mechanisms

WFP currently has no experience in accessing international climate financing mechanisms for their work in Guinea-Bissau. Existing climate resilience projects and proposals are relatively few, yet indicate suitable funds that WFP can target in their efforts of enhancing their project portfolio towards climate adaptation programming. The main and most promising funding sources for climate resilience projects in Guinea-Bissau that are also relevant for WFP include the most common environmental and climate funds. These funds include the GEF, the GCF, the Adaptation Fund, and the Least Developed Country Fund. Further donors with a track record of funding climate resilience projects in the country are IFAD, the EU GCCA+ Initiative, and the West African Development Bank.

If WFP seeks strategic partnerships with the above-mentioned organizations to develop project proposals, it will be well-positioned to secure funding for long-term climate adaptation programming in the upcoming CSP.

PART 5.

Synthesis

Current assessments of climate risks and future climate projections for Guinea-Bissau have revealed a diverse picture of climate impacts on the country's agricultural and livestock production. Embedding these insights into the wider context of national policies and strategies on climate impacts and vulnerabilities leads to a diverse set of recommendations for climate adaptation programming that WFP can pursue within current and future strategic programming in Guinea-Bissau. The table below provides a summary of the main insights from the climate, policy, and programming analysis of this study.

	Livelihood Zone		1: Eastern Highlands	2: Northeastern Plains	3: Northern Coastal Zone	4: Southern Coastal Zone
Analytical Insights	Current climate hazards	Drought	X	X	X	
		Heat stress	X	X	X	X
		Flood, waterlogging	X	X	X	X
		Sea level rise			X	X
	Projected climate changes through 2050	Temperature	Hot and increasing across all seasons, with higher risk of heat stress during summer	Hot and increasing across all seasons, with higher risk of heat stress during summer	Hot and increasing across all seasons, with higher risk of heat stress during summer	Hot and increasing across all seasons, with higher risk of heat stress during summer
		Precipitation	Increasing towards 2030 and decreasing towards 2050, overall wetter future	Increasing towards 2030 and decreasing towards 2050, overall increase is lowest in this livelihood zone	Increasing towards 2030 and decreasing again towards 2050	Increasing towards 2030 and slightly decreasing towards 2050, overall increase is highest in this zone
		Pluvial flooding	High and increasing flood risk during and shortly after rainy season, increasing towards 2030 and declining towards 2050	Medium risk, with decreasing trend in the future	Medium risk, with decreasing trend in the future	High and increasing flood risk during and shortly after rainy season, increasing towards 2030 and declining towards 2050
		Heat stress	Severe throughout the whole year	Severe throughout the whole year	Severe throughout the whole year	Severe throughout the whole year
		Drought	No significant increase of drought risk projected	Drought risk projected to increase significantly in the future	Drought risk projected to increase significantly in the future	No significant increase of drought risk projected
		Sea level rise	None	None	Projected to impact coastal zones	Projected to impact coastal zones
	Hotspot analysis of current non-climate vulnerabilities	Primary vulnerabilities	• Food insecurity • Poor health	• Food insecurity • Inequality • Poor health	• Food insecurity • Inequality • Poor health	• Food insecurity • Inequality
		Additional vulnerabilities		• Outmigration		• Outmigration

Analytical Insights	**IMPACT Analysis of climate change on food access and stability through 2050**	**Availability considerations**	+ More area can be harvested with climate change than with a no-climate change scenario, leading to net higher production + Cassava shows resilience towards climate change with higher yields than a no-climate change scenario - Groundnut yields are generally lower with climate change than with a no-climate change scenario, but rice, millet, and sorghum yields are only mildly lower			
		Stability considerations	- Negative climate trends in droughts, water logging can disrupt food supply and reduce incomes - Sea level rise in coastal areas will interrupt or permanently destroy crop land and can disrupt food supply - Combined heat stress and drought can increase animal mortality and reduce production, with detrimental impacts in areas where people depend on livestock for survival			
Programmatic Recommendations	**National-level policy support**		• National Adaptation Plan (NAP), Nationally Determined Contributions, streamlining climate resilience in national and province-level policies and strategies			
	Institutional capacity strengthening		• Employ multi-stakeholder coordination platforms to provide training and capacity development on effective adaptation planning, implementation, monitoring, and evaluation; accessing resources for enhanced climate preparedness at the national and provincial levels			
	Climate adaptation	**Flooding, waterlogging, drought, and heat stress**	Recommendations linked to SO1 – Act 01, SO4 – Act 04 (Table 2)	Recommendations linked to SO1 – Act 01, SO4 – Act 04 (Table 2)	Recommendations linked to SO1 – Act 01, SO4 – Act 04 (Table 2)	Recommendations linked to SO1 – Act 01, SO4 – Act 04 (Table 2)
	Institutional and policy level		• Recommendations linked to: SO5 – Act 05 (Table 2)			
	Climate resource mobilization		• EU GCCA+, West African Development Bank, International Fund for Agricultural Development (IFAD), Green Climate Fund (GCF), Global Environment Facility (GEF), Adaptation Fund (AF) and Least Developed Country Fund			
	Partnership opportunities		• FAO, IFAD, UNDP, national and provincial Ministries of Agriculture and Rural Development			

PART 6.

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PART 7.

Annexes

Annex 1: IMPACT results

In Guinea-Bissau, the yield, harvested area, and production of most key commodities is projected to increase in the coming decades (see Figure 22). In the case of rice and cassava, the projected increase in production is due primarily to a projected increase in yield. In the case of millet and sorghum, the projected increase in production is due primarily to a projected increase in area. Groundnut yield is projected to stagnate.

Future projections can present a misleading picture of the relative prevalence of commodities if not interpreted against their underlying baseline and future magnitudes. This is especially true if the baseline magnitudes are small. For this reason, a companion table of projections expressed as magnitudes is provided below (see Figure 23), and a more detailed view of harvested area is presented in the next section.

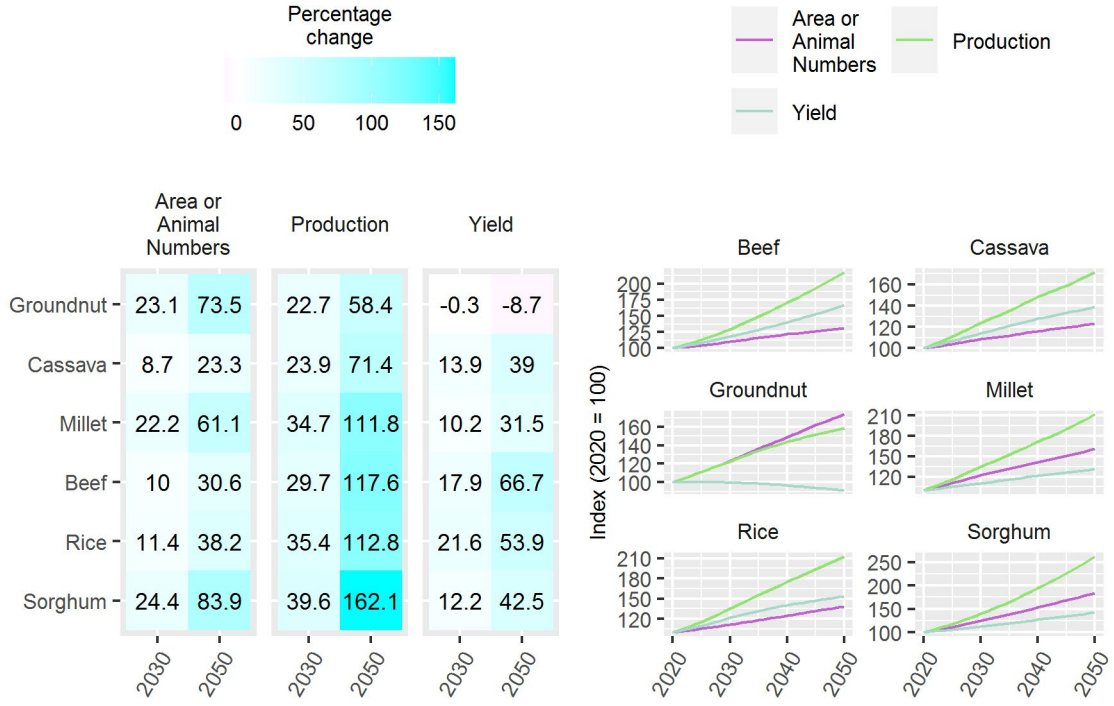

Figure 22: IMPACT 2020-2050 projection of changes in yield, production, and harvested area or number of animals for the main crop and livestock commodities. In the index graphs on the right, production, yield, and area are expressed as percentages.

Figure 23: The yield, production, and harvested area or number of animals projected by the IMPACT analysis for the main plant and animal commodities in 2020, 2030, and 2050.

CROPLAND USE TRAJECTORY

In IMPACT analyses, land area allocation among crops is modelled based on the relative values and productivity of the crops. An exogenous area growth factor is also included in this calculation to capture "factors other than direct market effects, such as government programs encouraging cropping expansion, contraction due to soil degradation, or conversion of land from agriculture to non-agricultural uses" (Robinson et al. 2015). These exogenous growth factors are based on historical trends and expert consultation regarding future trajectories.

A more detailed view of future cropland use trajectories is presented in Figure 24. The residual category of "other cereals" is included for context. From this perspective, it becomes clear that the land use of these key commodities is projected to change very little. Rice, millet, and sorghum are projected to occupy the largest share of harvested area until 2050. Groundnut, together with other cereals, is projected to occupy the second largest share. Cassava is projected to occupy a very small portion of harvested area until 2050.

TOTAL AND DISAGGREGATED DEMAND

Demand for key commodities is projected to grow considerably until 2050 (see Figure 25). The source of demand varies across commodities. For beef, rice, cassava, and potato, demand is projected to come from households, especially rural households. Note that potato demand is

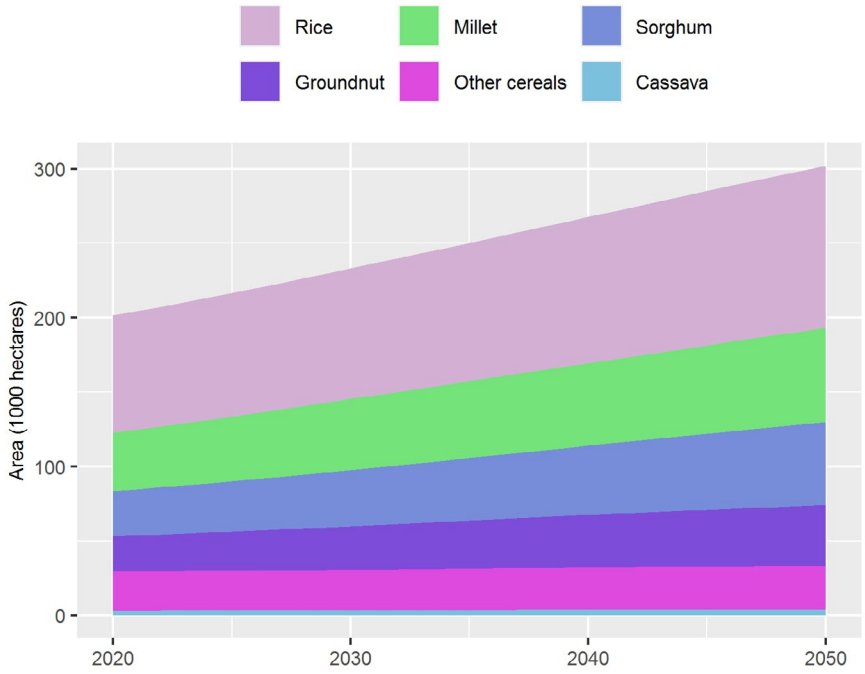

Figure 24: IMPACT 2020-2050 projection of harvested area for key crops and residual categories.

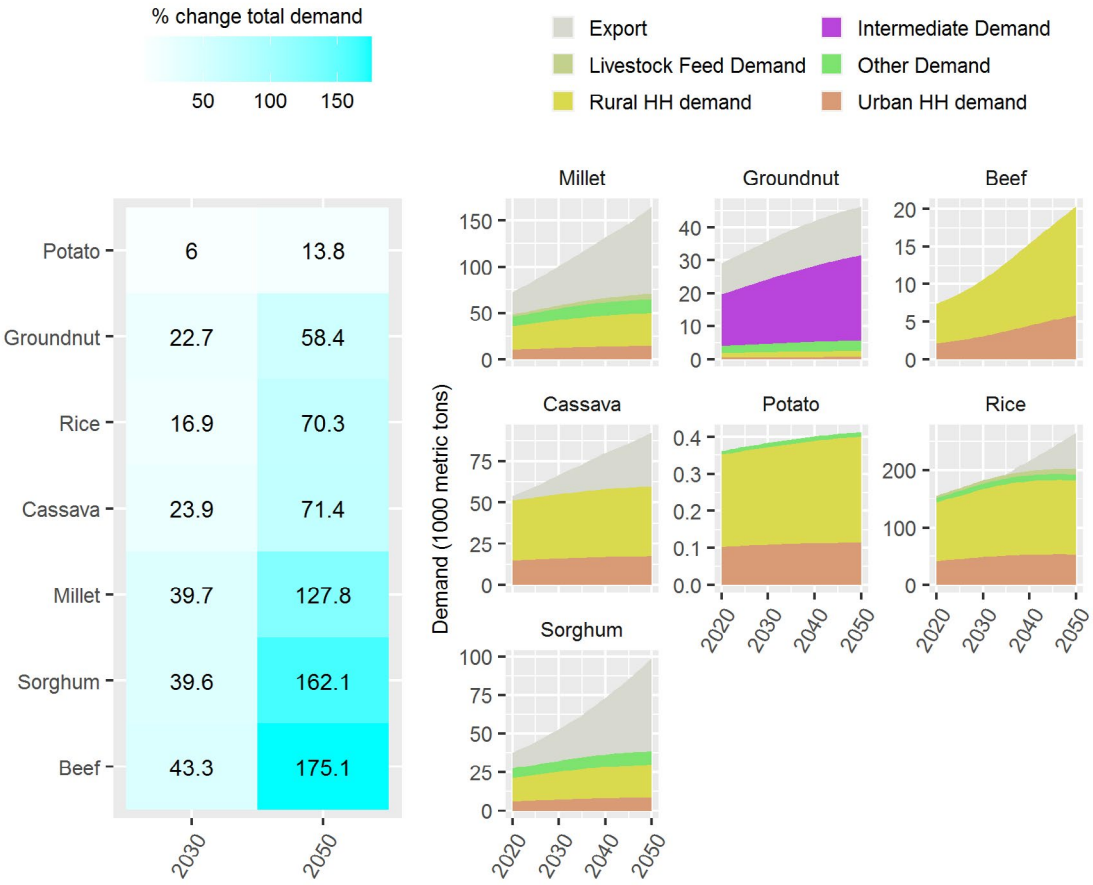

Figure 25: Projection of demand profiles for key crops according to the IMPACT 2020-2050 analysis.

extremely low relative to the population. Export demand is projected to become increasingly important for cassava and rice. For millet and sorghum, projected demand is mostly in the form of exports, with household and seed, industrial, or "other" demand projected to play a substantial secondary role. Groundnut demand is projected to be primarily intermediate demand.[3]

DIET TRAJECTORY

Figure 26 presents per capita diet composition until the year 2050. This figure accounts for food available from both domestic production and international trade[4]. The residual categories of "other cereals", "other animal products", and "other roots and tubers" are included for context. Per capita consumption of beef and other animal products, millet, rice, sorghum, and other cereals is projected to increase considerably in the coming decades . Per capita consumption of cassava and other roots and tubers, aside from potato, is projected to decrease. Per capita consumption of potato is projected to remain at a very low level - effectively zero.

In more aggregate terms, consumption of starchy staples like cereals, roots, and tubers is projected to rise from about 1425 kcal/capita/day currently to 1479 kcal/capita/day in 2030, and then decline slightly to 1470 kcal/capita/day in 2050. As a share of total diet, starchy staple consumption is projected to decline from about 75% to 72% in 2030, and then to 64% in 2050. This is consistent with Bennett's law, an empirical trend often seen in developing nations [48]. The receding starchy share of diet is replaced by consumption of animal products, which is projected to rise from about 7% to 9% of the total diet in 2030, and then to 15% in 2050.

The projected increase in total calorie intake per capita would clearly be a welcome development vis-à-vis food security. However, careful attention must be paid to composition. A developing nation's nutrition transition from starchy staples to animal calories and other carbohydrate sources is often a transition from starchy carbohydrates to sugary foods and fat calories, with the amount of protein calorie remaining constant [49], [50], [51]. Care must therefore be taken to promote the consumption of proteins of animal or vegetable origin, complex carbohydrates, and fibers while keeping consumption of fats and free sugars below the World Health Organization's recommended levels of 30% and 10% of the diet, respectively.

CLIMATE CHANGE IMPACTS ON THE DIET TRAJECTORY

IMPACT assessments output two explicit measures of food and nutritional security. These measures are the number of undernourished children in a given population and the share of that population that is at risk of hunger. These measures are calculated based on well-documented empirical relations. The share at risk of hunger indicator is calculated as a function of the ratio of available calories to a minimum level of required calories. The numbers of undernourished children indicator is calculated as a function of average per capita calorie consumption, women's' access to secondary education, the quality of maternal and child care, and health and sanitation [18]. Dependence on imports for the procurement of key dietary staples may also provide insight into a nation's food security.

3 Intermediate demand refers to processing factory demand and is based on the demand for final processed goods like peanut butter. The "other demand" category "summarizes all other demands for agricultural products from sectors outside of the focus of IMPACT (for example, seeds, industrial use)" (Robinson et al. 2015).

4 Calorie availability is widely accepted as a reasonable proxy for calorie consumption although the former may be higher than the latter by 10% to 14%, the difference being lost as waste at the retail and household levels. See for example Kearney 2010. (Popkin 1993).

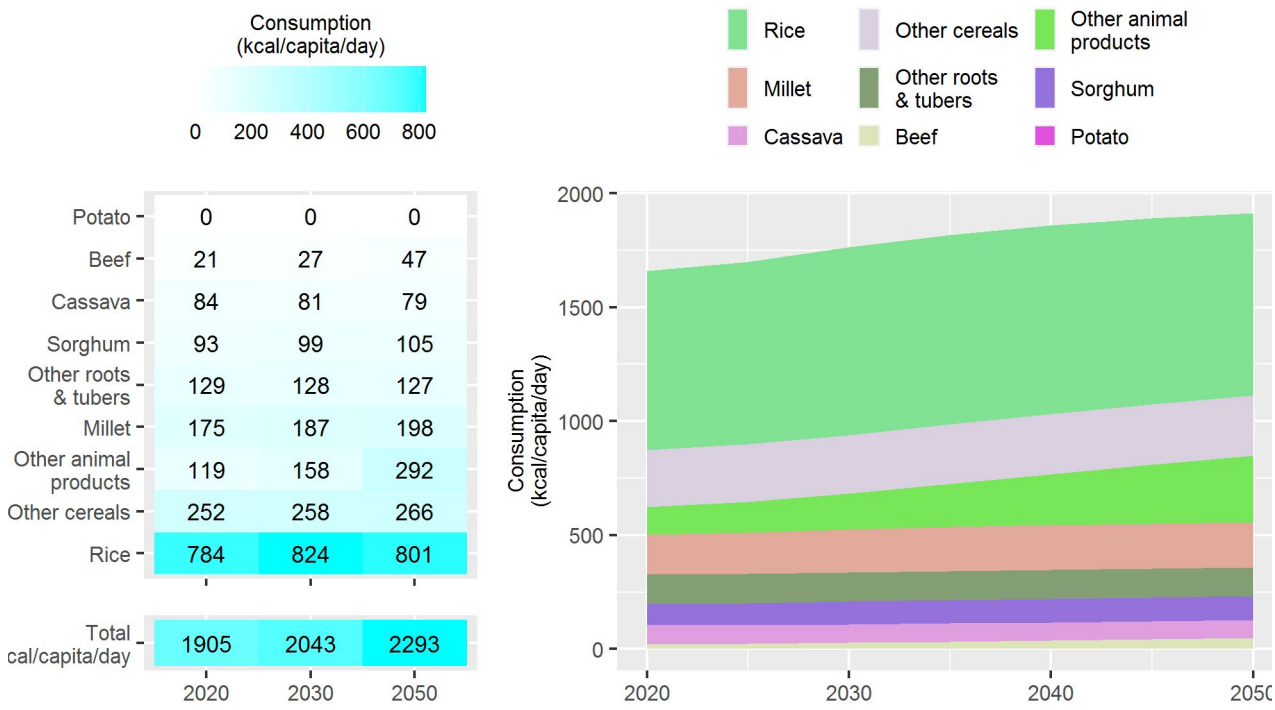

Figure 26: IMPACT 2020-2050 projection of energy value in kcal/capita/day for key products.

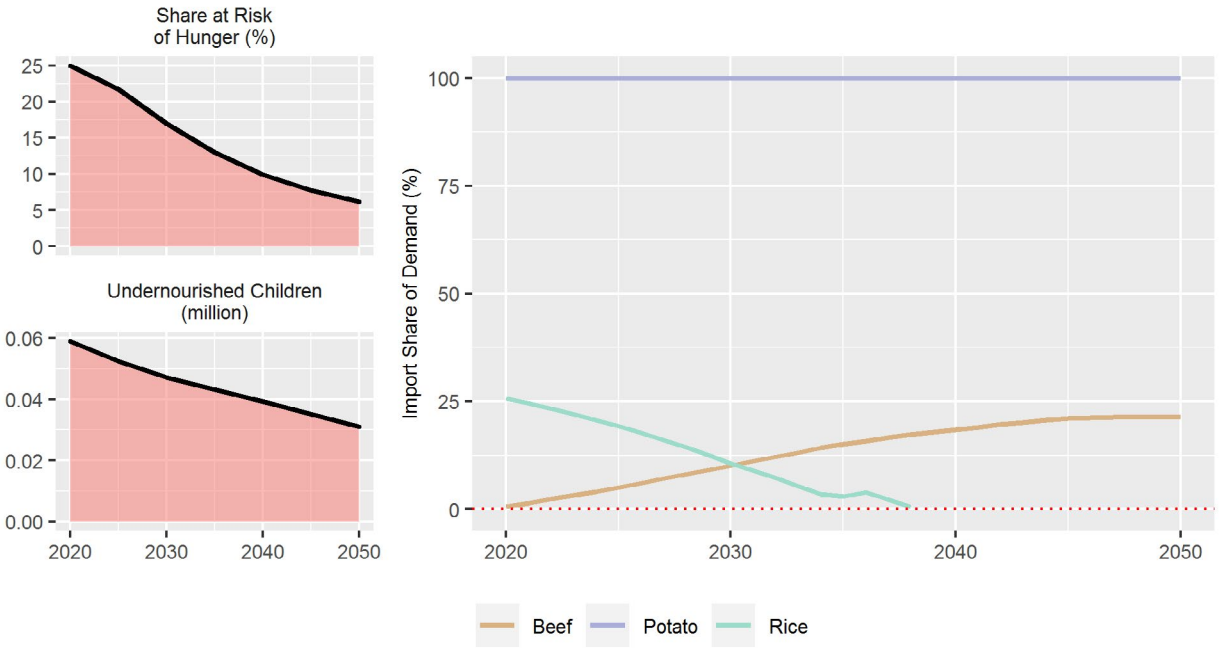

Figure 27: Projection of the proportions of the population that will be at risk of hunger and import dependency and numbers of undernourished children between 2020 and 2050. Import dependency indicates domestic demand for a given product that is imported.

Numbers of undernourished children and of people at risk of hunger are projected to decline substantially in the coming decades (see the left panel of Figure 27). Import dependence for rice is projected to decline, resulting in self-sufficiency by 2040. Import dependence for beef is projected to slowly rise but remain below 25% until 2050. All potato consumption in the country is projected to depend on imports.

Annex 2: Methods for spatial analysis to generate maps

For both primary and additional vulnerability indicators, we created raster map layers to show the total number of indices classified as "high", or hotspots, and the breakdown of which indicators showed geographical hotspots. Our analysis was comprised of the following steps:

VARIABLE SELECTION BASED ON SPATIAL VARIABILITY

All primary vulnerability variables were tested for sufficient spatial variation across all livelihood zones. However, only variables with sufficient spatial variation, or CV>=10%, were included in the analysis. Additional vulnerability variables were selected based on available data for indicators of interest identified by the WFP Country Office. They were then tested for sufficient spatial variation and either included or excluded from the analysis in the same way as the primary vulnerability variables. An exception was made for food security data, which was always included regardless of spatial variation; this was due to the limited number of food security datasets available and the necessity to represent food security in some respect to accurately capture overall vulnerability. All primary and additional variables considered for Guinea-Bissau, including whether they were included or excluded from the analysis, are shown in Table 1.

BINARIZATION OF VARIABLES

For the included continuous data variables, a binary score of 1 was allocated if any one metric exceeded the 80th percentile of values within the livelihood zones, indicating a negative outcome. The map shows the sum of these binary layers. Any dataset inputs which were already binary were always included where data was present and relevant to WFP's programmes. This condition was only applicable for additional variables. Exceptions were made in limited circumstances. For example, if a continuous dataset like the Hunger Map food consumption scores was extremely high, all values would be categorised as "high", or 1, as opposed to only those above the 80th percentile.

AGGREGATION INTO MAP FIGURES

The hotspots maps seen in Figures 1 and 2 were created using sets of these binary raster layers. Figure 1a shows the number of included primary variables that were assigned "high" vulnerability in any given cell. Figure 2a shows the same data for the included additional variables. Figure 1b is based on the sum of three further binary layers, each of which was calculated as the maximum value of all included binary layers in a given grouping of primary variables. These variables were food security and nutrition, inequality, and health. Figure 2b shows the combination of additional variables directly, without the use of any further intermediate layers. If part of a map displays "no areas of high vulnerability", this means that none of the indicators we included were binarized as 1, or high vulnerability, due to the values in the given cell or cells being below a predetermined threshold for "high" vulnerability. As previously mentioned, this threshold is the 80th percentile of the values for a particular indicator for all cells within the

livelihood zones. Higher percentiles correspond to greater vulnerability. All of the variables which have been included in the spatial analysis are presented as "included" in Table 1.

AVERAGE VALUES OF ALL VARIABLES IN EACH LIVELIHOOD ZONE, VARIABLE INCLUSION AND EXCLUSION WITH REASONS, AND DATA SOURCES. ALL VARIABLES LABELLED "INCLUDED" WERE USED IN THE SPATIAL ANALYSIS.

Variable grouping	Variable	1: Eastern Highlands	2: Northeastern Plains	3: Northern Coastal Zone	4: Southern Coastal Zone	Included / excluded from maps for Nepal	Data Source
Primary variables							
Food insecurity & nutrition	FEWSNET food insecurity (current situation, 1=minimal to 5=famine), 2020	NA	NA	NA	NA	Excluded (data not available)	FewsNet https://fews.net/fews-data/333
	WFP Hunger Map food consumption score (mean), 2019-2021	43.6	50.8	43.6	39.1	Included	Hunger Map https://hungermap.wfp.org
	Wasting prevalence in under 5s (%), 2000-2019	8.84	8.57	9.65	8.50	Excluded (insufficient variation)	Hunger Map https://hungermap.wfp.org
	Stunting prevalence in under 5s (%), 2000-2019	35.2	29.5	34.7	34.4	Excluded (insufficient variation)	Local burden of disease https://vizhub.healthdata.org/lbd/dbm
	Underweight prevalence under 5s (%), 2000-2019	17.5	15.5	18.6	16.6	Excluded (insufficient variation)	Local burden of disease https://vizhub.healthdata.org/lbd/dbm
Gender and educational inequality	Education, female (mean years in 15-49 year olds), 2000-2017	0.383	1.063	0.352	0.548	Included	Local burden of disease https://vizhub.healthdata.org/lbd/dbm
	Education, male (mean years in 15-49 year olds), 2000-2017	1.37	2.88	1.43	2.09	Included	Local burden of disease https://vizhub.healthdata.org/lbd/dbm
	Education gender gap (mean years in 15-49 year olds), 2000-2017	0.988	1.813	1.079	1.537	Included	Calculated from the Local burden of disease https://vizhub.healthdata.org/lbd/dbm
Health	Diarrhea prevalence (%), 2000-2017	25.7	34.3	26.4	31.2	Included	Local burden of disease https://vizhub.healthdata.org/lbd/dbm
	Falciparum incidence (incidence rate), 2019	16.5	11.7	13.9	16.4	Included	MAP https://malariaatlas.org/explorer/#/
	Vivax incidence (incidence rate), 2019	NA	NA	NA	NA	Excluded (insufficient variation)	MAP https://malariaatlas.org/explorer/#/
	Under 5 mortality (per 1000 live births), 2000-2017	1.04	6.51	6.21	3.02	Included	MAP https://malariaatlas.org/explorer/#/

Variable grouping	Variable	1: Eastern Highlands	2: Northeastern Plains	3: Northern Coastal Zone	4: Southern Coastal Zone	Included / excluded from maps for Nepal	Data Source
Additional variables							
N/A	Net out-migration (number of people), 2010	11,686	-5,061	10,705	-4,576	Included	WorldPop https://www.worldpop.org/geodata/listing?id=26
	Mean soil pH at 30cm depth (pH * 10), 2019	55.7	53.5	56.1	53.5	Excluded) (not specific to country)	Soil Grids https://soilgrids.org
	Mean soil organic carbon at 30cm depth (dg/kg), 2019	212	333	177	262	Excluded) (not specific to country)	Soil Grids https://soilgrids.org
	Total area of irrigated land (ha), 2005	363	133,572	96,668	96,682	Excluded) (not specific to country)	FAO irrigated area map http://www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas/latest-version/
	Conflict events (number of events), 2018-2021. n.b. Table shows fatal and non-fatal events. Map shows fatal events only	0	3	0	0	Excluded (insufficient variation)	ACLED Dashboard https://acleddata.com/dashboard/#/dashboard
	Active fires (count), 2019	1,000	652	1,542	960	Excluded) (not specific to country)	https://modis-fire.umd.edu/pubs.html, https://firms.modaps.eosdis.nasa.gov/active_fire/#firms-shapefile
	Ethnic group diversity (number of coexisting dominant groups), 2010	3	6	4	4	Excluded) (not specific to country)	Georeferencing of ethnic groups (GREG) database - http://worldmap.harvard.edu/maps/1894
	Ethnic group type (dominant group category), 2010	Mandingo, Fulbe, Balante	Diola, Mandjak, Pepel, Mandingo, Balante	Tenda, Fulbe, Mandingo, Balante	Nalu, Mandingo, Balante	Excluded) (not specific to country)	Georeferencing of ethnic groups (GREG) database - http://worldmap.harvard.edu/maps/1894
	Time to nearest city (minutes), 2015	202	129	114	214	Excluded) (not specific to country)	https://malariaatlas.org/research-project/accessibility-to-cities/
	Human appropriation of net primary productivity (% reduction), 2000	14.7	26.3	12.1	23.7	Excluded) (not specific to country)	Haberl et al, 2007 https://boku.ac.at/wiso/sec/data-download
	Access to improved water source (% of population), 2000-2017	60.1	55.5	57.7	59.3	Excluded) (not specific to country)	IHME ata.org/record/ihme-data/lmic-wash-access-geospatial-estimates-2000-2017

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