GROUNDSWELL AFRICA

INTERNAL CLIMATE MIGRATION IN WEST AFRICAN COUNTRIES

WORLD BANK GROUP

Kanta Kumari Rigaud, Alex de Sherbinin, Bryan Jones, Susana Adamo, David Maleki, Nathalie E. Abu-Ata, Anna Taeko Casals Fernandez, Anmol Arora, Tricia Chai-Onn, and Briar Mills

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000

Internet: www.worldbank.org

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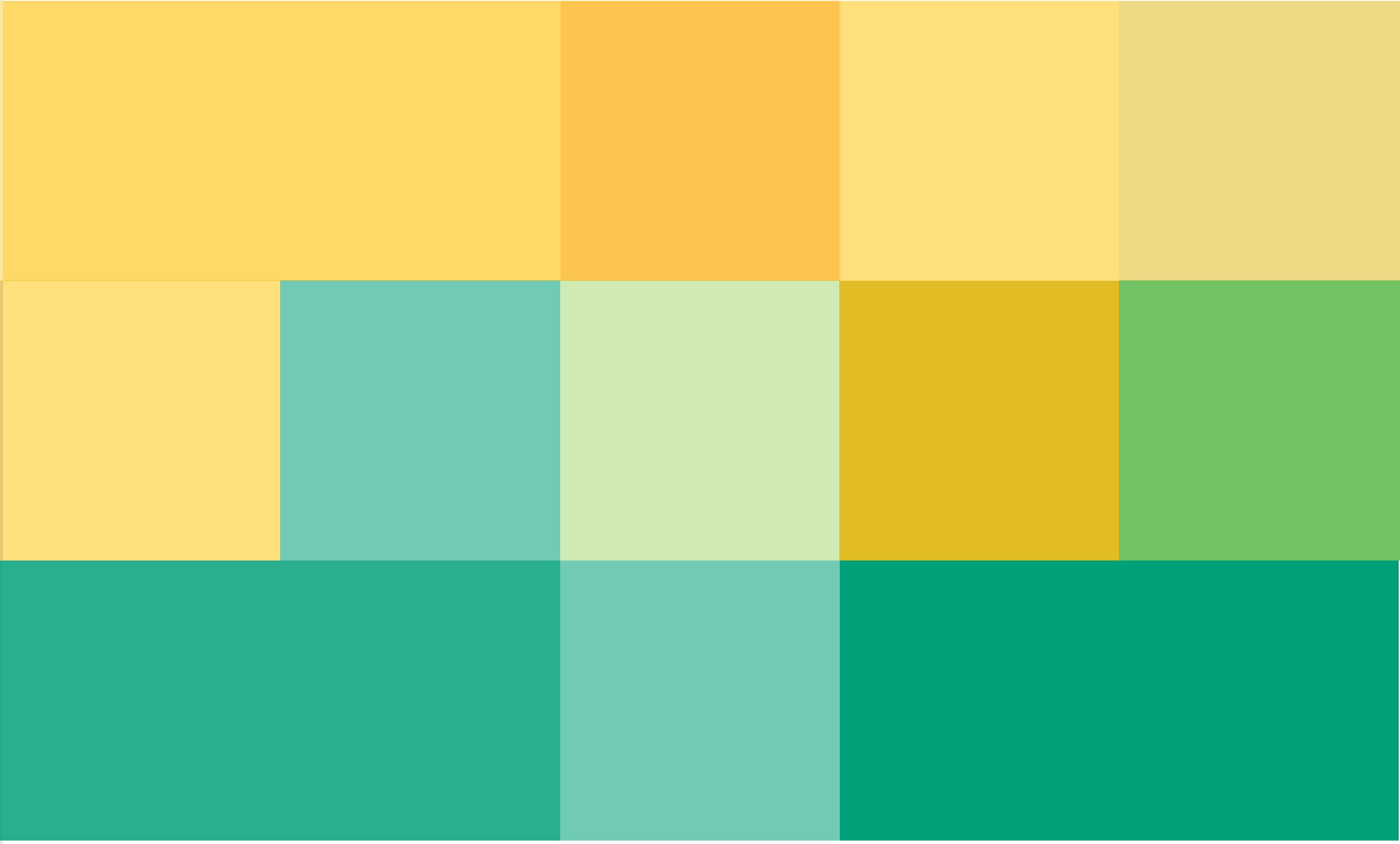

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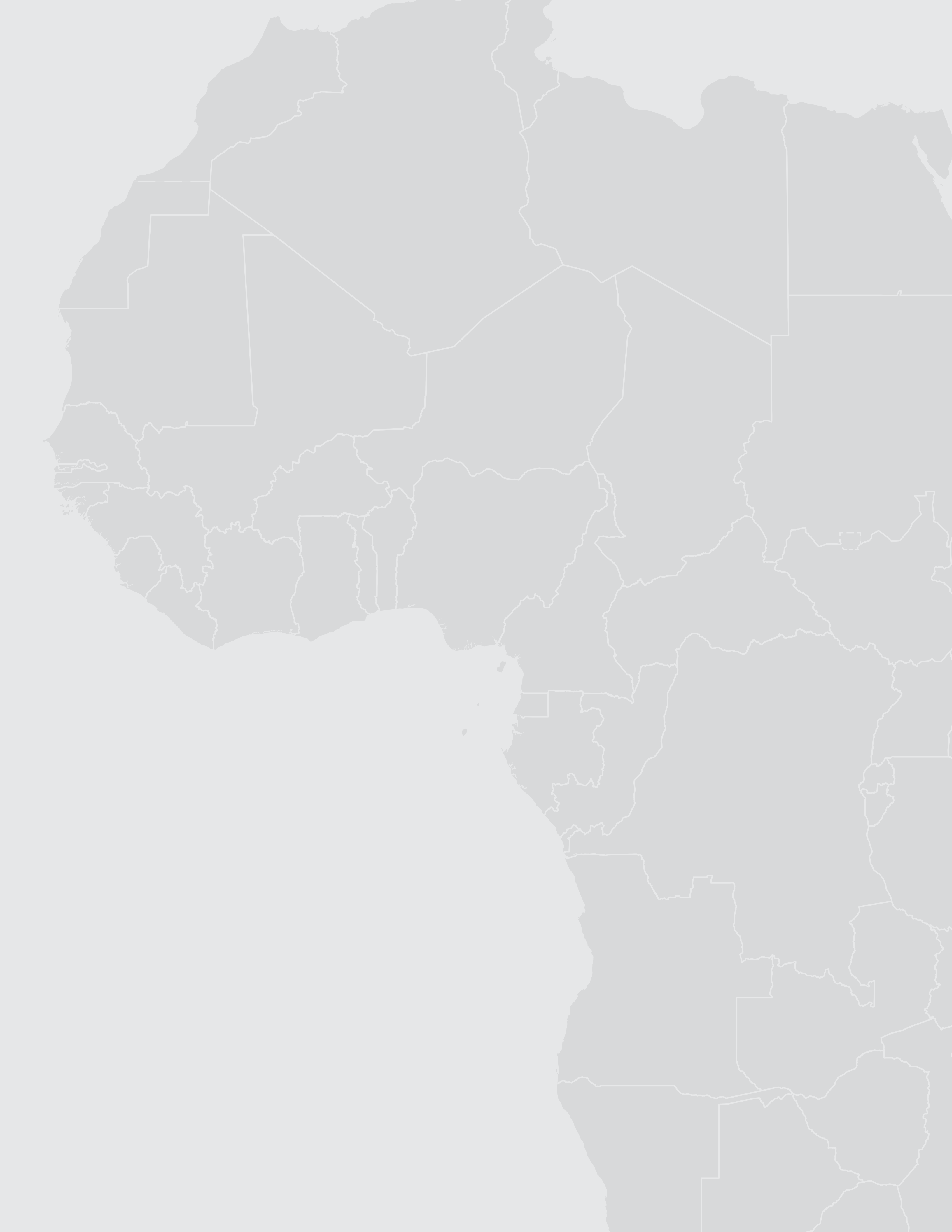

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Glossary

Adaptation: Process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate change and its effects.

Adaptive capacity: Ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, and respond to consequences of climate impacts.

Adapt in Place: The cost of relocation in response to actual or expected climate change and its effect can often be high. Adapt in place is the process of adjustment without relocation.

Agro-pastoralism: Combination of agriculture, crop-based livelihood systems, and pastoralism (see also pastoralism).

Anthropogenic biome: Anthropogenic biomes describe the terrestrial biosphere in its contemporary, human-altered form using global ecosystem units defined by patterns of sustained direct human interactions, for example, rainfed croplands.

Attractiveness: Desirability of a locale based on several factors including but not limited to economic opportunity, transportation infrastructure, proximity to family, the presence of social amenities, environment, and intangibles such as place attachment.

Biodiversity: Variety of plant and animal life in the world or in a particular habitat or ecosystem.

Biome: Large naturally occurring community of flora and fauna occupying a major habitat (for example, forest or tundra; see also anthropogenic biome).

Climate change: A change in the state of the climate that can be identified (for example, using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or because of human activity.

Climate change-induced migration (shorthand internal climate migration): In this report, climate change-induced migration is movement that occurs within countries that can be attributed largely to slow-onset impacts of climate change on livelihoods owing to shifts in water availability, crop and ecosystem productivity, flood risk, or sea level rise compounded by storm surge. The model also includes non-climate factors: demographic factors (median age and sex) and conflict.

Climate in-migration hotspot: For the purposes of this study, climate in-migration hotspots are areas that will see increases in population in scenarios that take climate impacts into account relative to a population projection that does not take climate impacts into account. These increases can be attributed to in-migration, the “fast” demographic variable. Areas were considered to have increases in population when at least two of the three scenarios modelled had increases in population density in the highest 5th percentile of the distribution.

Climate migrant/migration (shorthand internal climate migrant/migration): In this report, climate migrants are people who move within countries because of climate change-induced migration (see above). The modeling work captures people who move at spatial scales of over 14 kilometers within a country, and at decadal temporal scales. Shorter distance or shorter-term mobility (such as seasonal or cyclical migration) is not captured.

Climate out-migration hotspot: For the purposes of this study, climate out-migration hotspots are areas that will see decreases in population in scenarios that take climate impacts into account relative to a population projection that does not take climate impacts into account. These decreases can be attributed to out-migration, the “fast” demographic variable. Areas were considered to have decreases in population when at least two of the three scenarios modelled had decreases in population density in the highest 5th percentile of the distribution.

Climate risk: Potential for consequences from climate variability and change where something of value is at stake and the outcome is uncertain. Often represented as the probability that a hazardous event or trend occurs multiplied by the expected impact. Risk results from the interaction of vulnerability, exposure, and hazard.

Coastal erosion: Erosion of coastal landforms that results from wave action, exacerbated by storm surge and sea level rise.

Coastal zone: In this report, the coastal zone is land area within 5 kilometers of the coastline.

Conflict: Armed conflicts between groups. Armed Conflict Location & Event Data Project (ACLED) covers violent activity that occurs both within and outside the context of a civil war, particularly violence against civilians, militia interactions, communal conflict, and rioting. It is one of the nonclimate factors included in the model.

Country Partnership Framework (CPF): Strategic document that guides the World Bank country programs. The CPF identifies the key objectives and development results through which the World Bank intends to support a member country in its efforts to end extreme poverty and boost shared prosperity in a sustainable manner.

Crop productivity: Crop yield in tons per hectare on an annual time step.

Deforestation: Conversion of forest to non-forest.

Demographic dividend: The potential for economic growth made possible from shifts in a population’s age structure.

Disaster Risk Reduction: The practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters.

Displacement: Forced removal of people or people obliged to flee from their places of habitual residence.

Distress migration: Movements from the usual place of residence, undertaken when an individual and/or their family perceive that there are no options open to them to survive with dignity, except to migrate. This may be a result of a rapid-onset climate event, other disasters, or conflict event, or a succession of such events, that result in the loss of assets and coping capacities.

Environmental mobility: Temporary or permanent mobility because of sudden or progressive changes in the environment that adversely affect living conditions, either within countries or across borders.

Extreme heat event: Three or more days of above-average temperatures, generally defined as passing a certain threshold (for example, above the 85th percentile for average daily temperature in a year).

Extreme weather event: Event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally fall in the 10th or 90th percentile of a probability density function estimated from observations. The characteristics of extreme weather vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (for example, drought or heavy rainfall over a season).

Flood Risk: The risk of inundation from flooding owing to extreme precipitation events, indicated in this modeling work by flood extent.

Forced migration: Forced migration generally implies a lack of volition concerning the decision to move, though in reality motives may be mixed, and the decision to move may include some degree of personal agency or volition.

GEPIC: The GIS-based Environmental Policy Integrated Climate crop model (see Appendix A).

Gravity model: Model used to predict the degree of interaction between two places and the degree of influence a place has on the propensity of a population in other locations to move to it. It assumes that places that are larger or spatially proximate will exert more influence on the population of a location than places that are smaller and farther away.

Gross domestic product (GDP): The monetary value of all finished goods and services made within a country during a specific period.

HadGEM2-ES: Climate model developed by the Met Office Hadley Centre for Climate Change in the United Kingdom.

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

Immobility: Inability to move from a place of risk or choosing not moving away from a place of risk.

In-kind transfers: Unlike a cash transfer, it refers to the specific goods and services that migrants send back home.

Internal climate migrant (migration): In this report, climate migrants are people who move within countries because of climate change-induced migration (see above). The modeling work captures people who move at spatial scales of over 14 kilometers within a country, and at decadal temporal scales. Shorter distance or shorter-term mobility (such as seasonal or cyclical migration) is not captured.

Internal migration (migrant): Internal migration is migration that occurs within national borders.

International migration (migrant): Migration that occurs across national borders.

IPSL-CM5A-LR: Climate model developed by the Institut Pierre Simon Laplace Climate Modeling Center in France.

Labor mobility: The geographical and occupational movement of workers.

Land degradation: The deterioration or decline of the biological or economic productive capacity of the land for present and future.

Landscape approach: A framework that advances multiple land uses and sustainable landscape management to ensure equitable and sustainable use of land.

LPJmL: A global water and crop model designed by Potsdam Institute for Climate Impact Research to simulate vegetation composition and distribution as well as stocks and land-atmosphere exchange flows of carbon and water, for both natural and agricultural ecosystems.

Median Age: The age that divides a population into two numerically equal groups; that is, half the people are younger than this age and half are older.

Micro-watershed management: The management of land, water, biota, and other resources for ecological, social, and economic purposes with use of the micro-watershed as the unit of intervention (500-1000 ha).

Migration: Movement that requires a change in the place of usual residence and that is longer term. In demographic research and official statistics, it involves crossing a recognized political and administrative border.

Migration cycle: The three stages of migration process which can be leveraged for adaptation that is adapt in place, enable mobility, and after migration support to host and migrant communities.

Mitigation (of climate change): Human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Mobility: Movement of people, including temporary or long-term, short- or long-distance, voluntary, or forced, and seasonal or permanent movement as well as planned relocation (see also environmental mobility, labor mobility).

Nationally Determined Contributions (NDCs): The non-binding national plans by each country to reduce national emissions and adapt to the impacts of climate change enshrined in the Paris Agreement.

Net Primary Productivity (NPP): NPP measures ecosystem productivity, that is, the productivity of a location's natural biome, including grassland biomes.

Other internal migrant: In this report, the term other migrant is used in reference to migrants who move within countries largely for reasons other than climate impacts.

Peri-urban: An area immediately adjacent to a city or urban area.

Planned relocation: People moved or assisted to move permanently away from areas of environmental risks.

Radiative forcing: Measurement of capacity of a gas or other forcing agent to affect the energy balance, thereby contributing to climate change.

Rainfed agriculture: Agricultural practice relying almost entirely on rainfall as its source of water.

Rapid-onset event: Event such as cyclones and floods which take place in days or weeks (in contrast to slow-onset climate changes that occur over long periods of time).

Representative Concentration Pathway (RCP): Trajectory of greenhouse gas concentration resulting from human activity corresponding to a specific level of radiative forcing in 2100. The low greenhouse gas concentration RCP2.6 and the high greenhouse gas concentration RCP8.5 employed in this report imply futures in which radiative forcing of 2.6 and 8.5 watts per square meter, respectively, are achieved by the end of the century.

Resilience: Capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance by responding or reorganizing in ways that maintain their essential function, identity, and structure while maintaining the capacity for adaptation, learning, and transformation.

Riparian areas: The lands that occur at the interface between terrestrial and aquatic ecosystems.

Salinization: The accumulation of water-soluble salts in the soil which leads to substantial negative impact on plant productivity.

Sea level rise: Increases in the height of the sea with respect to a specific point on land. Eustatic sea level rise is an increase in global average sea level brought about by an increase in the volume of the ocean due to the melting of land-based glaciers and ice sheets. Steric sea level rise is an increase in the height of the sea induced by changes in water density due to the heating of the ocean. Density changes induced by temperature changes only are called thermosteric; density changes induced by salinity changes are called halosteric.

Sex Ratio: The number of males per 100 females in the population.

Shared Socioeconomic Pathway (SSP): Scenarios, or plausible future worlds, that underpin climate change research and permits the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. Shared Socioeconomic Pathways (SSPs) can be categorized by the degree to which they represent challenges to mitigation (greenhouse gas emissions reductions) and societal adaptation to climate change.

Slow-onset climate change: Changes in climate parameters (temperature, precipitation, and associated impacts, such as water availability and crop production declines) that occur over long periods of time—in contrast to rapid-onset climate hazards, such as cyclones and floods, which take place in days or weeks.

Storm surge: The rise in seawater level during a storm, measured according to the height of the water above the normal predicted astronomical tide.

Stressor: Event or trend that has important effect on the system exposed and can increase vulnerability to climate-related risk.

Sustainable livelihood: Livelihood that endures over time and is resilient to the impacts of various types of shocks including climatic and economic.

Systematic Country Diagnostic (SDC): World Bank tool to identify the most important challenges and opportunities a country faces in advancing towards the twin goals to end extreme poverty and boost shared prosperity in a sustainable manner.

System dynamics model: A model which decomposes a complex social or behavioral system into its constituent components and then integrates them into a whole that can be easily visualized and simulated.

Transformation: The strategies that can reduce the underlying causes of vulnerability to climate-induced migration or fundamentally alter the state that results in climate induced migration.

Tipping element: Subsystems of the Earth system that are at least subcontinental in scale and can be switched—under certain circumstances—into a qualitatively different state by small perturbations. See tipping point.

Tipping point: Particular moment at which a component of the earth's system enters into a qualitatively different mode of operation, as a result of a small perturbation.

Urban transition: The shift from rural to urban and from agricultural employment to industrial, commercial, or service employment.

Urbanization: The process by which a large number of people becomes concentrated in cities.

Vulnerability: Propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Water Availability: The water sector model outputs represent river discharge, measured in cubic meters per second in daily/monthly time increments.

WaterGAP2: The Water Global Assessment and Prognosis (WaterGAP) Version 2 global water model developed by the University of Kassel in Germany (see Appendix A).

Abbreviations

ACLED	Armed Conflict Location & Event Data
AfCFTA	African Continental Free Trade Area
CCDR	Country Climate Development Report
CIESIN	Center for International Earth Science Information Network
CMIP5	Coupled Model Intercomparison Project phase 5
COP24	24th Conference of the Parties to the United Nations Framework Convention on Climate Change
CPF	Country Partnership Framework
CVI	Coastal Vulnerability Index
DIVA	Dynamic Interactive Vulnerability Assessment
ECOWAS	Economic Community of West African States
ENSO	El Niño–Southern Oscillation
GCM	global climate model
GDP	gross domestic product
GHG	vgreenhouse gas
GHM	global hydrological model
GoG	Government of Ghana
GPW	Gridded Population of the World
GRID	Global Report on Internal Displacement
HDI	Human Development Index
ICT	Information and Communications Technology
ICZM	Integrated Coastal Zone Management
IDP	Internally displaced person
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Intersectoral Impacts Model Intercomparison Project
ITCZ	Inter-Tropical Convergence Zone
LECZ	Low Elevation Coastal Zone
LIC	low-income country
LMIC	lower-middle-income country
MACS	Migration and Climate-informed Solutions
MIC	middle-income country
NCAR-CIDR	National Center for Atmospheric Research-CUNY Institute for Demographic Research
NDC	Nationally Determined Contribution
NEMA	National Emergency Management Agency
NETIP	Northeastern Transport Improvement Project
NPP	net primary productivity
RCM	regional climate model
RCP	Representative Concentration Pathway
SCD	Systematic Country Diagnostic
SDG	Sustainable Development Goal
SSP	Shared Socioeconomic Pathway
WACA	West Africa Coastal Areas

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Andrea Borgarello / World Bank

GROUNDSWELL AFRICA

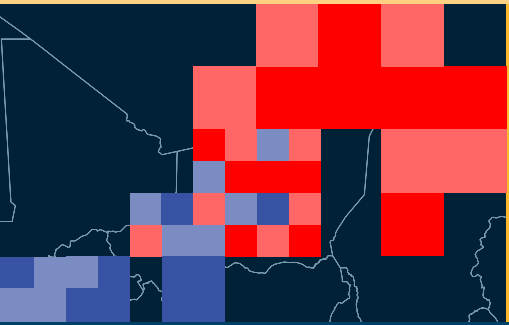
WEST AFRICAN COUNTRIES

Up to 32 million

internal climate migrants in West African countries by 2050 in the absence of concrete climate and development action.

0.3 – 2.2 million

people living along the West African coast could be compelled to move out of the 5-kilometer coastal belt by 2050 due to sea level rise compounded by storm surges.



Climate migration hotspots could emerge as early as 2030

and continue to intensify by 2050 across West African countries.

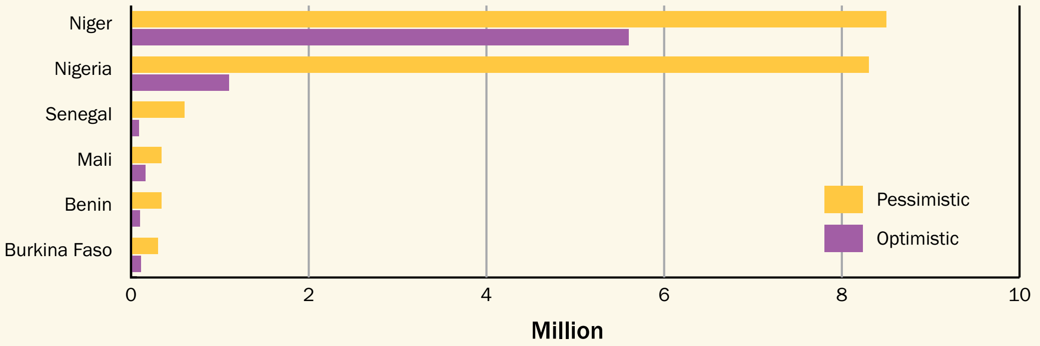
The population migration model and analysis combine climate and nonclimate factors—expanding the Groundswell approach—to better inform policy dialogue and action.

Water availability	Crop productivity	Ecosystem productivity	Sea level rise and storm surge
Conflict	Sex	Flood risk	Median age

Locality and context matter

Internal climate migration is not uniform across countries. Some areas will be more adversely impacted by climate change than others.

The optimistic scenario (inclusive development and low emissions) yields lower numbers of internal climate migrants than the pessimistic scenario (high emissions and unequal development).

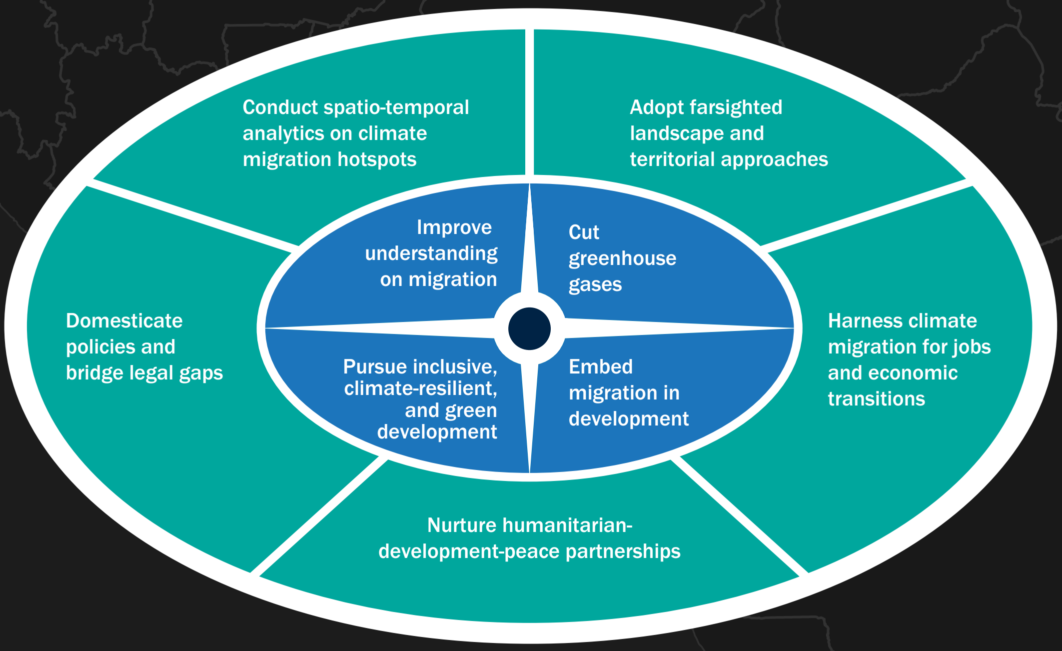


Internal climate migrants by 2050

The study also included Cabo Verde, Côte d'Ivoire, Ghana, The Gambia, Guinea, Guinea-Bissau, Liberia, Mauritania, São Tomé and Príncipe, Sierra Leone, and Togo.

TAKING RESULTS TO ACTION

Migration and Climate-Informed Solutions (MACS) Core Policy Areas and Action Domains



Conduct spatio-temporal analytics on climate migration hotspots

Adopt farsighted landscape and territorial approaches

Improve understanding on migration

Cut greenhouse gases

Domesticate policies and bridge legal gaps

Harness climate migration for jobs and economic transitions

Pursue inclusive, climate-resilient, and green development

Embed migration in development

Nurture humanitarian-development-peace partnerships

Andrea Borgarello / World Bank

Foreword

Ousmane Diagana
World Bank Vice President
Africa Western and Central

According to a popular African proverb, *"we do not inherit the earth from our ancestors, we borrow it from our children."* Global warming, with its causes and impacts, connects generations, and is a powerful example for how this holds true.

West Africans have a long history of coping with challenging climatic conditions. Mobility has always been a key strategy for people in the region to manage risks and avail opportunities, be it nomads traveling the Sahel to feed their livestock, fishermen braving stormy seas, or merchants crossing the desert. However, as climate shocks and stresses escalate in the coming decades, West Africans could face unprecedented challenges. Despite the region's relatively small carbon footprint, it will be one of those most affected by the impacts of climate change.

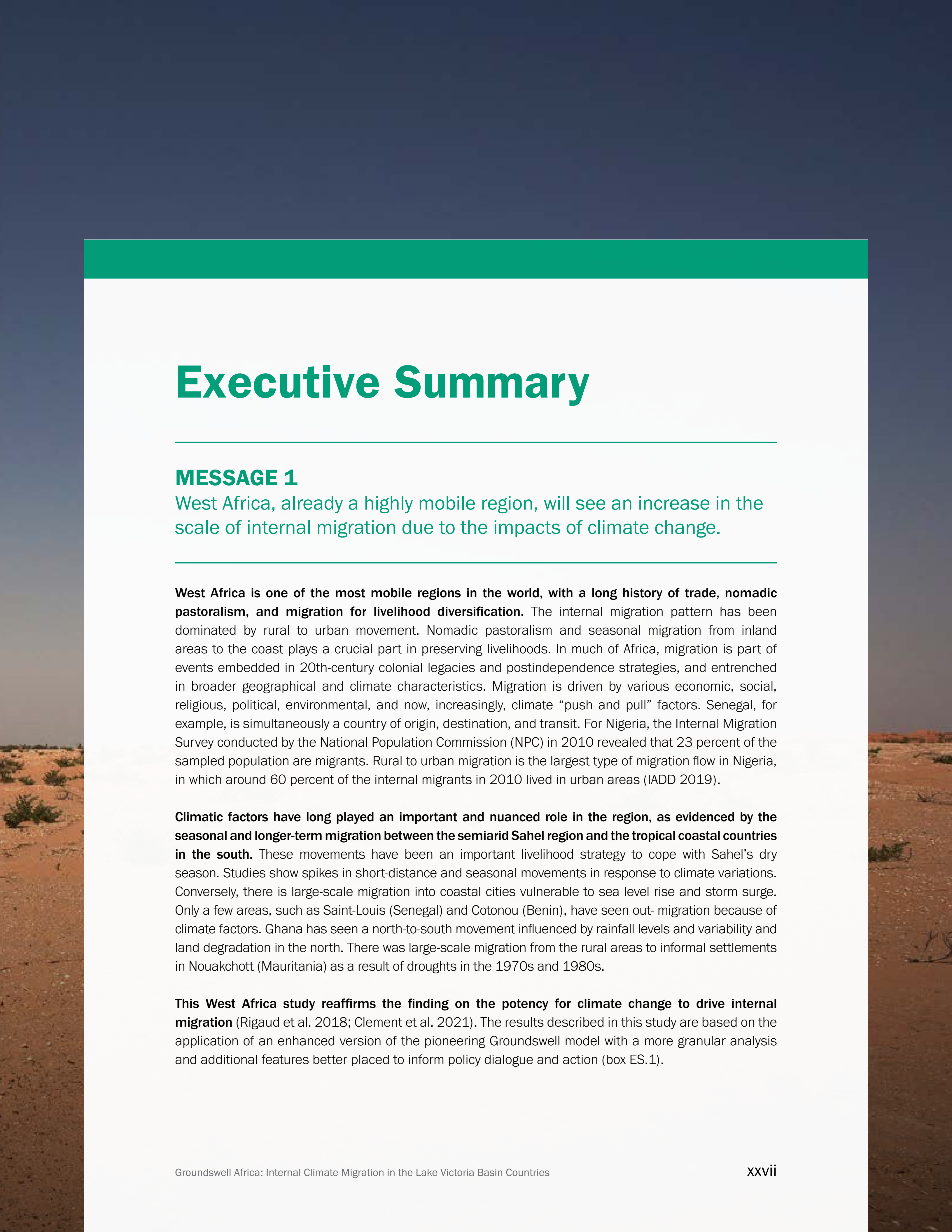
The study finds that without concrete climate and development action, up to 32 million people in West Africa could be compelled to move within their countries by 2050, in response to water scarcity, declines in crop and ecosystem productivity, and sea level rise, augmented by storm surge. By 2050, Niger alone could have up to 19.1 million internal climate migrants, which would account for up to 30.26 percent of the total population if no action is taken. Smaller coastal countries in West Africa like Benin could see climate migrants representing 45 percent of all internal migrants by 2050.

Locality matters. Countries in West Africa could see the emergence of climate migration hotspots as early as 2030—reflecting both the changing ability of ecosystems to sustain livelihoods, and the risk from flooding in low lying coastal areas. Climate out-migration hotspots coincide in some cases with important growth centers, including coastal cities like Lagos and Dakar. At the same time, climate in-migration hotspots could arise in areas that already have high incidence of poverty, like northern Nigeria, as well as the Mali-Burkina Faso border.

Importantly, these numbers are not predestined—and could be reduced at the regional level by about 60 percent. This study provides us with strong and compelling analysis, and a planning- and action-oriented framework to bring climate-induced migration into the policy dialogue and launch preventive action. It emphasizes that countries in West Africa must step up their efforts for inclusive and resilient development to successfully manage internal climate migration. At the same time, the global community must cut greenhouse gas emissions more rapidly and at scale, to avert or reduce the impacts that drive climate induced migration.

The bottom line is that we cannot afford to ignore climate migration in the development context if we are to ensure stability, security and help countries to delivery their sustainable development goals. The World Bank Group is committed to supporting the required move towards green, resilient and inclusive development. This is a promise to our client countries and to future generations in West Africa and beyond.

Andrea Borgarello / World Bank



Executive Summary

MESSAGE 1

West Africa, already a highly mobile region, will see an increase in the scale of internal migration due to the impacts of climate change.

West Africa is one of the most mobile regions in the world, with a long history of trade, nomadic pastoralism, and migration for livelihood diversification. The internal migration pattern has been dominated by rural to urban movement. Nomadic pastoralism and seasonal migration from inland areas to the coast plays a crucial part in preserving livelihoods. In much of Africa, migration is part of events embedded in 20th-century colonial legacies and postindependence strategies, and entrenched in broader geographical and climate characteristics. Migration is driven by various economic, social, religious, political, environmental, and now, increasingly, climate “push and pull” factors. Senegal, for example, is simultaneously a country of origin, destination, and transit. For Nigeria, the Internal Migration Survey conducted by the National Population Commission (NPC) in 2010 revealed that 23 percent of the sampled population are migrants. Rural to urban migration is the largest type of migration flow in Nigeria, in which around 60 percent of the internal migrants in 2010 lived in urban areas (IADD 2019).

Climatic factors have long played an important and nuanced role in the region, as evidenced by the seasonal and longer-term migration between the semiarid Sahel region and the tropical coastal countries in the south. These movements have been an important livelihood strategy to cope with Sahel’s dry season. Studies show spikes in short-distance and seasonal movements in response to climate variations. Conversely, there is large-scale migration into coastal cities vulnerable to sea level rise and storm surge. Only a few areas, such as Saint-Louis (Senegal) and Cotonou (Benin), have seen out- migration because of climate factors. Ghana has seen a north-to-south movement influenced by rainfall levels and variability and land degradation in the north. There was large-scale migration from the rural areas to informal settlements in Nouakchott (Mauritania) as a result of droughts in the 1970s and 1980s.

This West Africa study reaffirms the finding on the potency for climate change to drive internal migration (Rigaud et al. 2018; Clement et al. 2021). The results described in this study are based on the application of an enhanced version of the pioneering Groundswell model with a more granular analysis and additional features better placed to inform policy dialogue and action (box ES.1).

Collectively, West African countries[1] could see as many as 32 million internal climate migrants by 2050 (4.06 percent of the 2050 projected population) under the pessimistic scenario (figure ES.1). These results represent an aggregation of country based analysis. Of the alternative scenarios modeled, the optimistic scenario projects the lowest number of internal climate migrants, reaching a mean of 7.4 million by 2050. People will migrate from areas with lower water availability, declining crop and ecosystem productivity, and from areas affected by sea-level rise compounded by storm surges. Hence, pursuing concrete climate and development action could yield a reduction in the average number of migrants by 11.9 million (61.7 percent) by 2050 (figure ES.1).

No country in West Africa is immune to internal climate migration, but the scale in each country will depend on how the climate factors interact with demographic and socio-economic factors at the local level (figure ES.2). For example, Benin is projected to have 342,000 internal climate migrants by 2050 under the high end of the pessimistic scenario but could see a reduction of climate migrants by up to 72 percent, reaching a low of 97,000 at the low end of the optimistic scenario. Niger, Nigeria, and Senegal are projected to have the highest numbers of internal climate migrants by 2050: reaching a high of 19.1 million, 9.4 million, and 1.0 million, respectively, under the pessimistic scenario.

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[1] The study modeled the following West African countries: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Ghana, The Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, and Togo.

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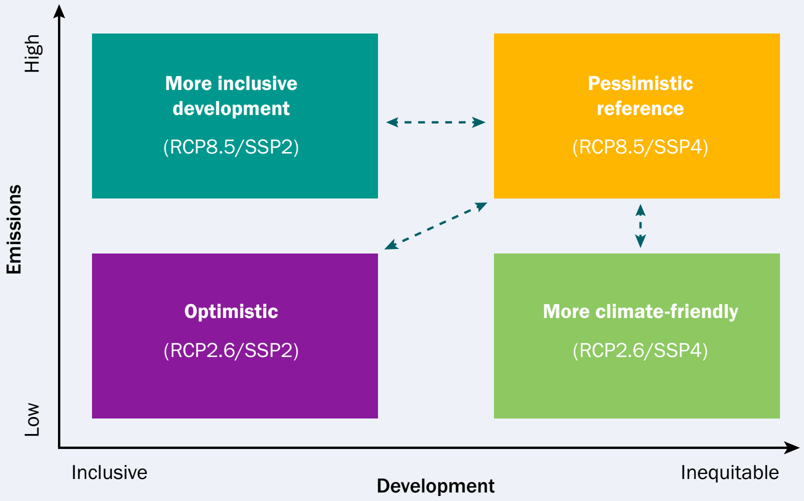
Box ES.1 An Enhanced Groundswell Model

The results described in this study are based on the application of an enhanced version of the pioneering Groundswell model (Rigaud et. al. 2018). The expanded model includes the optimistic scenario, and additional climate (net primary productivity, flood risk) and nonclimate factors as variables.

The modeling results presented here are based on four plausible scenarios—reflecting different combinations of future climate change impacts and development pathways, to characterize the scale and spread of climate migration by 2050.

Projecting Internal Climate Migration under Four Plausible Scenarios

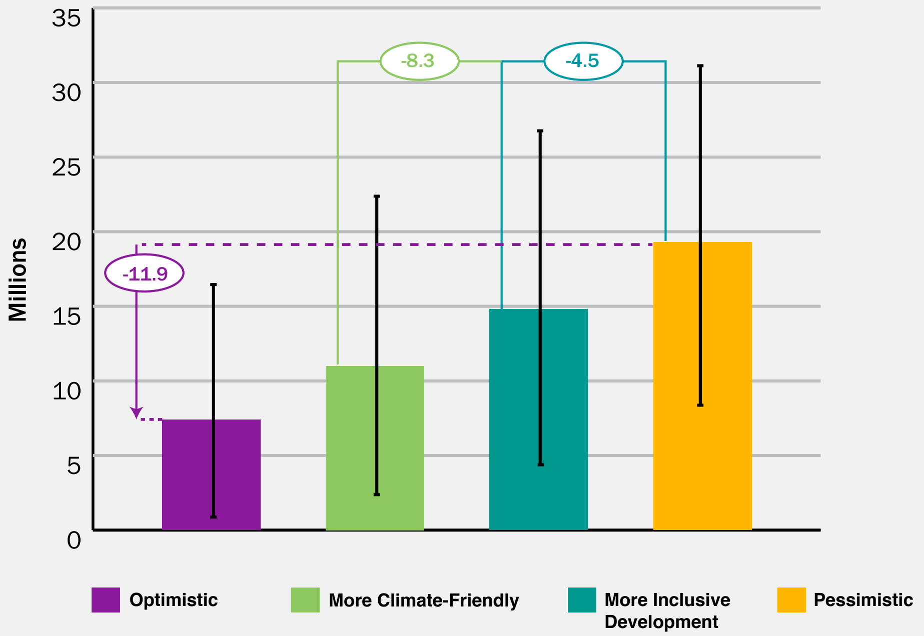


Note:

1. The scenarios are based on combinations of two Shared Socioeconomic Pathways—SSP2 (moderate development) and SSP4 (unequal development)—and two Representative Concentration Pathways —RCP2.6 (low emissions) and RCP8.5 (high emissions).
2. Estimates of climate migrants are derived by comparing these plausible climate migration (RCP-SSP) scenarios with development only (SSP) or the "no climate impact" scenarios

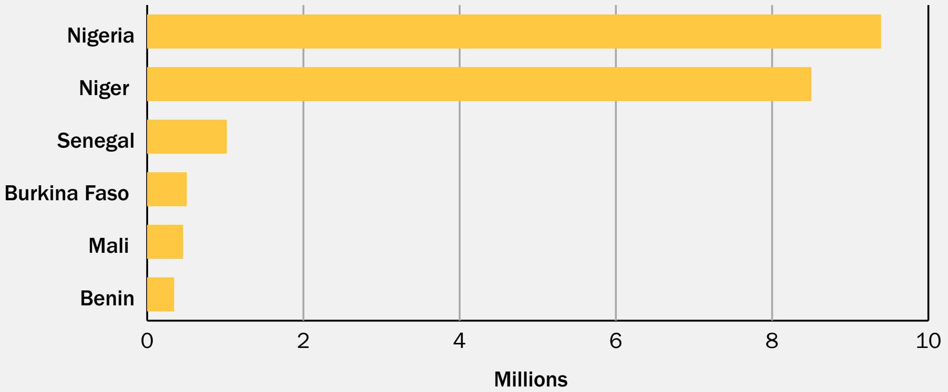
The expanded model provides a more granular analysis better placed to inform policy dialogue and action. To estimate the scale of internal climate migrants a population gravity model was used to isolate the portion of future changes in population distribution that can be attributed to climate change as a proxy for climate migration. To capture the effects of slow onset climate factors on internal migration, the methodology used state of the art simulations for crop, water, net primary productivity (NPP), flood risk models, and sea level rise with storm surge. Non-climate factors were considered, including demographic variables (sex and median age) and conflict. This expanded model was also used to analyze internal climate migration in West African countries (Rigaud et al. 2021a).

Figure ES.1 Projected Total Internal Climate Migrants, West Africa, by 2050



Note: The whiskers represent the lowest and the highest number of internal climate migrants in that scenario. .

Figure ES.2 Projected Internal Climate Migrants in Select West African Countries under the Pessimistic Scenario by 2050*



* Results for the rest of the West African countries are available in the fulll report (see Rigaud et al. 2021. *Groundswell Africa: Internal Cliamte Migrattion in West African Countries*).

MESSAGE 2

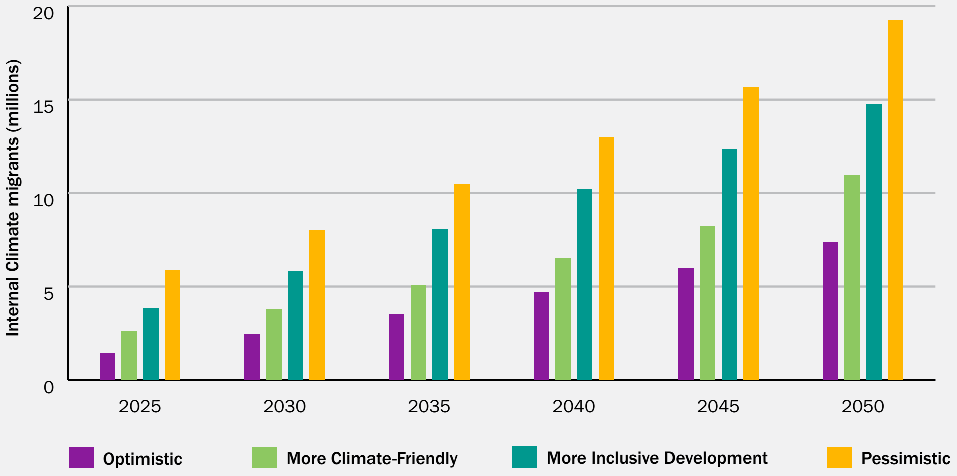
Internal climate migration will ramp up by 2050, with the share of climate migrants accelerating, unless we act early to pursue concerted climate and development action.

The trajectory of internal climate migration in West Africa could increase between 2025 and 2050—with variations on the acceleration of increase between scenarios and countries (figure ES.3). There is a consistent upward trend across the scenarios, with the higher emissions scenarios (pessimistic and inclusive development) showing higher rates of acceleration of internal climate migration over the decades. The scale of internal climate migrants in the countries within the region could see anywhere from a 3.3-fold increase to a 5.0-fold increase between 2025 and 2050. Greatest gains are realized under the optimistic scenario, which combines low emissions with equitable development. These projections emphasize the value of early action on both climate and development fronts.

Internal climate migration is not uniform across countriies—and depends on demograhic patterns and economic trends, but climate is increasingly a potent factor. Of the West african coastal countries, Nigeria is projected to have the highest mean number of internal climate migrants under the pessimistic scenario by 2050 (8.3 million) far ahed of Senegal (0.6 million) and Ghana (0.3). However, smaller countries, such as Benin, also exhibit high internal climate migration figures as a percentage of their total population (1.62 percent for Benin compared to 1.93 percent for Nigeria and with Senegal achieving the highest percentage at 1.98 percent).

Internal climate-induced migration could emerge as an important type of internal migration in West African countries by 2050. The number of internal climate migrants compared to other internal migrants is projected to increase across scenarios, decades, and countries, particularly under the high emission scenarios, and significantly so in Benin, Senegal, and Nigeria. At the regional level, internal climate migrants could account for one third of all internal migrants as early as 2030 under the pessimistic scenario.

Figure ES.3 Projected Trajectory of Internal Climate Migrants, West African Countries, 2025–50



Timely and concrete climate and development action can modulate the scale of future climate-induced human mobility, but the window of opportunity for optimum gains is quickly closing. The United Nations Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (2021) highlights the growing nature of the climate crisis and the urgency for action. The latest science on warming and impacts could challenge the prospects of reducing the scale of climate migration under the optimistic scenario. More extensive and extreme climate impacts on water availability, crop and ecosystems productivity, and sea level rise will have significant ramifications for population movements. For example, the number of climate migrants in Senegal could drop from a mean value of 603,000 under the pessimistic scenario in 2050 to 92,000 in 2050 under the optimistic scenario. These projections underscore the need for both inclusive development and low emissions for modulating the scale of climate migration, but also the need to pursue highly resilient policies and shifts toward less climate-sensitive sectors at scale.

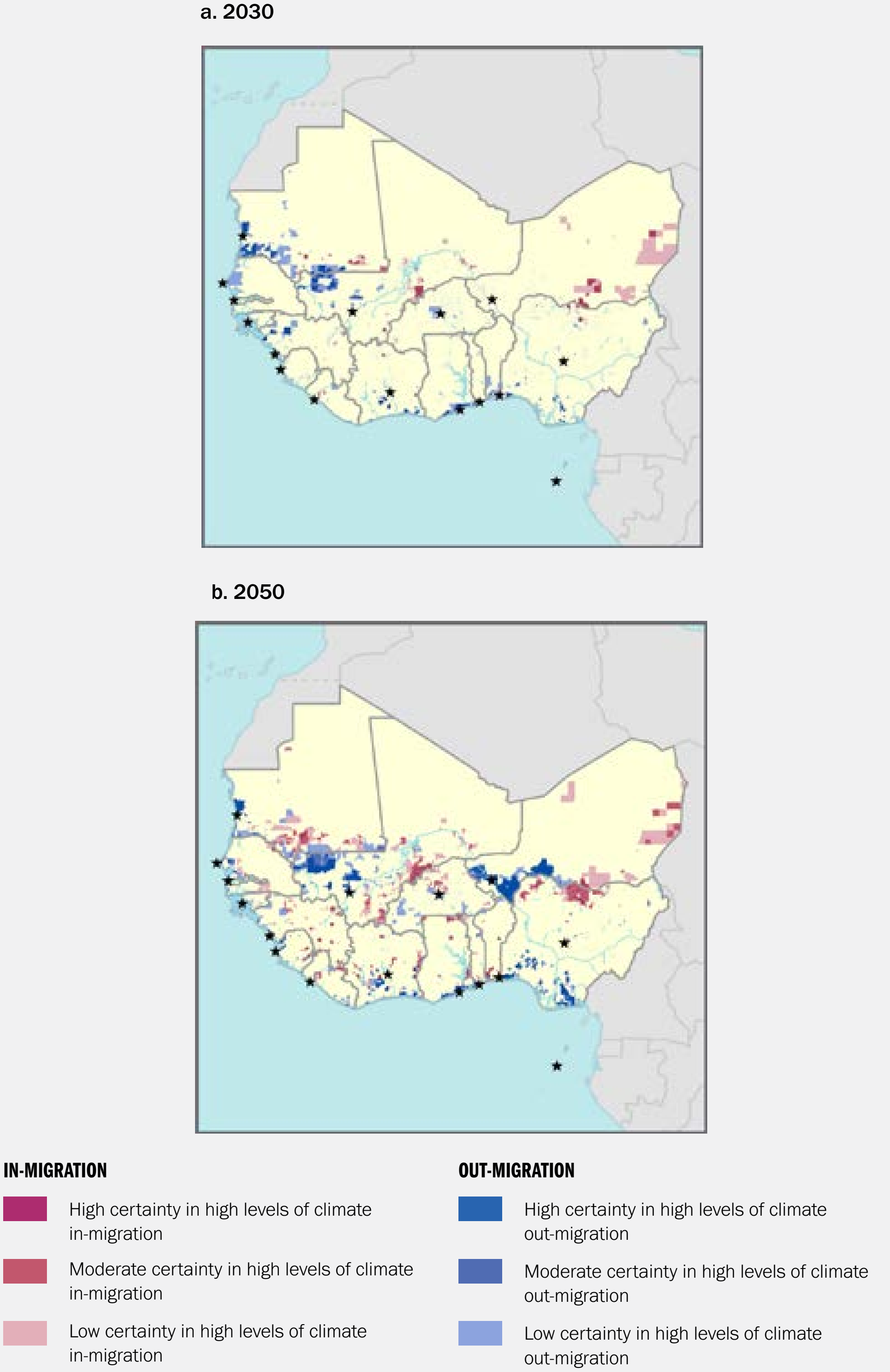
MESSAGE 3

The emergence of internal climate in- and out-migration hotspots in West African countries as early as 2030 requires holistic and far sighted approaches to ensure sustainable and durable outcomes.

Climate in- and out-migration hotspots in West African countries could emerge as early as 2030 and intensify and spread by 2050 (figure ES.4, panels a and b). These plausible hotspots, aggregated based on country analysis, represent areas where population movements are considered high certainty across the scenarios. Population movements are expected to shift in response to changes in the ability of ecosystem to support livelihoods, particularly in terms of changing water availability, crop productivity, and NPP, and habitability of coastal systems in a context of sea level rise compounded by storm surges. Climate out-migration hotspots reflect a dampening or increase in population growth in response to climatic factors and do not necessarily imply an absolute decline or growth of population numbers.

The emergence, spread, and intensity of hotspots within countries in West Africa calls for contextualized understanding and early action to avert and reduce adverse consequences and harness opportunities. Climate in-migration hotspots are projected to emerge in the Sahel because of increases in water availability and pasturage. These results must be interpreted against the low baseline of water availability in the region. South-central Mauritania, southeastern Mali, and northen Nigeria will be large climate in-migration hotspots in the area. Climate out-migration could become prominent in the Dakar-Diourbel-Touba corridor by 2050. Countries with high populations, such as Nigeria and Niger, dominate the hotspots map, but with normalization for population, demographically smaller countries such as Benin, Sierra Leone, Senegal, and Mauritania show prominent climate in- and out-migration hotspots.

Figure ES.4 Projected Hotspots of Climate In- and Out-migration within West African Countries by 2030 and 2050



Note: High, moderate and low certainty reflects agreement across all four, three, and two scenarios modeled respectively. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes. Data is based on compilation of West African country results between the climate and no climate impact scenarios by country for the top and bottom 5th percentile differences in the density distribution for climate in- and out-migration respectively.

Unmanaged climate migration patterns will not just undermine poverty eradication but can also roll back development gains in cities and centers of growth. Many climate in-migration hotspots in West Africa face severe environmental challenges due to climate change, including landslides, flooding, droughts, and land degradation, on top of other development challenges, such as high poverty rates, informal human settlements, and weak services and infrastructure. Climate in-migration hotspots projected for the northern and northwestern Nigerian states of Kano, Katsina, and Sokoto, coincide with areas of high poverty incidence. In contrast, Dakar and the west-central part of Senegal, where poverty levels are lower, could emerge as climate out-migration hotspots. These trends, in many cases, run counter to the historical development-induced migration trajectory. Better management of environmental and water resources and the rural landscapes is an essential part of any strategy to counter adverse consequences of migration and displacement.

Water stress, declining crop and NPP productivity, and sea level rise will become increasingly potent drivers of internal climate migration in West African countries over the next decades. Generally, areas that see positive deviations in water, crop and ecosystem productivity experience more in-migration, as reflected through spatial population distribution shifts. The coefficient for water availability in rural areas is around 2.7 times higher than that of crop production and 2.8 times that of NPP. Senegal, for example, is projected to become drier in the western and coastal areas. Under some models, the whole country could become drier, in some cases significantly. Ghana could see modest wetting in the north and drying across several models in the south. Drying could be high: up to 50 percent to 70 percent reductions in water availability projected in the Accra metropolitan area. In the south of Mauritania, crop production declines under most model runs by 2050. Across the region, the climate signal will become far stronger toward the end of the 21st century.

In the West Africa study, the addition of nonclimate factors (median age, sex, and conflict) applied to individual countries provides a more complete representation of how climate-induced migration trends could manifest within countries. For example, higher median age, associated with the migrant-attracting urban areas in West Africa, dampens the effects of water stress, which would otherwise drive climate out-migration. This was observed in the coastal areas from Côte d'Ivoire to Nigeria. Conflict hotspots tend to be associated with slow or declining rural population growth and slightly more rapid urban population decline, because when civil conflicts break out it may be easier to shelter in place in rural areas than in urban areas.

The climate migration hotspots are not predestined, but the agreement across the scenarios on climate in- and out-migration underscores the need for farsighted and anticipatory approaches to address the adverse consequences of climate-induced migration (box ES.2). For example, in the climate out-migration hotspot in Lomme Commune in Togo, the number of climate out-migrants would be reduced almost threefold in the optimistic scenario compared to the pessimistic scenario. These approaches may require adapt-in-place measures to protect communities and assets and provision of basic services and job opportunities. Managed retreat will need to be facilitated in areas that pose high levels of climate risks. Box ES.2 summarizes the results of a workshop in Accra in September 2019 and a virtual consultation in March 2021.

Table ES.1 summarizes the regional results, aggregated based on country level data and analysis.

Table ES.1 Summary of Results Aggregated for the West African Countries

Factors	Regional Results
Population in 2025 and 2050	Increases from 430.1 million to 676.1 million (in SSP2) or 447.4 million to 789.1 (in SSP4)
Total population at baseline (2010)	306.9 million
Primary drivers	Water availability, followed by crop productivity and changes in NPP, which will affect livestock herding
Number of internal climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 19.3 million (2.44% of projected population) and a high end of 32.0 million climate migrants (4.06%).
Trajectory to 2050	Relatively persistent increase in the number of climate migrants: roughly 2.5 million additional climate migrants per decade from 2025 to 2050 under the pessimistic scenario. There is a slight upward inflection after 2040 under the high emissions scenario (pessimistic and inclusive development scenarios).
Internal climate in-migration hotspots	In the Sahel: relatively large, spatially contiguous climate in-migration hotspots (south-central Mauritania, southeastern Mali, and northern Nigeria) because of projected increases in water availability and pasturage. These increases are consistent with climate model projections that show wetting in the eastern portions of West Africa, but there are uncertainties not fully captured in the two climate models used in this report.
	In coastal countries: coastal urban areas could still grow due to their job opportunities and amenities, but climate impacts are likely to shift populations slightly inland.
Internal climate out-migration hotspots	In the Sahel: large climate out-migration hotspots are projected in southern Niger and on the border between Mali and Mauritania.
	In coastal countries: climate out-migration hotspots are associated with major urban areas, which generally entail large numbers of migrants, despite the small areas, because they attract migrants searching for employment, etc.
Coastal dynamics	The coastal zone (defined as the 5-kilometer band along the coast) is projected to see an average of out-migration of 1.8 million people (and a high of 2.2 million people) in 2050 under under the high emissions scenario. Under the low emissions scenario this could be between 300,000 and 800,000 people. Major climate out-migration hotspots are projected in coastal Senegal and along the entire coastline of the Gulf of Guinea (from Abidjan to Lagos). Monrovia, Liberia, and Conakry, Guinea, could emerge climate in-migration hotspots.
Climate migrants compared to other migrants by 2050	The projected number of internal climate migrants by 2050 is 19.3 million and that of other internal climate migrants is 36.4 million, in the pessimistic scenario.

Note: Based on aggregated individual country data. SSP2 represents a moderate development pathway, and SSP4, an unequal development pathway. NPP = net primary productivity; SSP = Shared Socioeconomic Pathway.

Box ES.2 Regional Consultation on Internal Climate Migration

The report benefited from a regional consultation on internal climate migration with participants from civil society, government institutions, academia, and to international bilateral and multilateral organizations (World Bank, unpublished). There was consensus among participants on key results areas: on the growing importance of the factors related to water stress, drops in crop productivity and sea level rise, and the overall potency for climate factors to drive migration and displacement. Participants also found the scenarios and climate in- and out-migration hotspots in this report plausible and highlighted the importance of preparedness and resiliency. The consultation stressed the need to assess additional factors affecting the vulnerability of certain sectors and demographic groups, such as the link between migration, conflict, and instability, and the need for an early, integrated and holistic approach to climate-induced migration.

MESSAGE 4

Global responsibility for swift action to cut greenhouse gas emissions is critical to reducing the scale of internal climate migration.

Global commitments to cut greenhouse gas (GHG) emissions are off-track to meet the Paris targets. The latest IPCC report (2021) finds that the global average temperature increase will exceed 1.5°C during the 21st century unless there is a deep reduction in greenhouse gas emissions in the upcoming decades. Without immediate, rapid, and large-scale reductions in GHG emissions, limiting warming to 2°C will be beyond reach. Beyond the threshold temperatures, extreme events will rise and climate-related risks for natural and human systems become higher, with disproportionate impacts on the poorest and most vulnerable (IPCC 2021; UNEP 2020). Some impacts are already locked-in. Increased warming and climate impacts will have consequences for the changing viability of ecosystems and associated livelihoods, and on low-lying cities and coastlines vulnerable to sea, fueling increased levels of migration.

Without aggressive global emission reductions to meet the Paris targets, the opportunity to reduce the scale of internal climate migration as set out under the low emission scenarios will be hard to achieve. The far-reaching consequences of internal climate migration means that the international community cannot relinquish its efforts. The responsibility for solving the challenges of internal climate migration cannot be delegated solely to the very communities that may have to move in response to increasing intensity and frequency of climate impacts.

Strong, inclusive, and resilient development may be the first line of defense in the face of stalling action on GHG emissions, but will not suffice by itself. Managing environmental and land degradation, vulnerable coastal systems, and pastoral livelihoods is particularly challenging, and countries must pursue green, resilient, and inclusive development that cuts across spatial and timescales. Major GHG emission countries must find direct and indirect ways to complement countries' efforts on climate-induced migration through support of technologies, capacity, and financing.

MESSAGE 5

Coastal hazards will accelerate on the West African coast to become a major driver of internal climate migration, projecting a reversal in the conventional migration trend towards coastal cities.

West Africa's coastline is particularly vulnerable to erosion, sea level rise, increasing temperatures, and flooding. The capitals and other large cities of Benin, Côte d'Ivoire, Ghana, Mauritania, Nigeria, Senegal, São Tomé and Príncipe, and Togo are all located on the coast. Despite risks, coastal cities such as Dakar, Abidjan, Accra, and Lagos continue to grow and provide economic opportunities to migrants from economically depressed areas. More than 6 million Nigerians live in the low elevation coastal zone, followed by Senegal (1 million), Mauritania and Benin (0.8 million each), Côte d'Ivoire (0.7 million), Ghana (0.6 million), and Togo (83,000) (CIESIN and CIDR 2021).

A special focus on the 5-kilometer coastal zone of West Africa reveals that between 0.3 million and 2.2 million people could be compelled to move within their countries by 2050. Mauritania is projected to face the highest relative sea level rise over the course of this century because of coastal subsidence, and parts of Nouakchott already prone to flooding seawater intrusion and rising groundwater will likely see climate out-migration as early as 2030. Major climate out-migration hotspots are projected in coastal Senegal and along the entire coastline of the Gulf of Guinea. In Nigeria, climate out-migration is projected in the south and southeast and coastal states, including Lagos, Ogun, Rives, Ondo, Delta, Bayelsa, Rivers, and Akwa. By 2050, Senegal could have up to 443,000 coastal climate out-migrants under the high end of the pessimistic scenario (5.58 percent of the coastal population), while Benin could have up to 154,000 (4.97 percent). Nigeria could have the highest number of coastal climate out-migrants, with close to 1 million by 2050 under the high end of the distribution for the pessimistic scenario. By contrast, Côte d'Ivoire is projected to have 25,000 climate out-migrants (1 percent).

The exposure and vulnerability of West Africa's coastal activities and infrastructure to climate change risks will increase the probability of secondary reverse migration. Sea level rise, storm surge, and declining water availability will likely reduce the growth of coastal urban areas in certain countries (notably Senegal and Ghana). Large cities such as Dakar, Abidjan, Accra, and Lagos will continue to grow because they provide economic opportunities to those from more economically depressed areas, but the population growth at the hotspots will be dampened as a consequence of climate factors. Early, farsighted, and inclusive action to reinforce these coastal areas with green and gray infrastructure, where appropriate, and comprehensive coastal zone planning are essential.

MESSAGE 6

Internal climate migration cannot be divorced from development, and as the human face of climate change must be addressed in a holistic, end-to-end manner.

Internal climate migration in West Africa is a reality that can be nurtured into a positive force through a focus on a core set of policy areas and domains of action. The Migration and Climate-informed Solutions (MACS) framework (figure ES.5) brings together domains of action, buttressed by core policy areas, to reduce the scale of climate-induced migration across time and space, usher in social and economic transformation, and reduce vulnerabilities. This anticipatory approach will ensure that the countries' economies are braced not just for the challenges but have the readiness to harness the opportunities of internal climate migration.

The core policy areas, as advocated by the first Groundswell report, remain critically important:

- Cut GHGs now.
- Pursue inclusive, climate-resilient, and green development.
- Embed migration in development planning.
- Invest in an improved understanding of migration.

The diverse context of West African countries where internal climate migration will play out calls for focused attention and solidarity. It can be guided by these five aciton domains to avert migration driven by adverse impacts of climate change:

- Conduct spatio-temporal analytics to understand the emergence of climate migration hotspots.
- Adopt farsighted landscape and territorial approaches.
- Harness climate migration for jobs and economic transitions.
- Nurture humanitarian-development-peace partnerships.
- Domesticate policies and bridge legal gaps.

Action must be pursued through dedicated local and national action and regional cooperation, as appropriate.

Unfortunately, a certain amount of warming is already locked-in due to historical GHG emissions, so pursuing inclusive and climate-resilient development policies must be a priority. Policies must focus on the full migration life cycle, including creating measures that can help communities to *adapt in place* where local adaptation options are viable and sensible; or *enable mobility* or movement for people facing unavoidable climate risks when the limits of local adaptation and ecosystems are reached. Critically, *after migration*, policy measures and other support must ensure that sending and receiving areas, and their people, are well-connected and adequately prepared to accommodate both outflows and inflows of people for the medium and longer term.

Box ES.3 MACS Framework

The MACS framework is the outcome of the World Bank's efforts through the Groundswell reports and subsequently deeper dives through Groundswell Africa to better understand the implications of climate-induced migration and mainstream this phenomenon into development plans, programs, and policies. It stems from the result of the abovementioned modeling exercise, contextualized against current and historical mobility patterns, peer-reviewed literature, and multistakeholder consultations. A portfolio review of the design features of 165 World Bank projects operating at the climate-migration-development nexus further informs this framework (Rigaud et al. 2021b). MACS is flexible and adaptive, based on the premise that climate migration is linked to broader development challenges across spatial scales. It can guide policy makers and practitioners by offering critical information and insights related to development and policy implications of climate-induced internal migration. This reflects the call for anticipatory approaches over larger time and spatial scales to avert and minimize the adverse consequences of climate-induced migration and harness opportunities brought forth by migration.

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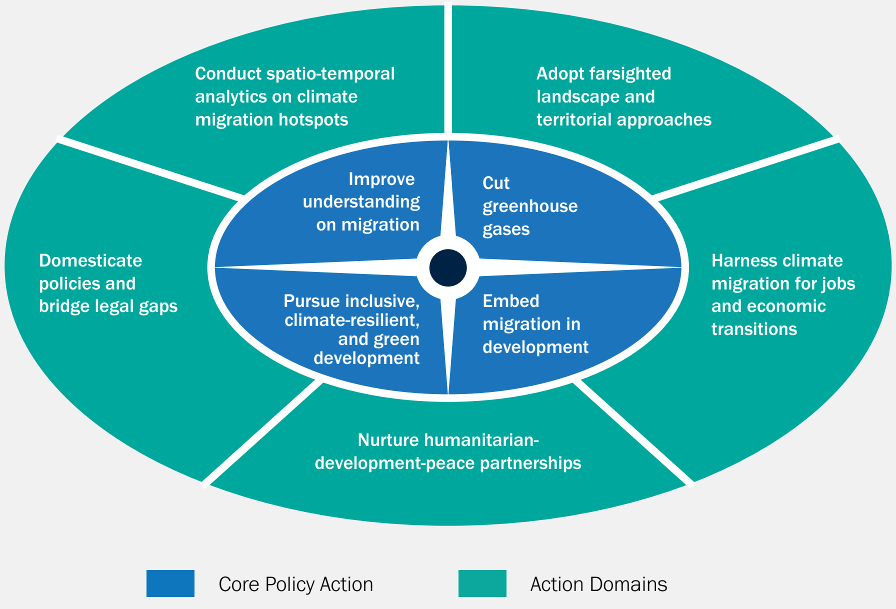
Figure ES.5 Migration and Climate-informed Solutions (MACS) Framework



The scale, trajectory, and geographical spread of internal climate migration in West African countries calls for focused attention and urgent policy action. Addressing long-standing environmental challenges is a time-sensitive imperative in West Africa, where lives, livelihoods, and the economy are integrally linked with climate-sensitive livelihoods. Attention to environment degradation, pressures on pastoral livelihoods, water stress, declines in crop productivity and sea level rise must be addressed as part of landscape and territorial approaches. Unattended, these adverse consequences will lead to climate-induced migration, deepen existing vulnerabilities, and increased poverty, fragility, conflict, and violence.

Underpinned by the MACS framework and in support of a country's development vision and plans, the right set of climate and development policies measures taken today can help avert adverse outcomes and harness opportunities of climate-induced migration in West Africa. For example, Nigeria's Economic and Recovery Growth Plan aims to achieve agriculture and food security and create jobs for youth skilled in information and communications technology (ICT) hardware. These goals have much in common with the priorities in the MACS framework. Nationally Determined Contributions (NDCs) recognize climate-induced migration as an adaptation strategy and a way to counter the adverse consequences of climate impacts. The Country Partnership Frameworks (CPFs) through which the World Bank supports its client countries could include polices and investments that can take a longer-term view to addressing climate migration, such as job diversification, land and landscape management, climate change resilience, environmental risk management, and provision of basic rural and urban services. The Country Climate Development Report (CCDR), a new World Bank diagnostic, provides a further opportunity to understand and address climate-induced migration as a crucial part of supporting countries to identify low-carbon and resilient pathways and deliver the sustainable development goals.

The development community is not starting from zero. For example, the World Bank carried out a portfolio review (Rigaud et al. 2021b) to draw actionable insights from 165 World Bank projects operating at the climate-migration-development nexus, with commitments reaching US$197.5 billion (from 2006 to 2019). The learnings show that a more systematic and anticipatory approach in designing projects geared toward addressing climate migration is possible. Increasingly, projects not only address migrants' direct needs but support for enabling interventions (early warning systems and social safety nets) and address underlying causes of mobility. There is a need to step up such integrative approaches with great vigor and urgency—acting in partnership and engagement with those directly affected.

MESSAGE 7

Climate migration, as a cross-cutting issue, has to be addressed through policy-informed action that is farsighted in its approach and execution.

The five action domains outlined in the MACS framework can bolster the delivery of the core policies to reduce, avert, and minimize distress-driven internal climate migration. The call for action on internal climate migration is clear and compelling. Conceiving effective responses by investing in iterative scenario modeling, grounded in new data and development progress, will be crucial to support decision-making. While the report does not focus exclusively on cross-border migration, the modeling identifies numerous migration hotspots in areas close to national borders. Climate change can be an inhibitor or a driver of cross-border migration, depending on a range of factors that propel individuals to decide to move or stay. Such investments should try to facilitate long-term planning, such as in adaptive capacity, to secure climate resilience. This will require cooperation not only at the international level but also at the local levels. One example is through the Regional Sahel Pastoralism Support project, which seeks to improve access to essential productive assets, services, and markets for pastoralists and agropastoralists in selected transborder areas and along transhumance axes across six Sahel countries (Plante 2019).

Conduct spatio-temporal analytics to gauge the emergence of climate migration hotspots in coastal areas, particularly cities as engines of growth (Dakar, Lagos, Cotonou, Accra, Nouakchott, São Tomé, and Lomé) and areas of high poverty incidence (Kano in Nigeria, Korhogo in Côte d'Ivoire, and near Matam in Senegal) to set out for the challenges and opportunities. More investment is needed to better contextualize and understand climate migration, particularly at scales ranging from regional to local, where climate impacts may deviate from the broader global trends. Building country-level capacity to collect and monitor relevant data can increase understanding of the interactions among climate impacts, ecosystems, livelihoods, and mobility, and help countries tailor policy, planning, and investment decisions.

Embrace landscape and territorial approaches to enable early planning and action across spatial and time scales to devise strategies that straddle hotspots (Accra and lower Volta River Basin in Ghana; San Pedro and Yamoussoukro in Cote d'Ivoire) in response to the dynamics of climate in- and out-migration localities. The coastal erosion rates are high in Togo and expected to exacerbate under sea level rise especially in low-lying areas of Lomé. Nouakchott, the capital of Mauritania, faces severe risks from sea level rise and coastal erosion. Its rapidly growing urban areas extend into low-lying portions, putting more inhabitants at risk. The agriculture- and livestock-dependent households in northeast Senegal (the Sahelian zone) are sensitive to land degradation and desertification. However, in Senegal's Saint-Louis, coastal erosion has become an existential threat and planned relocation has taken place. Site-based and locally driven practices for forest and water management, integrated community programs, and land use plans, including for coastal areas, can be part of the landscape approaches for emerging hotspots in high-poverty regions.

Harness climate-induced migration for jobs and economic transitions to leverage growth and development opportunities based on West African countries' youth bulge, structural transformations in climate sensitive sectors (e.g. agriculture, rainfed crops), and investment in human capital for green growth, including through skills development and education. For instance, Abidjan, Côte d'Ivoire, has high social vulnerability with low levels of maternal education. Mauritania could see a relatively large level of climate migration out of the coastal zone: up to 300,000 under the pessimistic scenario. The main impacted area is the surrounding and to the north of Nouakchott. Supporting climate-smart urban transitions with energy efficient, green, and resilient urban infrastructure and services, and embracing secondary cities or peri-urban areas as new growth poles, will offer ways to make migration a force for positive transformation.

Nurture development-humanitarian-peace partnerships to capitalize on comparative advantages to support the needs of migrants and host communities. Stepped-up action by development, humanitarian, security, and disaster communities across the mobility continuum will help overcome barriers around funding sources, coordination mechanisms, and project timelines. Ultimately, this commitment will help countries pursue durable and holistic solutions. In Nigeria, conflicts between pastoralists and farmers in the northern states of Borno, Yobe, and Adamawa, in a context of terrorism and insecurity linked to Boko Haram, call for a new look at farmer-herder conflicts and the integration of humanitarian-development-peace efforts.

Domesticate policies and bridge legal gaps in response to existing legal frameworks, agreements, and processes, and mobilize action, for example through the Kampala Convention. Climate-induced migration lies at the intersection of human rights, climate change, sustainable development, disaster risk reduction, and countries' sectoral frameworks pertaining to the environment and management of natural resources. The Economic Community of West African States (ECOWAS) Protocol on the Free Movement of Persons, Residence and Establishment (1979) and the adoption of the ECOWAS Transhumance Protocol (1998) and Regulation (2003) are major achievements to facilitate human and livestock mobility. The legally binding African Union Convention for the Protection and Assistance of Internally Displaced Persons in Africa (also known as the Kampala Convention) is a key regional framework for protecting internally displaced persons. The Convention, which has been either signed or ratified by several countries in West Africa, addresses internal displacement caused not only by armed conflicts but also by natural or humanmade disasters and focuses on the root causes of internal displacement to provide durable solutions.

These collaborative and legal efforts should be applauded, but they remain insufficient to address the wide range of factors driving people to move internally and across borders. Domestication of regional (such as the Kampala Convention) and global frameworks and agreements (such as the Global Compact for Migration), and the operationalization of regional protocols (ECOWAS) into national practices, including to protect affected communities, can foster meaningful consultation about temporary migration and relocation, and secure people's tenure at their new location and ability to move with dignity. World Bank financing instruments support climate and mobility, and further support could focus on developing opportunities and policies for the safe movement of people and on providing viable options for in situ adaptation.

Climate-induced migration will be a reality in West Africa, and action cannot be postponed—the stakes are too high. The countries in the region can embark on a green, resilient, and inclusive path for development by exploiting new economic opportunities, recognizing that structural transformations must be informed by and responsive to climate change. Climate actions and plans should consider climate-induced migration and displacement. Spatial dimension and emergence of hotspots are critical to resilience-building efforts. Anticipatory and transformative action across the migration cycle will help to ease people out of vulnerability. The global community must do its part to contain GHG emissions as a critical part of reducing climate-induced migration. Climate migration is a reality, and acting now will lead to sustainable outcomes for all concerned. This latest World Bank report on climate migration in West Africa is also a call for collective action to reduce GHG emissions and for the development, humanitarian, disaster, and security communities to come together. Responding today will help secure the foundations of a peaceful, stable, and secure region for the people of West Africa, the continent of Africa, and the global community.

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Understanding when, where, and how internal climate migration will unfold in West African countries is critical to address the challenges and opportunities of climate-induced migration. This report conveys the scale and patterns of internal climate migration in West African countries and sets out a framework for response.

Andrea Borgarello / World Bank

Chapter 1

Introduction

Researchers, policy makers, and the wider public are increasingly concerned that the impacts of climate change will have a massive effect on global migration patterns in the coming decades. The magnitudes of migration are already large, with more internal than international movements (UN DESA 2019; UNDP 2009).[2] Although there is no consensus on the current number of climate migrants, most research recognizes that the rate of climate migration is increasing and that the increase in climate risks in the coming decades will accelerate this trend (Adger et al. 2015; Black et al. 2011; Gemenne 2011; GoUK 2011). The latest Intergovernmental Panel on Climate Change (IPCC) report finds that the global average temperature will likely increase more than 1.5°C within the next two decades, and could even surpass an increase of 2°C by the end of the century if carbon-intensive human activities continue at the current pace (IPCC 2021). Migration has important effects on people, places, and development. It can enhance adaptive capacity under certain conditions—but it can also destroy livelihoods if not adequately planned for and managed (McLeman 2016).

The World Bank's flagship report *Groundswell: Preparing for Internal Climate Migration* set out the potency for climate change to drive internal climate migration across three regions—Sub-Saharan Africa, South Asia, and Latin America (Rigaud et al. 2018). The sequel *Groundswell: Acting on Internal Climate Migration* (Clement et al. 2021) built on the robust and pioneering scenario-based modeling approach of its predecessor and extended the analysis to three additional regions—East Asia, North Africa, and Latin America.[3] The combined results across the six regions show that without early and concerted climate and development action, as many as 216 million people could move within their own countries due to slow-onset climate change impacts by 2050. The study reaffirms the potency for climate to drive migration within countries, with people migrating from areas with lower water availability and crop productivity and from areas affected by sea-level rise and storm surges. Sub-Saharan Africa is projected to have the highest numbers of internal climate migrants, reaching up to 86 million by 2050 (Riguad et al. 2018).

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[2] About 9 million people migrate between countries each year (Abel and Sander 2014), and about 244 million people live outside their country of birth (IOM 2016). This total of international migrants is equivalent to about 3 percent of world population, a percentage that has not changed much since 1990 (Abel and Sander 2014). Internal migration is not as precisely defined as international migration. It generally entails people moving between administrative units (generally states or provinces, but possibly counties or districts) within their country. Internal migration rates are far higher than international rates, though data gaps make it difficult to precisely characterize the level. UNDP (2009) estimates 740 million internal migrants globally, or three times the number of international migrants, while Bell and Charles-Edwards (2013) estimate 763 million people.

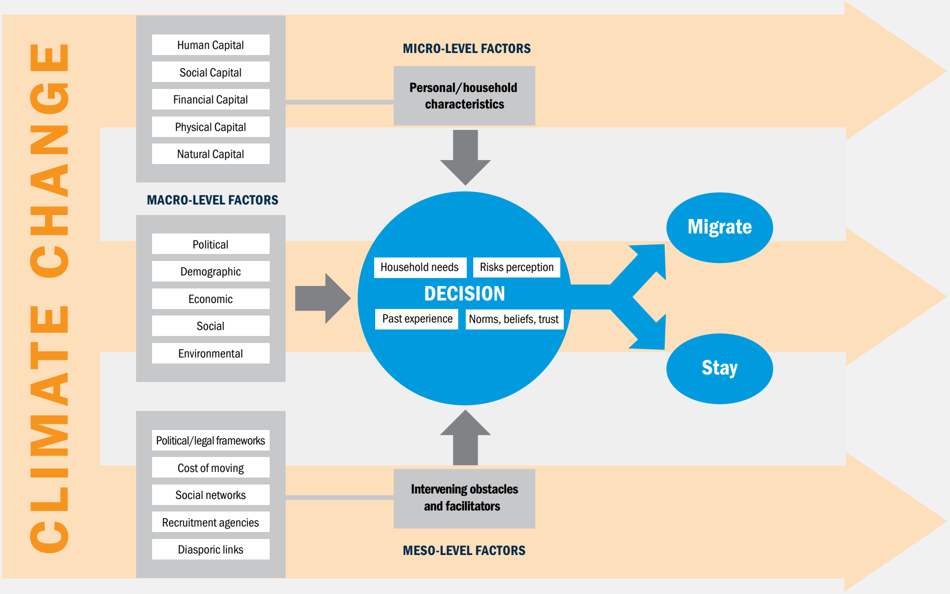
[3] The report also provide analysis on Middle East and Small Island Developing States (SIDS).

West Africa has been frequently identified as a hotspot of current and future climate impacts (Muller et al. 2014; Niang et al. 2014; Turco et al. 2015). Major impacts include rising temperatures, heat waves, erratic rainfall (delays in monsoon onset or dry periods during the rainy season), increasingly intense rainfall events, flooding, and coastal erosion because of heightened storms and sea level rise. Climate change affects precipitation and temperature in West Africa, with consequences on livelihoods, particularly where these are climate sensitive, including agriculture, pastoral, and livestock sectors.

Countries in West Africa are exposed to natural and potentially damaging events. High tides, storms, and heavy precipitation are responsible for both "slow" but permanent processes (such as coastal erosion) and rapid but temporary phenomena (such as coastal and riverine flooding). In 2020, there were 4.3 million new internal displacements due disasters in Sub-Saharan Africa, representing one of the highest figures ever for the region according to the latest Global Report on Internal Displacement (GRID) (IDMC 2021). In addition, there were 6.8 million new displacements associated with conflict and violence in 2020 (IDMC 2021).

West Africa faces increasing rates of mobility both within countries and across international frontiers. While recent economic growth in the region has fueled migration to urban areas, it also has made rural areas more viable than in the past due in part to the agriculture-led nature of this growth. Migration and mobility patterns are, therefore, neither easy to predict nor simply a projection of past trends. For instance, climate alone does not explain how, when, and where people move. As seen in figure 1.1, a complex array of social, political, economic, and environmental factors drives mobility, and climate change tends to work through those factors rather than independently.

Figure 1.1 Foresight Model Adapted to Illustrate Climate Change, Livelihoods, and Household Migration Behavior



Source: Rigaud et al. 2018.

West Africa is one of the most mobile regions of the world. It has a long history of trade (trans-Saharan and intraregional), nomadic pastoralism, dry season migration for livelihood diversification, legacies of colonialism (labor expropriation from the interior toward coastal plantations), and economic linkages to former colonial powers. Migration has been greatly facilitated by an enabling policy framework, the free movement protocol of the Economic Community of West African States (ECOWAS), which enshrines the ability of West African citizens to live and work in any country of the region. The region has experienced and is likely to experience some of the worst impacts of climate change, including rising temperatures, erratic rainfall, increasingly intense rainfall events, flooding, and coastal erosion because of heightened storms and sea level rise. Due to the high dependence of most coastal countries on the agriculture and fisheries sectors, a growing coastal tourism sector, and the high concentration of people and assets along the coast, the economy and livelihoods of West African countries are highly vulnerable to climate variability and change.

Governments and development partners can no longer assume that the evolution of population distributions will remain unchanged. Productive systems may reach limits to adaptation as climate impacts become more severe over the course of this century, which may result in shifts in population distribution. Mostly rural agriculturalists are expected to move from highly affected areas toward regions with better conditions for the crops and livestock on which they depend. In areas where development deficits and adapt-in-place opportunities persist, the chances for internal migration may be accelerated as people move to secure livelihood options in more viable areas. Inaction would mean missing a vital opportunity to reconfigure where, when, and how climate-resilient investments are made to support robust economies.

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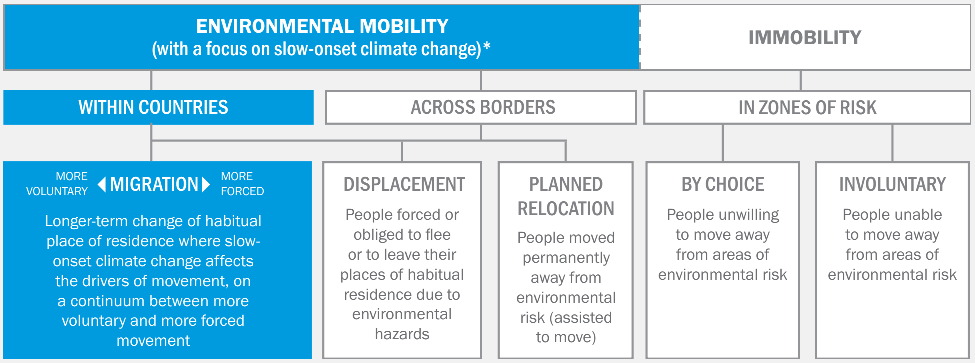
Understanding when, where, and how internal climate migration will unfold is critical for countries and communities to pursue the right policies and targeted action. Drivers of displacement in the region are part of a complex overlap of social, political, economic, and environmental factors, particularly slow-onset hazards such as drought, desertification, coastal erosion, and land degradation. Concrete climate and development action can reduce the scale of internal climate migration (Rigaud et al. 2018) and must be pursued to achieve sustained development outcomes in the face of a changing climate.

1.1 OBJECTIVE AND SCOPE

The objective of this report is to examine the potency of climate-induced migration in West Africa, with a focus on coastal countries, to inform policy makers and practitioners about the urgency for near- and farsighted planning, policy, and action as an integral part of the development response. This report is developed in support of the World Bank's West Africa Coastal Areas Management Program (WACA), which helps countries access expertise and financing to sustainably manage their coastal areas. Results will inform the policy dialogue and policy direction for West African governments.

This report also provides strategic policy responses to guide West African countries to better anticipate and prepare for the scale and effects of internal climate migration. While there is no universally agreed upon terminology for human movement in the context of environmental change (Dun and Gemenne 2008), the focus of this report is on internal climate migration (within countries) and uses terms depicted in figure 1.2. Overarching policies must embed climate risks and opportunities, as well as climate migration, into national and local development planning. Today's policy decisions will shape the extent to which the effects of climate change will be positive for migrants and their families, sending and receiving communities, and equitable national economic growth.

Figure 1.2 Human Mobility and Immobility Patterns



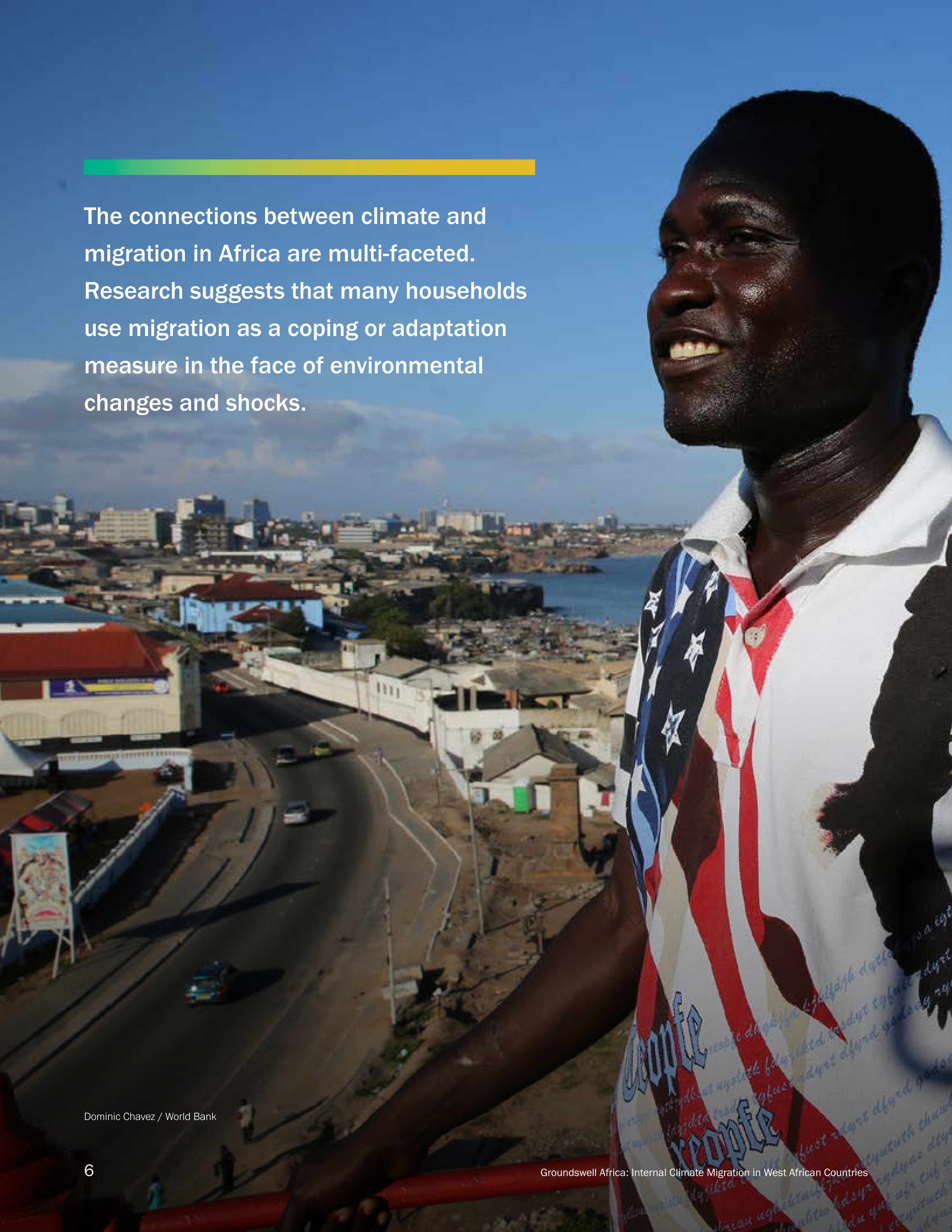
* This report uses an expanded model that also focuses on flood risk and non-climate variables (median age, sex ratio, and conflict-related fatalities).

Source: Expanded and adapted from Rigaud et al. 2018.

1.2 TARGET AUDIENCE AND OUTLINE OF REPORT

The report's analysis and recommendations speak to both high-level decision-makers and practitioners, including local actors on the front line of the movements that may be induced by climate and other factors. The work required across spatial and temporal scales—and the continuum of mobility forms and types—would be most effective if the development community worked with the humanitarian, security, and disaster response communities to address the climate-migration-development nexus as a continuum.

The report is organized as follows: chapter 2 sets out the development and demographic context and addresses the past, present, and future climate of West Africa and regional patterns of migration. It draws on research on environmental factors, including climate, that influence migration patterns. Chapter 3 describes the Groundswell methodology and enhancements applied in this study. Chapter 4 presents the climate impact modeling results and chapter 5, the modeling results on plausible future climate migration scenarios from 2020–50, with a focus on the climate migration trends and patterns for West Africa and countries of focus. Chapter 6 discusses core policy directions and key domains of action that can foster concrete climate and development action to mainstream climate migration into development planning. Chapter 7 provides country snapshots and modeling results and qualitative assessments for the West Africa Coastal Areas (WACA) focus countries. Additional details on modeling inputs and methods are found in appendixes A and B, and projections of climate impacts out to 2050–2100 are found in appendix C. Appendix D compares the results of this report with those of the 2018 Groundswell report.



The connections between climate and migration in Africa are multi-faceted. Research suggests that many households use migration as a coping or adaptation measure in the face of environmental changes and shocks.

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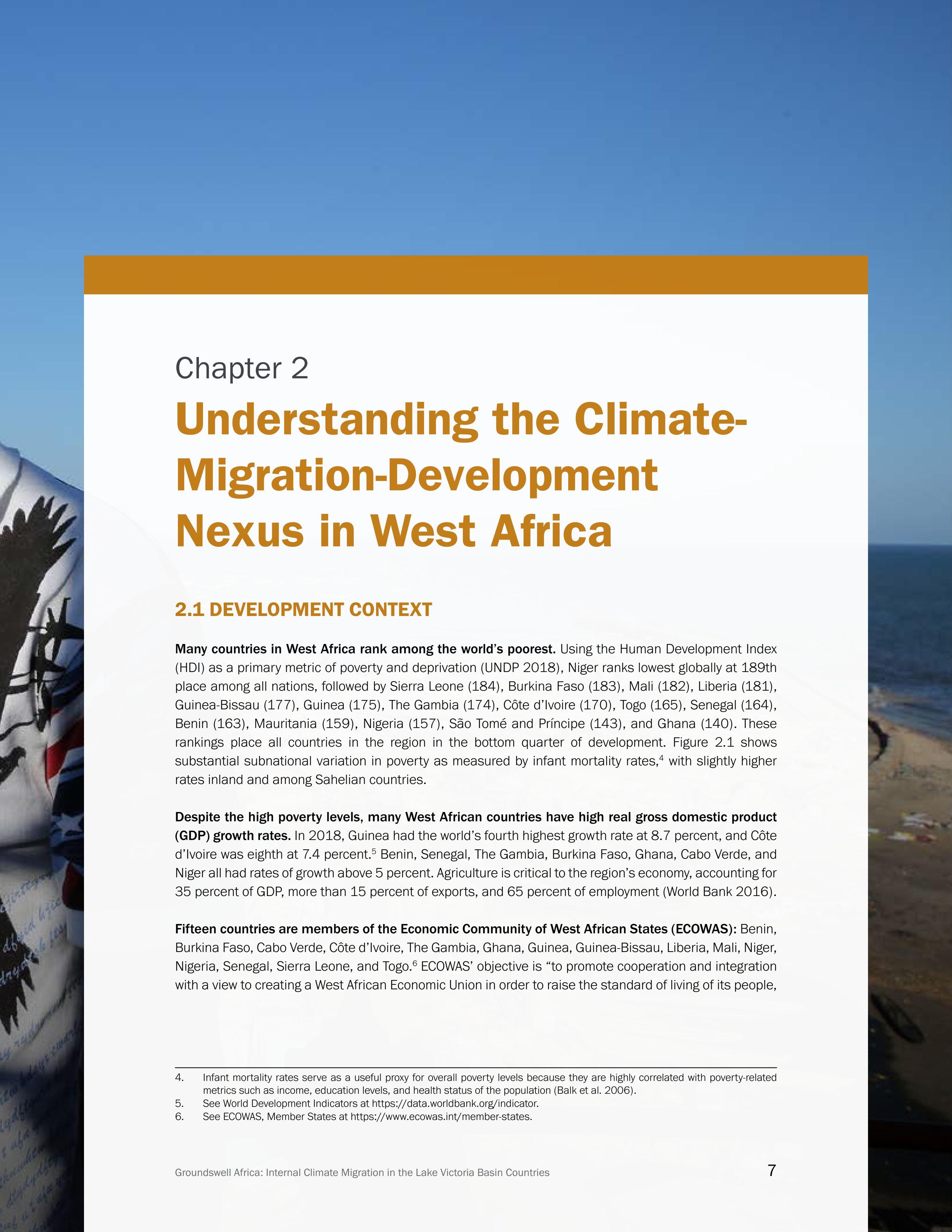

Chapter 2

Understanding the Climate-Migration-Development Nexus in West Africa

2.1 DEVELOPMENT CONTEXT

Many countries in West Africa rank among the world's poorest. Using the Human Development Index (HDI) as a primary metric of poverty and deprivation (UNDP 2018), Niger ranks lowest globally at 189th place among all nations, followed by Sierra Leone (184), Burkina Faso (183), Mali (182), Liberia (181), Guinea-Bissau (177), Guinea (175), The Gambia (174), Côte d'Ivoire (170), Togo (165), Senegal (164), Benin (163), Mauritania (159), Nigeria (157), São Tomé and Príncipe (143), and Ghana (140). These rankings place all countries in the region in the bottom quarter of development. Figure 2.1 shows substantial subnational variation in poverty as measured by infant mortality rates,[4] with slightly higher rates inland and among Sahelian countries.

Despite the high poverty levels, many West African countries have high real gross domestic product (GDP) growth rates. In 2018, Guinea had the world's fourth highest growth rate at 8.7 percent, and Côte d'Ivoire was eighth at 7.4 percent.[5] Benin, Senegal, The Gambia, Burkina Faso, Ghana, Cabo Verde, and Niger all had rates of growth above 5 percent. Agriculture is critical to the region's economy, accounting for 35 percent of GDP, more than 15 percent of exports, and 65 percent of employment (World Bank 2016).

Fifteen countries are members of the Economic Community of West African States (ECOWAS): Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.[6] ECOWAS' objective is "to promote cooperation and integration with a view to creating a West African Economic Union in order to raise the standard of living of its people,

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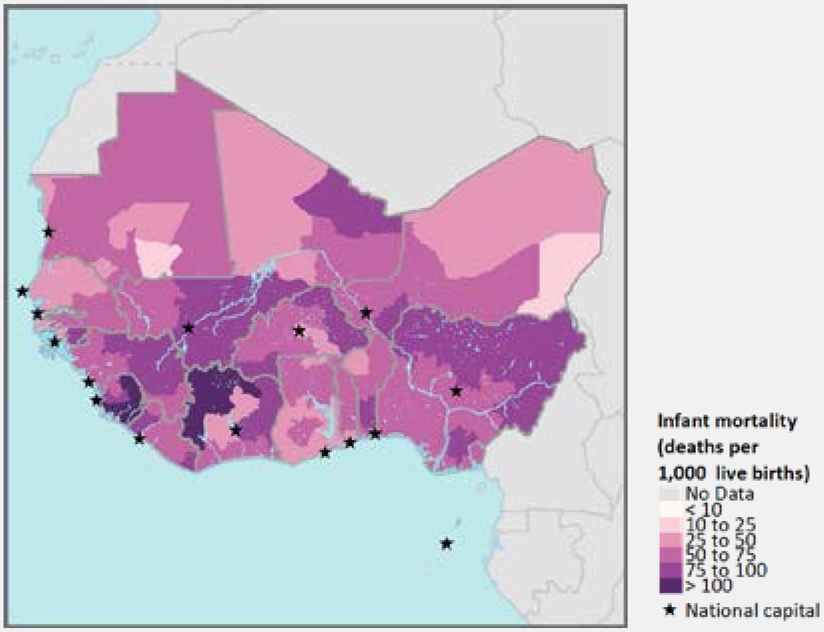
[4] Infant mortality rates serve as a useful proxy for overall poverty levels because they are highly correlated with poverty-related metrics such as income, education levels, and health status of the population (Balk et al. 2006).

[5] See World Development Indicators at https://data.worldbank.org/indicator.

[6] See ECOWAS, Member States at https://www.ecowas.int/member-states.

maintain and increase economic stability, strengthen relationships among member States and contribute to the progress and development of the continent" (Kuye and Shuping 2012). Within ECOWAS, the African Continental Free Trade Area (AfCFTA) agreement facilitates movement of persons to deepen the economic integration and prosperity of the African continent.

Figure 2.1 Infant Mortality Rates, West Africa, 2015



Source: CIESIN 2019.

2.2 CLIMATE OF WEST AFRICA

West Africa is composed of 17 countries extending over a total land and water area of approximately 7.9 million square kilometers.[7] Cabo Verde (not included in this study) and São Tomé and Príncipe are island archipelagos; Mali, Burkina Faso, and Niger are landlocked Sahelian countries; and Mauritania, Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, and Nigeria possess low-lying coastal zones and tidal ecosystems exposed to seaward hazards along the Atlantic Ocean and inland areas that experience floods and droughts.

The climate varies from a humid tropical zone in the southern part of the region to semiarid and arid zones in northern areas bordering the Sahara Desert (figure 2.2). Due to latitudinal rainfall patterns, the landscapes transition from tropical rainforest to tropical moist deciduous forest, tropical dry forest, tropical shrub land (or savannah), drylands, and desert with increasing northern latitude (FAO 2000).

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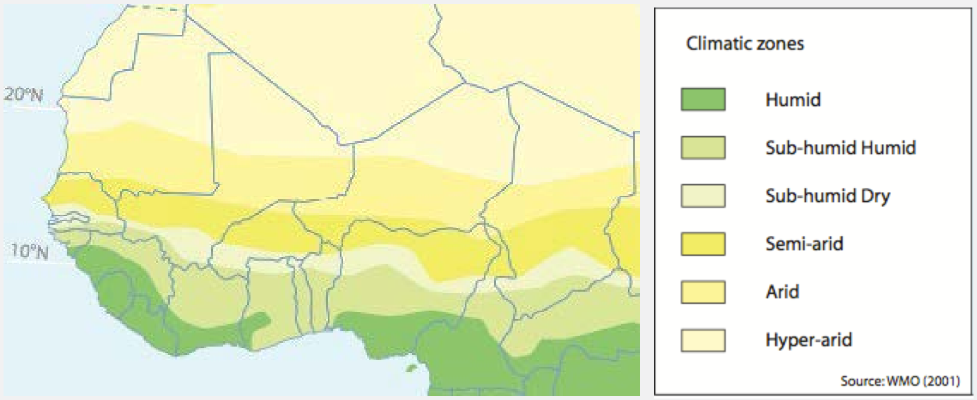
[7] The following two sections are updated and amended from CIESIN (2013a). Background Paper for the ARCC Regional Climate Change Vulnerability Assessment for West Africa. Produced for the USAID African and Latin American Resilience to Climate Change (ARCC) project.

Figure 2.2 Climatic Zones, West Africa



Source: Adapted from OECD 2008a, 7.

In the absence of significant mountain ranges and water bodies, rainfall and its seasonal shift are the main climate drivers in West Africa. The distribution of climatic zones and vegetation, and by extension cultivable areas, follows closely the distribution of annual total precipitation (figure 2.3a). This is characterized by a latitudinal gradient sharply decreasing from the southern coastal region, where precipitation exceeds 1,500 millimeters per year, toward the Sahara, where precipitation is lower than 50 millimeters per year. The highest precipitation levels are in more mountainous coastal regions: the Fouta Djallon in the southwest and the Cameroon line in the southeast. Water availability is the main limiting factor for rainfed agricultural and pastoral activities, especially in the drier areas.[8]

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[8] In the Sahel, 400–500 millimeters of rainfall per year usually mark the limit of areas suitable for agriculture.

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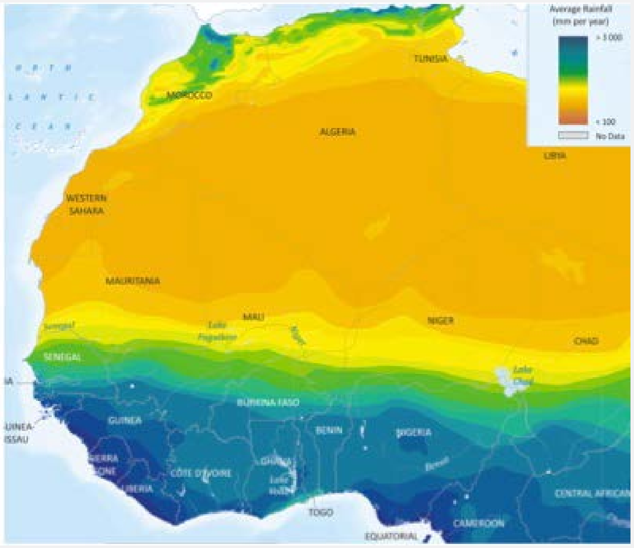
Figure 2.3a Average Annual Rainfall Totals, West Africa

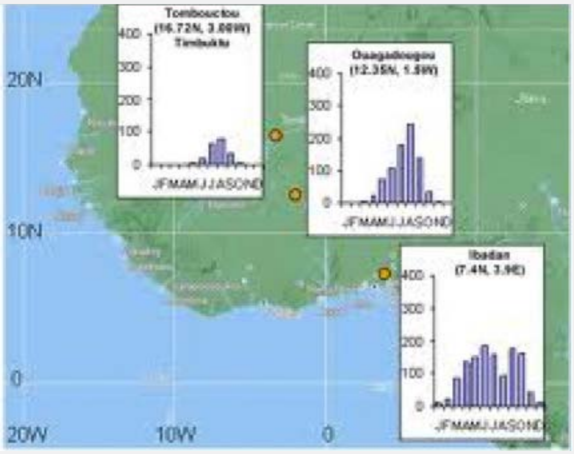


Source: UNEP/GRIS 2012.

Note: In millimeters per year.

Note: Cycles shown for Ibadan in southwestern Nigeria near the coast; Ouagadougou, Burkina Faso, in the Sahel; and Timbouctou, Mali, in the Sahelo-Saharan region.

Figure 2.3b Mean Seasonal Cycle, West Africa

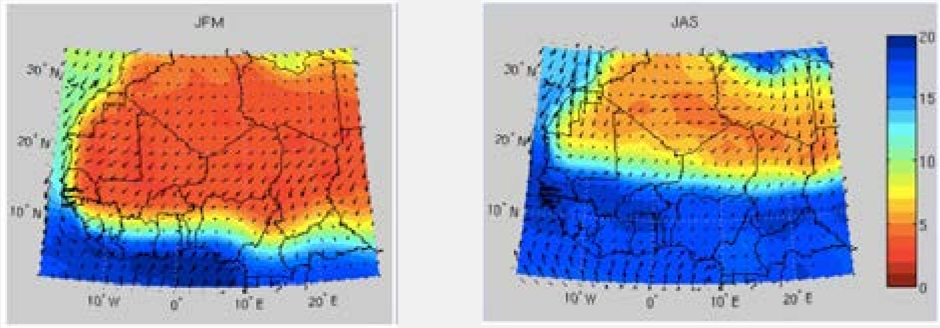


Source: Laing and Evans 2011.

Annual precipitation is higher in the coastal zone because of a longer rainy season. Further north, rain occurs only a few months in the year, centered on July through September (figure 2.3b). This seasonality is linked to the seasonal cycle of radiative heating of the Earth's surface that follows the sun's movement (reaching its northernmost location at the summer solstice) and drives low-level atmospheric circulation and the West African monsoon. As the sun moves north, the air overlaying the warmest regions rises and is replaced by air from neighboring regions to the north and south. Southern air is cooler and moister, fueling rainfall. The region of the uplift migrates northward and reaches its maximum northern location in August before retreating southward. This leads to contrasting wind and moisture patterns between the July-September and January-March seasons (figure 2.4, panels a and b) and a latitudinal migration of the rainbelt. When the rainbelt is in its northernmost location, precipitation lessens in the southern coastal region, referred to as the "little dry season." Thus, a distinction is made between the monomodal Sahel region (with one rainy season during July-September) and the bimodal coastal zone (with two main rainy seasons during April-June and September-November). This bimodal zone is not strictly confined to the coasts and extends several hundred kilometers inland, with a relatively narrow transition zone.

Figure 2.4 Climatology of Near Surface Wind and Atmospheric Moisture, West Africa

a. Average for January-February-March season b. Average for July-August-September season



Source: CIESIN 2018a with data from Kalnay et al. 1996.

Note: Wind shown by arrows. Shading depicts gram/kilogram.

The rainy season in the north generally starts abruptly, signaling the beginning of the farming season in the Sahel. The retreat of the rains to the coastal zone is more progressive. Even in the heart of the rainy season, rainfall occurs in events separated by several days of rainless conditions, or dry spells. The distribution of rainfall within the season generally has greater impacts on livelihoods than the overall seasonal total. The onset, cessation, and distribution of rainy days and dry spells show strong annual variations to which crop, livestock, and fisheries systems are generally well-adapted. However, depending on soil moisture conditions and plant development stages, long dry spells can have a strong negative impact on crops and their productivity. Prolonged dry spells after the first rains usually require resowing, shortening the crop growing season. In the Sahel, delayed rainfall onset or early retreat also shorten the growing season, reducing productivity, while delayed retreat often leads to floods and crop loss due to high humidity during the harvest and postharvest processing. Similarly, if the rainbelt is blocked in its northward progression, the coastal zone experiences flooding and crop loss due to excessive humidity.

Annual rainfall amounts vary strongly from year to year, and the relative departures from average precipitation can exceed 30 percent in some areas. The variations are usually consistent across very wide areas because they stem from variations in the West African monsoon dynamics. Dry years are characterized by weakening of the monsoon circulation thus reducing moisture advection. The latitude of the northernmost location of the rainbelt also varies from year to year. Variations in the strength of the West African monsoon and their impact on rainfall amounts are directly linked to global sea surface temperatures (Folland, Palmer, and Parker 1986; Giannini, Saravanan, and Chang 2003). Sea surface temperatures in the tropical Atlantic, south and north of the equator, are directly associated with the seasonal location of the Inter-Tropical Convergence Zone (ITCZ)—the main rainbelt over the oceans—and with the meridional land-sea thermal contrast that drives the monsoon (Servain 1991). El Niño–Southern Oscillation (ENSO) events[9] have been related to rainfall deficits in West Africa (Bader and Latif 2003; Giannini, Saravanan, and Chang 2003).

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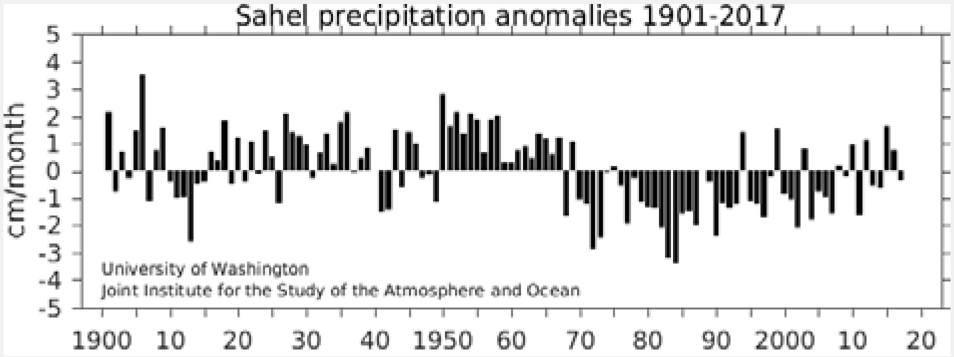
[9] ENSO, although occurring in the equatorial Pacific, affects rainfall and temperatures around the globe (Ropelewski and Halpert 1989). It affects the West African monsoon by modifying sea surface temperatures in the equatorial Atlantic and the strength of the monsoon.

2.3 CLIMATE TRENDS IN WEST AFRICA

West Africa is a hotspot of current and future climate impacts (Muller et al. 2014; Niang et al. 2014; Turco et al. 2015). The major impacts identified in the literature include rising temperatures, heat waves, erratic rainfall (delays in monsoon onset or dry periods during the rainy season), increasingly intense rainfall events, flooding, and coastal erosion because of heightened storms and sea level rise. These trends are exacerbated by a degraded natural resource base because of rising population densities sustained by low-input agriculture.

The Sahel has had a series of widespread droughts with extreme impacts on food security and humanitarian crises leading to displacement and migration. The analysis of long-term rainfall time series over the Sahel (figure 2.5) shows the interannual persistence of dry conditions starting in the late 1960s and lasting until the 2000s, while the previous 50 years (roughly 1920 to 1968) were much wetter. These oscillations, which occur in roughly 10-year increments, are referred to as “decadal variability.” The coastal zone has not had persistent dry conditions to the same degree, and a similar analysis shows a stronger interannual variability there, although a long-term decline is noticeable.

Figure 2.5 Long-Term Evolution of Seasonal Rainfall in the Sahel, 1900–2017



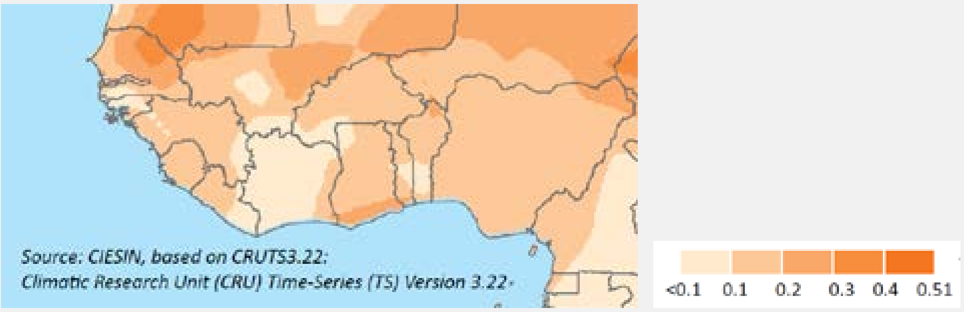
Source: Joint Institute for the Study of the Atmosphere and Ocean (JISAO), Sahel Rainfall Index, doi:10.6069/H5MW2F2Q.

Note: Bars represent rainfall averaged over June to October seasons (in centimeters/month) over the area 10o–20oN, 20oW–10oE.

Early claims that the great Sahelian droughts were initially attributed to the local changes in vegetation and land use and their subsequent feedback on monsoon dynamics (Charney, Stone, and Quirk 1975) have been disputed and laid to rest. Local change mechanisms cannot explain sporadic increases in rainfall during the dry epoch or a more recent return of rainfall to more average conditions. Thus, the early claims that declining precipitation in the region was due to land surface feedback because of land degradation from population pressures have largely been discarded (Kandji, Verchot, and Mackensen 2006). Research since the 1990s has demonstrably shown that the source of this decadal variability lies in the decadal variability of global sea surface temperatures (Janicot, Trzaska, and Poccard 2001), with a potential impact of the Indian Ocean (Bader and Latif 2003), and vegetation feedback plays only a secondary role (Zeng et al. 1999). Seasonal rainfall amounts have partially recovered since the major droughts of the 1980s, but rainy season characteristics have changed: rainfall is more intense and intermittent and wetting is concentrated in the late rainy season and away from the west coast (Biasutti 2019).

The existence of decadal variability in the Sahel—and to a lesser extent in the coastal region—masks potential longer-term temperature and rainfall trends in West Africa. The drier years of the droughts in the 1970s and 1980s have tended to be hotter than average. Further, temperature levels recorded over the past 20 years are only slightly higher than the temperatures recorded in the 1920s and 1930s. Further monitoring of temperatures is needed to assess the impact of anthropogenic climate change. All of West Africa has experienced temperature increases, and northeastern Senegal and southern Mauritania, eastern Mali, northern Benin, and coastal Ghana have experienced higher temperature changes of up to 1.5°C to 2.0°C from 1950 to 2013 (figure 2.6). According to research by Turco et al. (2015), regional climatic changes—including changes in temperature (trends and extremes), precipitation (total and variation) since 1950 to 1981—have been extreme enough to qualify West Africa as one of a handful of globally observed climate change hotspots.

Figure 2.6 Temperature Change in Degrees Celsius per Decade in West Africa from 1951–2013



Source: CIESIN, based on CRUTS3.22:
Climatic Research Unit (CRU) Time-Series (TS) Version 3.22

Source: Zomers et al. 2016.

Note: Temperatures recorded in degrees Celsius.

Whether changes are due to anthropogenic warming or natural variability is still debated, and several modeling studies have attempted to discriminate between these factors in the Sahel. Some studies attribute the multidecadal drying of the Sahel to changes in atmospheric composition (Biasutti and Giannini 2006). Others show that only 10 percent of the Sahelian drying in the 20th century was attributable to anthropogenic climate change and global warming, and that long-term variations in sea surface temperatures are significantly more influential (Mohino, Janicot, and Bader 2011). Most studies highlight the current difficulty in robustly attributing and quantifying the role of competing influences over the region (Caminade and Terray 2010; Ting et al. 2009).

There is high confidence that warming will continue (Knutti and Sedlacek 2013). Temperature projections over West Africa for the end of the 21st century from global climate simulation range between 3°C and 6°C above the late 20th century baseline, depending on the emission scenario (Niang et al. 2014; Riede et al. 2016), and the increase is projected to be higher in the Sahelian than in the coastal region. This will have significant impacts on water availability and crop production, because higher temperatures drive higher rates of evapotranspiration no matter what the future trends in rainfall are. Temperature extremes alter the optimal growing conditions of a plant and negatively affect plant reproduction, resulting in reduced yields (Battisti and Naylor 2009). Further, temperature is more difficult to control than soil moisture, which can be altered through irrigation (Dillon, Mueller, and Salau 2011). By 2050, it is expected that 70 percent to 90 percent of summer average temperatures in West Africa will exceed the highest summer temperature observed on record (Battisti and Naylor 2009).

Multimodel means from the Coupled Model Intercomparison Project phase 5 (CMIP5) archive suggest a drying in the coastal portions of West Africa and wetting in the eastern Sahel for the rainy season.[10] But the models generally do not agree, so results are not considered robust (Knutti and Sedlacek 2013). For the Sahel region, climate projections show a slight increase of total precipitation and a longer rainy season with a drier phase within (Riede et al. 2016). Yet capturing the West African monsoon remains a challenge to climate modeling groups. Most models do not produce sufficient precipitation across the

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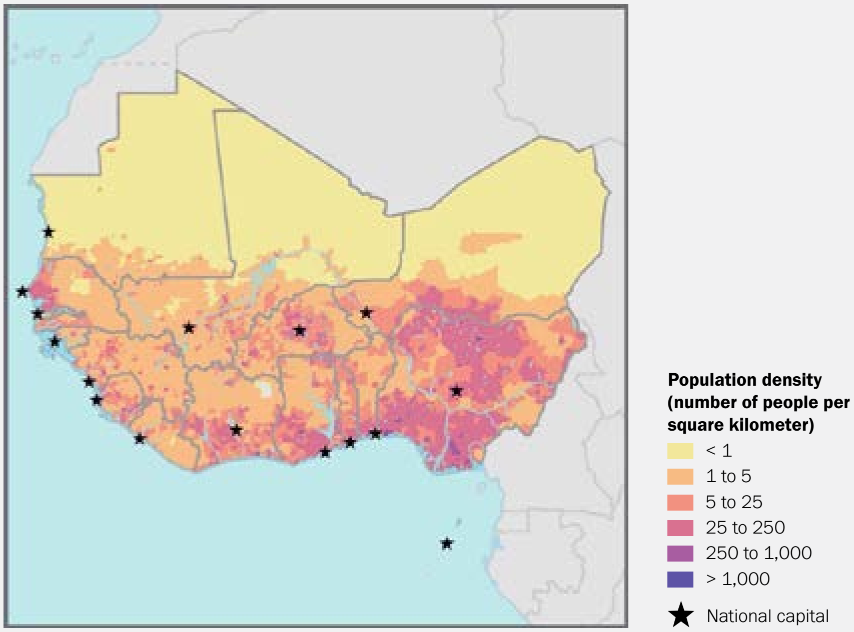
[10] As will be seen in the methods section (Chapter 3), the climate models upon which this migration modeling work is built adhere to this pattern, with consistent drying in Senegal and western Mali, and relatively consistent patterns of drying along the coastal zone from Côte d'Ivoire to Benin, in some cases stretching all the way to the northern border of these countries.

Sahel in summer (Biasutti et al. 2008), even though they tend to overestimate the length of Sahelian rainy season—starting the monsoon too early and extending it too late (Biasutti and Sobel 2009). They also fail to reproduce the fast shift between the coastal and the Sahelian locations of the rainbelt. Several important features of the monsoon are not well-represented, mostly due to the coarse resolution of the models. Regional models seem to simulate a more realistic West African monsoon although they still exhibit large biases in the extent and timing of the rainfall (Druyan et al. 2010). In addition, observed climate variability in West Africa is only partially reproduced by the models. Variations among the onset, cessation, and length of the season are underestimated, and a very high variation exists among the models. It is difficult to narrow the selection of models to use in deriving the projections because the models that produce the best mean state (that is, average precipitation) may inadequately represent the variability, and vice versa. Biasutti and Giannini (2006) also show that the models that correctly capture long-term evolution of Sahelian rainfall in the 20th century might project strong but opposite evolutions for the end of 21st century. That said, while uncertainty in future projections remains, overall rainfall depends on large-scale drivers of atmospheric circulations that are well-resolved by current climate models (Biasutti 2019).

2.4 POPULATION DYNAMICS

According to the UN World Population Prospects median variant, the 2019 population of West Africa is estimated at 392.2 million (UN DESA 2017), which is projected to more than double by 2050. The region's population distribution is heavily concentrated along the coast, particularly in southern Nigeria, but with areas of high density surrounding the inland capitals of Bamako, Ouagadougou, and Niamey as well as Kano in northern Nigeria (figure 2.7). While the region has seen improvements in recent decades, life expectancy is still relatively low, and infant mortality rates remain among the world's highest: in many (particularly inland) areas the rates range well above 75 deaths per 1,000 live births.

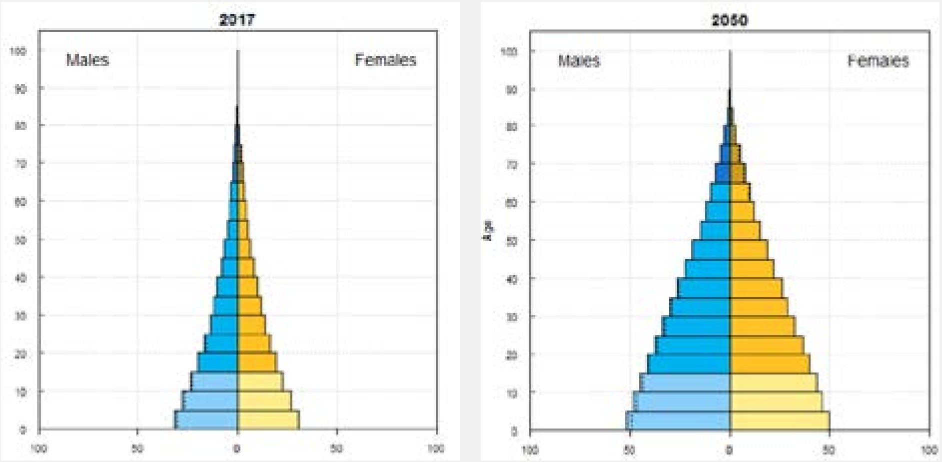
Figure 2.7 Population Density, West Africa, 2015



Source: Adapted from CIESIN 2018b.

Even if the fertility rate were to drop to replacement levels immediately—reducing the current total fertility rate from 5.2 to 2.1 children per woman—West Africa's population would grow for several decades because of the large share of young people (figure 2.8, panels a and b). UN medium variant population projections suggest that by 2050, West Africa may have between 736 million (low variant) and 887 million (high variant), with a medium variant population of 810 million (UN DESA 2017).[11] The high proportion of people under 18 creates future challenges for labor markets and economic stability, particularly if continued population growth cannot be absorbed in either agriculture or nonagricultural sectors. Given existing pressure on land resources, it is unlikely that future productivity gains in agriculture will be able to absorb such a rapidly growing population. Population growth is likely to exert enormous pressure on the region's natural resources and institutions. Massive investments in services are necessary to boost economic growth, including infrastructure, housing, and food production.

Figure 2.8 Projected Population Age Structure by Gender, West Africa, 2017 and 2050



a. Population, 2017

b. Projected population, 2050

Population (millions)

Population (millions)

Source: UN DESA 2017

2.5 MIGRATION TRENDS

West Africa has historically been a highly mobile region featuring trans-Saharan trade links, nomadic pastoralism, movements of fisherfolk in the coastal zone, forced labor migration by colonial authorities, and seasonal movements from inland to the coasts to ensure livelihoods in the face of a variable climate. Postcolonial policy has officially recognized and encouraged this mobility. In May 1979, ECOWAS member states adopted their first protocol relating to the Free Movement of Persons, Residence and Establishment.[12] It stipulates the right of ECOWAS citizens to enter, reside, and establish economic activities in the territories of other member states and offers a three-step roadmap of five years each to achieve freedom of movement of persons after 15 years. This has greatly facilitated regional migration.

Rural to urban migration increased significantly during the postcolonial period, particularly in response to the droughts of the 1970s and 1980s. The concentration of jobs, services, and educational opportunities in cities have made them powerful magnets, particularly for the region's youth. According to the World Urbanization Prospects, regional urban growth rates since 2000 have averaged from 4.1

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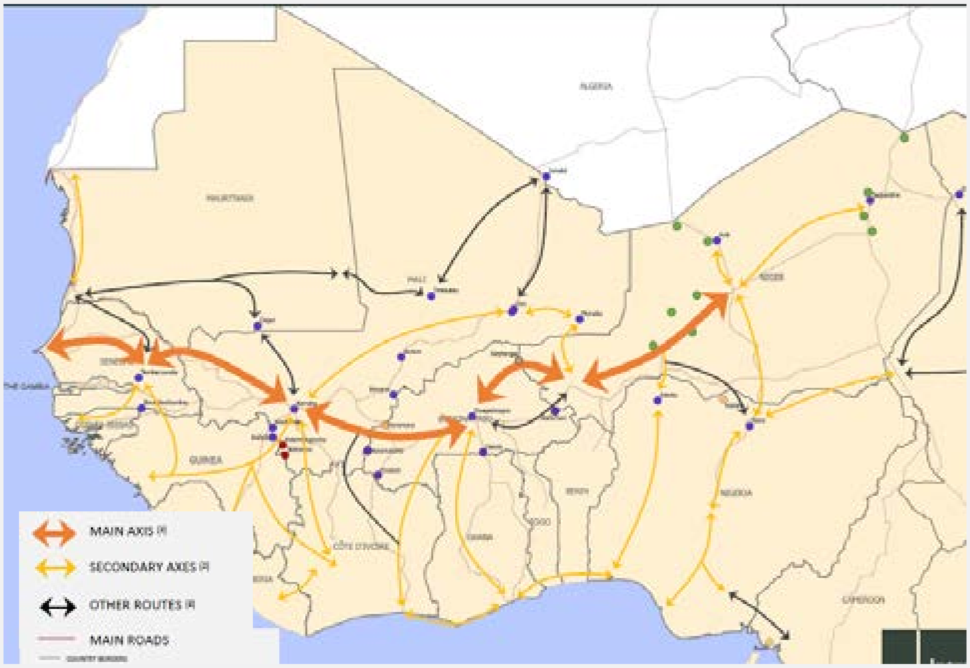
[11] The UN high variant projection is for 887 million people. Note that the population projections for this modeling work were developed by IIASA for the Shared Socioeconomic Pathways (SSPs). The low scenario is under SSP2, which projects a total population of 675.9 million, whereas the high scenario is under SSP4, which projects a population of 788.9 million. Both projections are well below the medium and high variants of the UN World Population Prospects (UN DESA 2017).

[12] See ECOWAS, Free Movement of Persons, at https://archive.uneca.org/pages/ecowas-free-movement-persons.

percent to 4.4 percent, whereas rural growth rates have hovered around 1.5 percent to 1.6 percent.[13] The highest rates of urbanization are in Burkina Faso and Mali, with urbanization rates of between 5 percent and 6 percent per five-year increment over the past 20 years. A rate of 6 percent or above implies a doubling of population almost every decade. Moriconi-Ebrard, Harre, and Heinrigs (2016) highlight the importance of small- and medium-sized agglomerations and the emergence of new urban agglomerations through in situ urbanization, a key characteristic in West Africa. Rapid population growth alone, quite apart from migration, can contribute to these phenomena, but other factors include decentralization policies and colonial and even precolonial legacies. Merging of villages into larger agglomerations challenges some urban definitions, since apart from high continued population density the combined villages do not have other characteristics of typical cities.

Most mobility remains within countries in the region (figure 2.9). In terms of migrant stocks, the International Organization for Migration Displacement Tracking Matrix (IOM-DTM)(2020) reports that Côte d'Ivoire has the largest foreign-born population (1.4 million), followed by Nigeria (0.7 million), Burkina Faso (0.3 million), Ghana, Togo, and Mali (around 0.25 million each), followed by Senegal (146,000) and Mauritania (98,000). In terms of migrant flows, from 2005 to 2010, 96 percent of in-migration to all West African countries was from other countries in the region (Abel and Sander 2014). The country with the largest share of sending and receiving is Nigeria, which also has the largest population: about 50 percent of the region's total population (PRB 2018).

Figure 2.9 Intraregional Migration Routes, West Africa, January 2020



Source: IOM-DTM 2020.

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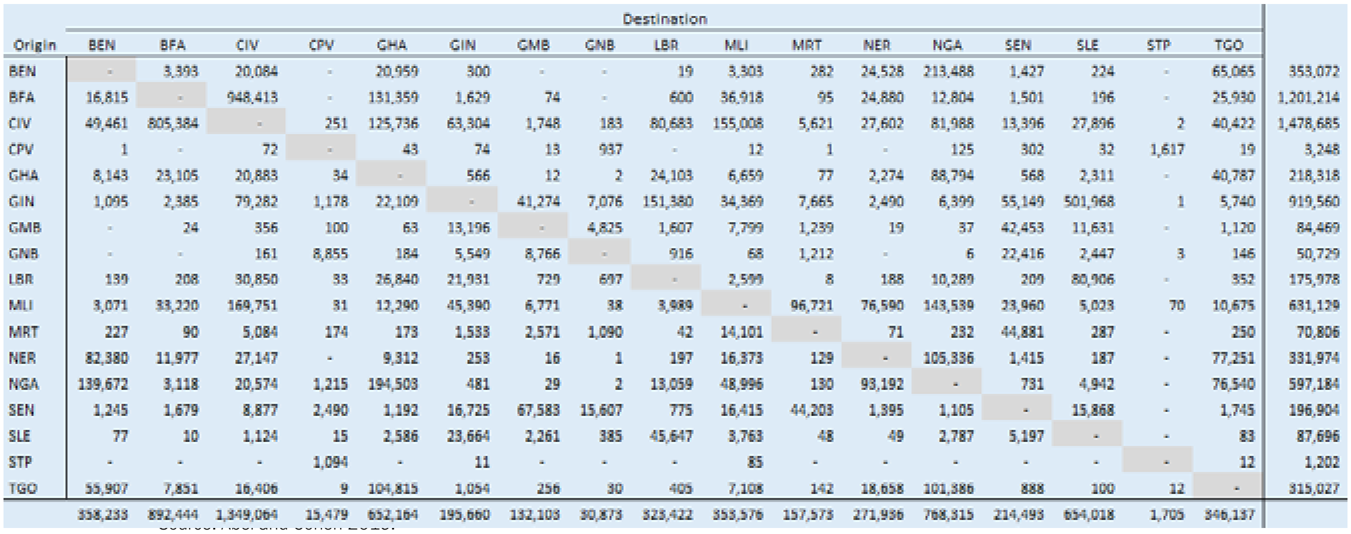
13. See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Urbanization Prospects 2018 at https://population.un.org/wup.

Data compiled by Abel and Cohen (2019) show that several other countries have disproportionate shares of total migratory movements to other countries in the region from 2000 to 2015, including Burkina Faso (1.2 million out-migrants), Côte d'Ivoire (1.5 million out-migrants), and Guinea (0.9 million out-migrants) (table 2.1). Others are disproportionate recipients, once again including Côte d'Ivoire (1.4 million in-migrants), Nigeria (0.8 million in-migrants), and Ghana (0.6 million in-migrants).[14] There are strong neighborhood effects as well: countries with shared borders have among the highest bilateral flows.

Table 2.1 Migration Matrix for West Africa, 2000–15



	Destination																
Origin	BEN	BFA	CIV	CPV	GHA	GIN	GMB	GNB	LBR	MLI	MRT	NER	NGA	SEN	SLE	STP	TGO	
BEN	-	3,393	20,084	-	20,959	300	-	-	19	3,303	282	24,528	213,488	1,427	224	-	65,065	353,072
BFA	16,815	-	948,413	-	131,359	1,629	74	-	600	36,918	95	24,880	12,804	1,501	196	-	25,930	1,201,214
CIV	49,461	805,384	-	251	125,736	63,304	1,748	183	80,683	155,008	5,621	27,602	81,988	13,396	27,896	2	40,422	1,478,685
CPV	1	-	72	-	43	74	13	937	-	12	1	-	125	302	32	1,617	19	3,248
GHA	8,143	23,105	20,883	34	-	566	12	2	24,103	6,659	77	2,274	88,794	568	2,311	-	40,787	218,318
GIN	1,095	2,385	79,282	1,178	22,109	-	41,274	7,076	151,380	34,369	7,665	2,490	6,399	55,149	501,968	1	5,740	919,560
GMB	-	24	356	100	63	13,196	-	4,825	1,607	7,799	1,239	19	37	42,453	11,631	-	1,120	84,469
GNB	-	-	161	8,855	184	5,549	8,766	-	916	68	1,212	-	6	22,416	2,447	3	146	50,729
LBR	139	208	30,850	33	26,840	21,931	729	697	-	2,599	8	188	10,289	209	80,906	-	352	175,978
MLI	3,071	33,220	169,751	31	12,290	45,390	6,771	38	3,989	-	96,721	76,590	143,539	23,960	5,023	70	10,675	631,129
MRT	227	90	5,084	174	173	1,533	2,571	1,090	42	14,101	-	71	232	44,881	287	-	250	70,806
NER	82,380	11,977	27,147	-	9,312	253	16	1	197	16,373	129	-	105,336	1,415	187	-	77,251	331,974
NGA	139,672	3,118	20,574	1,215	194,503	481	29	2	13,059	48,996	130	93,192	-	731	4,942	-	76,540	597,184
SEN	1,245	1,679	8,877	2,490	1,192	16,725	67,583	15,607	775	16,415	44,203	1,395	1,105	-	15,868	-	1,745	196,904
SLE	77	10	1,124	15	2,586	23,664	2,261	385	45,647	3,763	48	49	2,787	5,197	-	-	83	87,696
STP	-	-	-	1,094	-	11	-	-	-	85	-	-	-	-	-	-	12	1,202
TGO	55,907	7,851	16,406	9	104,815	1,054	256	30	405	7,108	142	18,658	101,386	888	100	12	-	315,027
	358,233	892,444	1,349,064	15,479	652,164	195,660	132,103	30,873	323,422	353,576	157,573	271,936	768,315	214,493	654,018	1,705	346,137	

Source: Abel and Cohen 2019.

Note: Benin, Burkina Faso, Cote d'Ivoire, Cabo Verde, Ghana, Guinea, The Gambia, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sao Tome And Principe, Togo

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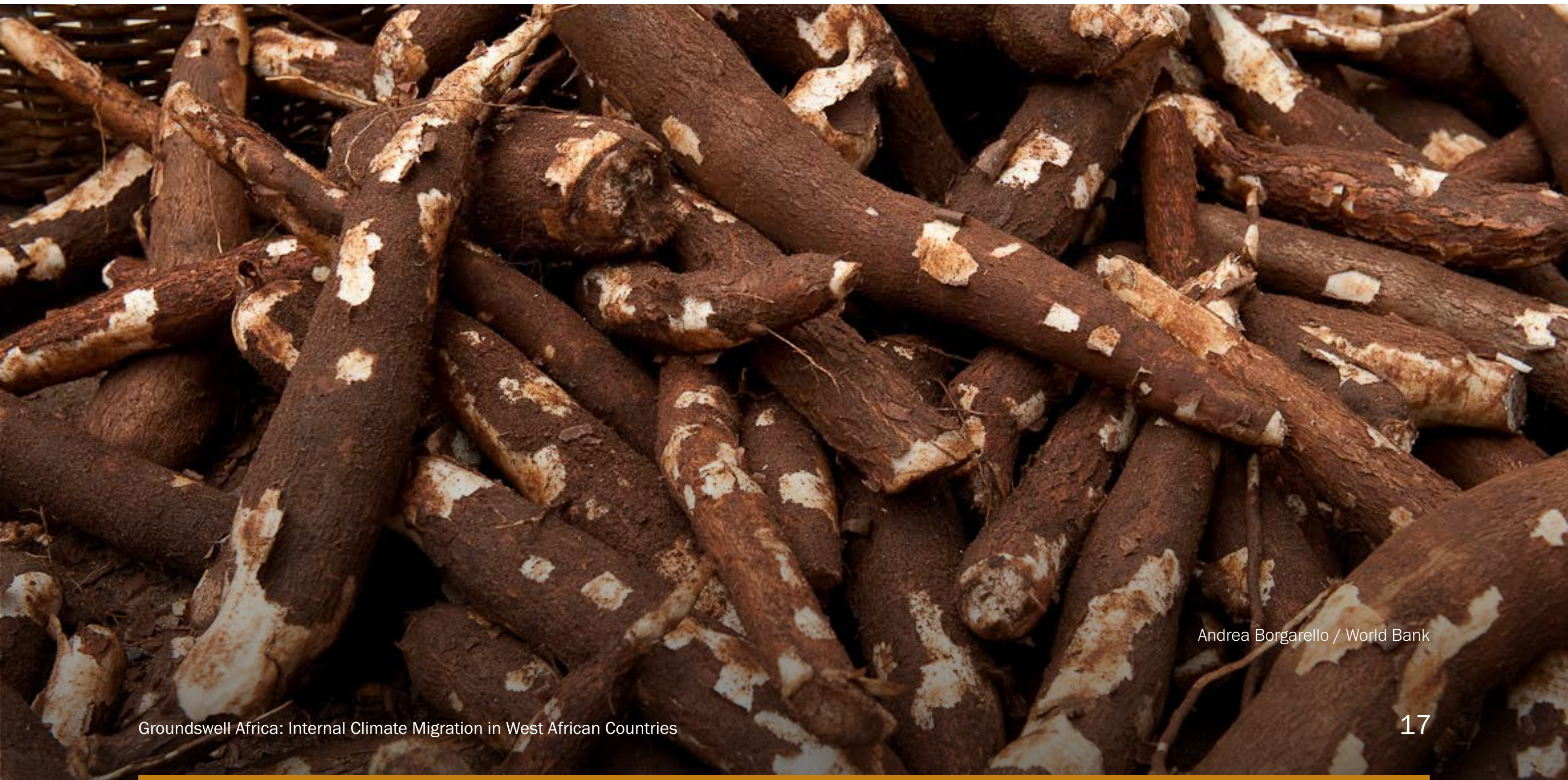
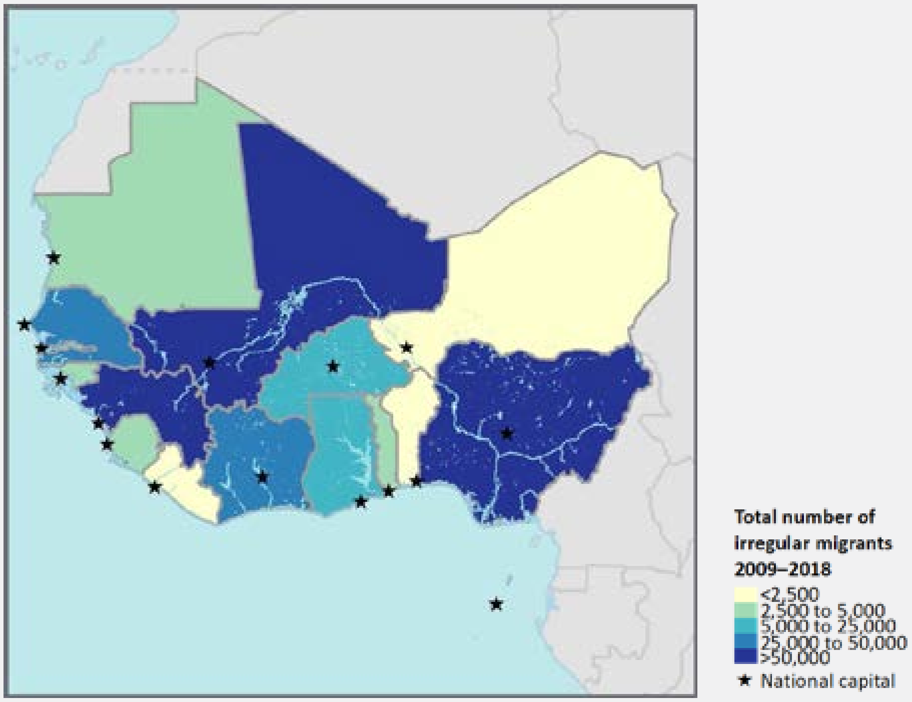
[14] The migration data challenges in the region are evident. Abel and Cohen (2019) measure flows over a 15-year period and not stocks, but it is clear that the numbers on stocks produced by IOM-DTM (2020) are not consistent with these flow numbers. Generally, the flow numbers are much higher.



Andrea Borgarello / World Bank

In recent years, international migration levels from West Africa to more developed regions, particularly Europe and North America, have grown. The precise reasons for this growth are complex. Migrant interviews reveal poor economic prospects in countries of origin, demographic pressures on land, a culture of migration, the collapse of Libya (which has created a lawless "southern border" to the European Union), conflicts in Mali and Nigeria, and the prospects of making it economically in Europe (Crawley et al. 2016). Figure 2.10 shows a map of the total irregular migration flows from origin countries toward Europe over the period 2009–18 using Frontex data. Nigeria, Senegal, Mali, Guinea, Côte d'Ivoire, and Ghana have high levels of irregular migration to Europe.

Figure 2.10 Estimated Number of Irregular Migrants to Europe per Origin Country, West Africa, 2009–18



Source: Frontex data.

2.5.1 Environmental Migration

West Africa has high levels of internal and intraregional migration because of a history of seasonal and longer-term migration as a livelihood strategy (Bruning and Piguet 2018; Tacoli 2011), especially between the semiarid Sahel region and the tropical coastal countries to the south. The long history of migratory movements—short term, circular, seasonal, and longer term—has affected the culture in significant ways, such that some speak of a "migratory culture" and migration as a "rite of passage" for young men (Bruning and Piguet 2018; Romankiewicz and Dovenspeck 2015). Yet, these same authors note that environmental, social, and economic changes are affecting long-standing cultural norms. Disentangling which factors are most important gets to the crux of contemporary research on environmental migration. Culturally embedded understandings and perceptions of the changes may be more important than the objective changes themselves (de Longueville et al. 2020; Romankiewicz and Dovenspeck 2015).

Research on drylands adaptation strategies in Africa suggests that households use migration as one option among coping or adaptation measures in the face of environmental changes and shocks, but it is generally not the most important (Wiederkehr et al. 2018). Crop, livestock, soil, and water management are by far the most common; migration, livelihood diversification, food aid, social networks, and religious activities are also widely used. Job seeking and livelihood diversification influence migrant decision-making in the Sahel (Neumann and Hermans 2017), but research has found that these decisions are influenced by climate change and variability that affect livelihoods (van der Land, Romankiewwicz, and van der Geest 2018). Climate, land scarcity, and degradation operate indirectly on economic factors (for example, through variable and declining crop yields), which affect food availability and incomes at the household level.

Connections between climate and migration are complex (Borderon et al. 2018). The costs and risks associated with migration as an adaptation strategy are behind this complexity. Hardship from crop failure may increase the appeal of migration but reduce the resources needed to migrate. Conversely, improved livelihoods, such as after good crop yields, may provide sufficient resources to enable a family member to migrate and further diversify and ensure future family incomes. Consequently, relations between climate factors and migration are complex.

In a study of the 1983–85 drought in Mali that severely stressed families, Findley et al. (1994) find that short-distance, seasonal movements of people increased, but costly international migration rates dropped. Using data from a long-term demographic observatory in the Niakhar District of Senegal, Lalou and Delauney (2017) find that temporary migration, especially among men, has a fairly strong sensitivity to climatic variations. They note, however, that internal migratory movements from the peanut basin have long been linked with high population density and environmental shocks, and long-term migration is still relatively rare. In a panel study from 1981–2009 in two villages in eastern Mali, Grace et al. (2018) find that a decrease in rainfall does not directly lead to a higher out-migration, but they posit that in areas of circular seasonal migration, drought may induce more people to stay put. They hypothesize that resources may be too scarce to migrate, and that local migration destinations would be similarly drought affected, providing fewer work opportunities. Romankiewicz and Dovenspeck (2015) use multilevel ethnographic approaches to examine environmental migration in northern Senegal and eastern Mali, finding that local meanings and perceptions of environmental change are important for understanding migration motivations. They observe that increases in rainfall do not automatically lead to better crop yields, since other factors intervene, including its distribution within the rainy season and access to inputs (seeds, pesticides, and fertilizer), decreasing soil fertility, insufficient cropland and equipment, and lack of labor.[15]

Using available census data for ten countries in Sub-Saharan Africa (four of which are in West Africa), Garcia et al. (2015) find that climatic variables have only a limited impact on migration, but with strong heterogeneity across sample countries. In Burkina Faso, Gray and Wise (2016) observe that rising temperatures (associated with declining crop yields) correlate with lower migration, both domestic and international, suggesting reduced resources to migrate. In contrast, lower levels of precipitation seem to positively affect international migration. Also in Burkina Faso, a nationally representative retrospective study on rainfall and migration conducted from 2000 to 2002 (Henry, Schoumaker, and Beauchemin 2004) finds that people from drier northern regions are more likely to migrate temporarily and to a lesser extent permanently to other rural areas (rural to rural migration) compared with people from wetter areas. Rainfall deficits increase rural to rural migration but decrease international migration, with no changes in urban to rural migration (in contrast to findings of Gray and Wise [2016]). Other evidence from northern Burkina Faso suggests that recent droughts have led pastoralists in the Sahel Province to either abandon livestock raising and move west or to urban centers, or to move herds to more vegetation-abundant, low-lying areas, resulting in the degradation of the few fertile areas left (Traoré and Owiyo 2013). Consistent with Wiederkehr, Beckmann, and Hermans (2018), migrating is mentioned as an adaptation strategy by 41 percent of households facing drought, behind modifying food consumption (87 percent), selling property (79 percent), spending less money (73 percent), and receiving support (51 percent). Dillon, Mueller, and Salau (2011) find that higher temperatures are associated with increased migration in northern Nigeria, positing that such temperature increases reduce agricultural yields.

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15. Note that the crop modeling used in this study considers a number of these factors, and thus is not merely reflecting changes in rainfall.

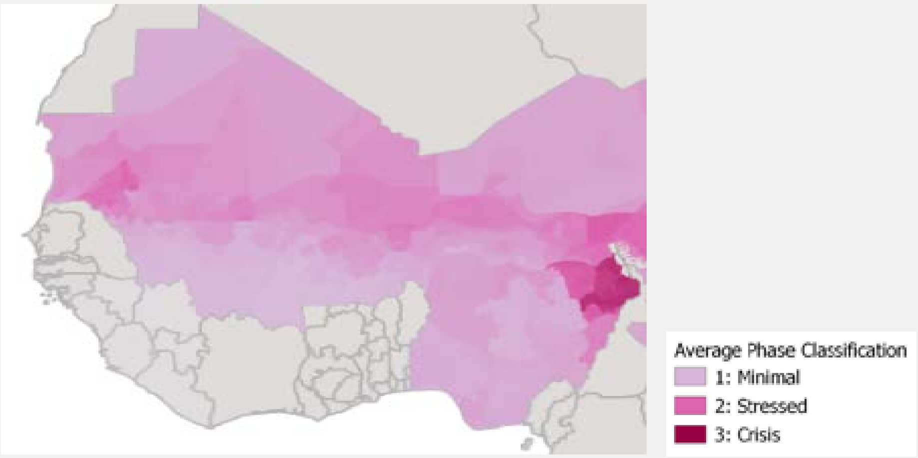
According to Hunter (2016), "gender—as a central axis of differentiation within socio-cultural structures—shapes individual experiences with mobility, including the likelihood of not moving," and gender differentials in migration propensities can be significant. In West Africa, women are more likely to move for family reasons, while men are more likely to migrate for economic reasons (Henry et al. 2004), and the propensity among females to migrate declines significantly after marriageable age (Grace et al. 2018). Men have a higher propensity to leave rural areas for cities and other rural areas than females, including for reasons of climate stresses (Henry et al. 2004, Kniveton, Smith, and Black 2012; Ribot, Faye, and Turner 2020). Gender differentials in migration in West Africa are reflected in the sex ratios for urban and rural areas, which are generally high (more males than females) in urban areas, and low (more females than males) in rural areas of the region.

Recent systematic reviews (Borderon et al. 2018; Bruning and Piguet 2018; Van der Land et al. 2018; Wiederkehr, Beckmann, and Hermans 2018) show little consensus on the importance of climate variables as drivers of migration because of a diversity of methods employed, differences in local contexts, and hypotheses. Part of the reason conclusions differ is that there are often radically different theoretical framings between quantitative analyses and anthropological approaches. Anthropologists and others adopting a political ecology perspective critique quantitative approaches based on secondary data analysis insufficiently aware of local contexts (power dynamics, market access, culture, local perceptions of the "environment") and are overly willing to ascribe causality to climate factors (Hochleithner and Exner 2018; Ribot, Faye, and Turner 2020; Romankiewicz and Dovenspeck 2015). Quantitative approaches are sometimes accused of "climate determinism," but this moniker may be an oversimplification. This is because both camps agree that climate factors do not operate in isolation but work through existing migratory systems and the economic and social factors that are the proximate determinants of migration (Bruning and Piguet 2018; GoUK 2011). Very few studies argue that climate factors are among the preeminent drivers.

Recent studies are limited because they do not address future impacts of climate change, which are likely to be significant in the Sahel. New et al. (2011) report on the potential for "high end" climate change (more than 4°C this century) to affect resources and society in ways that might trigger migration and displacement. They find that five West African countries (Senegal, Guinea, The Gambia, Sierra Leone, and Mauritania) are at risk of multiple impacts affecting water supplies, agriculture, and coastal zones (because of sea level rise), which place them in the top 30 of such countries around the world. White (2011) suggests that if the Sahel tips toward a "greener" and moister state, migration, if correlated with drying, could actually decline. Kniveton, Smith, and Black (2012) conducted agent-based modeling for Burkina Faso based on multiple population change and migration scenarios. Their report finds that most of the scenarios show that the percentage of people migrating (from the original population) declines because of a "wetting rainfall trend" in the ensemble scenarios, but that drier scenarios produce enhanced migration. They find that with increasing levels of projected population growth, the climate change signal is enhanced, producing more migration. This interaction between population growth and climate impacts could be very important in West Africa.

Whatever the average rainfall trends for the Sahel, the number of extreme events is likely to increase, including both floods and droughts (IPCC 2012; Niang et al. 2014; Warner et al. 2012). The UK Government's Foresight project on migration and environmental change finds that under two scenarios of future climate and economic change there is a substantial risk of increased population displacement from river flooding in the region, along with displacement from sea level rise and flooding in the coastal zone (GoUK 2011). Drought risks remain a significant threat to the region, as evidenced by recurring droughts and associated food insecurity in the region (figure 2.11), and will likely drive displacement unless adaptive responses are developed. Cervigni et al. (2016) find that the number of vulnerable people in drylands in Niger will more than triple between now and 2030, and will more than double in Liberia, Senegal, and Togo. A new World Bank Study "Ebb and Flow: Water, Migration and Development" (Borgomeo et al. 2021; Zeveri et al, 2021) finds that on average, water deficits result in five times as much migration as do water deluges, even though floods are much more likely to gain national or international attention.

Figure 2.11 Average Value of Quarterly Reports of the Integrated Phase Classification for Food Security, West Africa, 2009–19



Source: CIESIN 2020.

2.5.2 Coastal Migration Trends

While most studies on environmental migration relate to the agricultural communities in dryland regions, there are repercussions for coastal zones. This includes the humid southern regions of West Africa, because migrants from the interior may be attracted to urban areas along the coasts (Adepoju 1995; Bruning and Piguet 2018). Table 2.1 shows that most coastal countries have a net positive balance of number of migrants from 2000–15, but the inland countries have a net negative balance. In recent years, southward migration and urbanization have continued in the forest and savannah countries, with climatic factors contributing to the movement (Rademacher-Shulz and Mahama 2012; UNEP 2011; van der Geest, Vrieling, and Dietz 2010). The UK Foresight project funded a global migration modeling effort; results are that roughly 10.6 million people left the West African drylands from 1970 to 2000, whereas a nearly equivalent number, 9.2 million, migrated to coastal ecosystems (CIESIN 2011). Of the 9.2 million migrants to the coastal ecosystems, some 6.6 million people moved to the low elevation coastal zone (the area from 0–10 meters above sea level), mostly to urban areas, which suggests that many of West Africa's migrants are moving toward areas at risk of sea level rise (de Sherbinin et al. 2012). Consistent with this finding, urban growth rates have generally outstripped rural population growth rates in the region by two to three times in magnitude,[16] and most of the region's largest urban areas are in the coastal zone.

Approximately 10.8 million people live in the low elevation coastal zone under 5 meters in elevation, and 19 million (7 percent of the population) live between 0–10 meters (CIESIN 2013b). Those numbers are increasing because of natural increase and migration. As in much of the world, West Africa's coastal zone hosts the largest cities and is a magnet for new migrants (de Sherbinin, Schiller, and Pulsipher 2007; de Sherbinin et al. 2012). The impact of sea level rise and increased storm surge have yet to register in terms of increased out-migration from the coast, except in limited areas such as Saint-Louis, Senegal (Zickgraf 2018), and Cotonou, Benin (Dossou and Glehouenou-Dossou 2007). Research in Ghana's Volta Delta, for example, finds a modest level of out-migration largely driven by the search for employment and not environmental hazards, though these hazards put livelihoods at risk (Ayamga, Das, and Banerjee 2019).

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[16] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Urbanization Prospects 2018 at https://population.un.org/wup.

Data on sea level rise are generally sparse because of the lack of tide gauge data, although recent work supported by the West Africa Coastal Areas Management Program (WACA) is filling some gaps (World Bank 2020). Melet et al. (2016) find that sea levels have risen by 3.21 millimeters per year from 1993 to 2012 at Cotonou, Benin. Most of this change is because of thermal expansion of the oceans and land ice loss in response to climate change. Sea level rise projections for West Africa vary, depending on the model used, from 0.4–0.5 meters by 2090 (Brown et al. 2016), but these do not consider storm surge and increased wave action (Melet et al. 2018).[17] Wave action affects coastal erosion in the region. Appeaning Addo (2013) developed a Coastal Vulnerability Index (CVI) for Accra, Ghana, based on the methodology of Gornitz et al. (1994), which provides a numerical basis for ranking sections of coastline based on potential change because of several factors, including sea level rise, geology, wave action, and geomorphology (Gornitz, White, and Cushman 1991). A vulnerable coastline is characterized by low coastal relief, subsidence, extensive shoreline retreat, and high wave and tide energies. Appeaning Addo (2013) categorizes the vulnerability of the Accra coast as moderate. Hinkel et al. (2012) apply the Dynamic Interactive Vulnerability Assessment (DIVA) model to the West African coast, finding that Nigeria, Guinea-Bissau, Guinea, Benin, Ghana, Sierra Leone, The Gambia, Liberia, and Côte d'Ivoire are ranked among the top 15 most vulnerable countries in Africa.

Flood risk is an issue in many coastal areas of West Africa and particularly affects urban areas (ActionAid 2006; Dickson et al. 2012; Douglas et al. 2008; GCLME 2010). In 2009, many West African cities experienced torrential rains that caused loss of life and the destruction of important socioeconomic infrastructure (GCLME 2010). In Nigeria, floods represent a major issue for urban areas due to the low-lying topography, limited capacity of drainage systems, and blockage of waterways and drainage channels (Adeoye, Ayanlade, and Babatimehin 2009). The frequency, magnitude, and impacts of urban flooding have more than doubled recently because of population growth and settlement in flood-prone areas (Agbola and Agunbiade 2009) and the more intense and frequent rainstorms potentially associated with climate change. For example, in a flood impact assessment in Nigeria, Adeoye et al. (2009) determine that the impacts of floods have increased from significant to threatening during the past three decades, based on flood records from the National Emergency Management Agency (NEMA) and records of flood events recorded in Nigerian newspapers.

2.5.3 Conflict Displacement and Migration

Climate factors are generally considered "threat multipliers" that can negatively affect the proximate determinants of instability, which are largely related to weak governance, social fragmentation, and economic instability (Day and Caus 2020; Heinrigs 2010). Studies and reports have linked environmental change, conflict, and migration in West Africa (Benjaminsen 2012; Heinrigs 2010; Werz and Conley 2012). Some conflicts have emerged from age-old competition for resources between pastoralists and sedentary agriculturalists (Benjaminsen et al. 2012; Benjaminsen and Ba 2009), which are exacerbated by state bias toward sedentarism and long-standing grievances among pastoralists. In 2020 there were 6.8 million new internal displacements in Sub-Saharan Africa because of conflict and violence (IDMC 2021).

Growing Islamist activity in northern Nigeria, Mali, and Burkina Faso has created refugee movements as people flee strict Islamist controls and violence (figure 2.12) (Werz and Conley 2012). The region could face a long-term conflict, and conflict is often associated with large population displacements. According to the UNHCR (2019b) in 2018, Nigeria experienced new internal displacement of 581,700 people, and Mali experienced 82,100 internally displaced people (IDPs). There are currently 276,900 Nigerian refugees in Niger and Cameroon and 158,300 Malian refugees in Niger and Mauritania.

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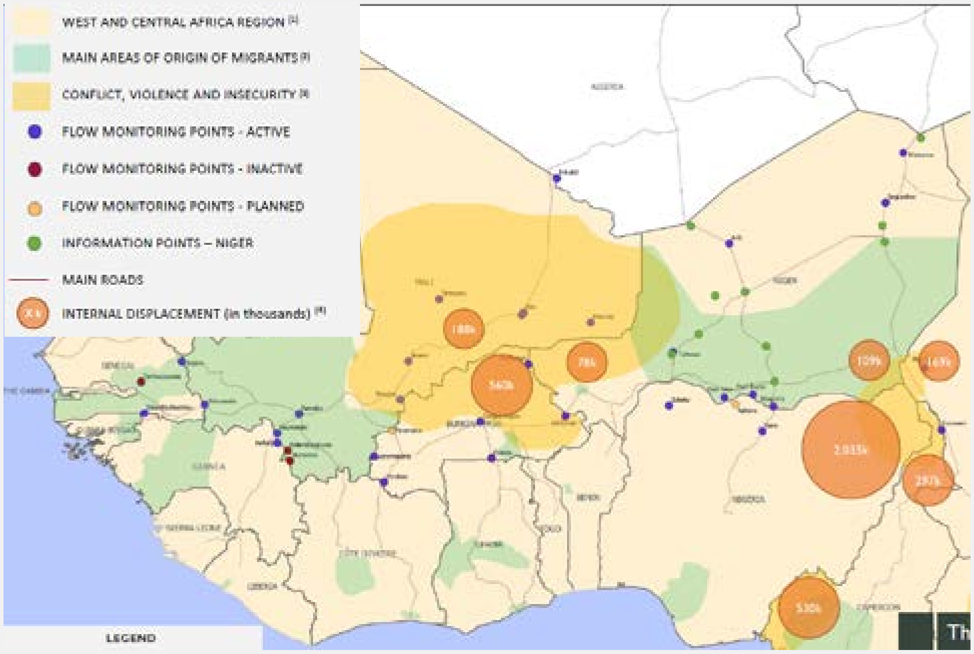
[17] The modeling in this report considers storm surge and potential tipping points in the Greenland and West Antarctic ice sheets, and therefore assumes sea level rise and surge of 1 meter under a low emissions scenario and 2 meters under a high emissions scenario.

Figure 2.12 Internal Displacement due to Conflict and Origin Areas of Migrants Attempting to Migrate to North Africa and Europe from West Africa, January 2020



Source: IOM DTM 2020.

2.6 LEGAL AND POLICY FRAMEWORKS

International and regional legal and policy frameworks addressing human mobility in the context of climate change, although fragmented, can play a significant role in informing policy makers at domestic level when designing and updating national frameworks. Aligning national frameworks with relevant international and regional frameworks and closing any existing normative and implementation gaps through national policy and legislation is crucial in ensuring effectiveness of responses at national level by creating an enabling environment for resource allocation and providing entry points for sustainable development outcomes. The issue of human mobility in the context of climate change lies at the intersection of various legal and policy fields, including relating to human rights, climate change, sustainable development, disaster risk reduction, and sectoral frameworks pertaining to environment and management of natural resources. Accordingly, policy makers and other relevant actors need to be aware of various frameworks available and that effective responses to this issue require concerted action across different sectors.

Human rights law is among the most pertinent regimes applicable to human mobility in the context of climate change. As highlighted by various UN human rights treaty bodies and others, it is now clear that climate change impacts peoples' lives, health, and livelihoods threatening the enjoyment of a wide range of substantive and procedural human rights, either directly or indirectly (McInerney-Lankford, Darrow, and Rajamani 2011; OHCHR 2014).[18] These human rights implications are often further exacerbated in the context of migration and displacement. Vulnerable groups and segments of the community who are already marginalized may be affected disproportionately due to pre-existing inequalities, discrimination, and lack of or limited access to resources. States' legal obligations under human rights law prescribe minimum standards of treatment that States must afford to individuals within their territory or subject

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[18] See also General Assembly resolution 41/21, Human rights and climate change, A/HRC/41/L.24 (9 July 2019), available from undocs.org/en/A/HRC/41/L.24

to their jurisdiction, including migrants. In this vein, human rights law and States' legal obligations to respect, protect and fulfil specific rights, must inform the ways in which States design their domestic laws and policies to help affected communities adapt in place and enable movement in dignity when this is necessary. In addition to the core international human rights treaties,[19] regional human rights treaties and mechanisms such as the African Charter on Human and Peoples' Rights and the jurisprudence of the African Commission on Human and Peoples' Rights' can offer further guidance.

Effective climate action can also reduce the scale of climate migration and help communities adapt locally. The 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the 2015 Paris Agreement remain as key legal instruments guiding climate action at global level, including through climate change mitigation, adaptation, and finance. Article 4 of the Paris Agreement requires each Party to "prepare, communicate and maintain successive nationally determined contributions [NDCs] that it intends to achieve" with respect to reducing anthropogenic GHG emissions but also recognizes special circumstances of least developed countries and small island developing States in accordance with the principle of common but differentiated responsibilities and respective capabilities. Article 2 of the Paris Agreement states that increased ambition is crucial under this framework to reduce GHG emissions and mitigate climate change to the extent possible in light of the Paris Agreement's temperature goal. In this respect, NDCs reflect Parties' national commitments to achieve the global climate objectives and reducing GHG emissions. However, they can also be used in communicating medium- and long-term adaptation needs in addition to NAPs and other communication processes under the UNFCCC regime, which can also help them access climate finance under this framework.

Although not a legally binding instrument per se, the 2010 Cancun Framework under the UNFCCC is particularly significant in its recognition of human mobility in the context of the climate regime and creates the possibility for it to be addressed under the adaptation framework (UNFCCC 2010). The Cancun Framework paragraph 14 (f) recognizes human mobility as a form of adaptation and invites all Parties to enhance adaptation action including "measures to enhance understanding, coordination and cooperation with regard to climate change induced displacement, migration and planned relocation, where appropriate, at the national, regional and international levels." Furthermore, the UNFCCC Task Force on Displacement, established under the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts (WIM), has been set up specifically to facilitate cooperative approaches among relevant stakeholders to "avert, minimize and address displacement related to the adverse impacts of climate change" (UNFCCC 2018). The WIM Task Force provided a set of recommendations, endorsed at COP24, for various stakeholders focusing on legal, policy, and operational frameworks (UNFCCC 2018).

Sustainable development frameworks are also crucial to increase community resilience. Integrating adaptation strategies into sustainable development policies and programs could be another important tool helping people to stay and enable voluntary migration when this is necessary. The findings of this report demonstrate that inclusive resilient development can reduce the scale of climate migration. In that regard, investing in poverty reduction and social protection programs, diversifying income generating activities, and empowering vulnerable groups through development programs can increase resilience and potentially reduce climate-induced human mobility. The 2030 UN Agenda for Sustainable Development explicitly acknowledges the importance of climate action (Goal 13). Although the 2030 UN Agenda for Sustainable Development does not specifically address human mobility in the context of climate change, the Sustainable Development Goals (SDGs) do provide meaningful entry points for further action.[20] The African Union's Agenda 2063 as the continent's strategic framework for inclusive and sustainable development identifies climate change adaptation as one of the urgent priorities in Africa. Agenda 2063 includes no specific reference to climate migration in this context, however, some of the issues mentioned in the agenda closely interact with migration including the peace and stability nexus.

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19. Including, e.g., International Covenant on Civil and Political Rights; International Covenant on Economic, Social and Cultural Rights; International Convention on the Elimination of all Forms of Discrimination Against Women; International Convention on the Protection of the Rights of All Migrant Workers and Members of Their Families; International Convention on the Rights of the Child. For status of ratification, see: https://indicators.ohchr.org/
20. Particularly relevant goals include Goal 1 (no poverty), Goal 2 (zero hunger), Goal 10 (reduced inequalities), Goal 11 (sustainable cities and communities), and Goal 13 (climate action).See IOM 2018a..

Moreover, legal and policy frameworks addressing disaster risk reduction also constitute an important basis to increase the resilience of communities. The Sendai Framework, although not legally binding, provides valuable guidance in addressing disaster risk reduction through governance, policymaking, investment, and international cooperation.[21] It also stresses the need to develop disaster risk reduction policies considering particular vulnerabilities of affected communities. Such policies are important to both address climate change impacts as one of the drivers of disaster risk and protect human rights and achieve sustainable development.The 2020 Africa Regional Assessment Report prepared by the UN Office for Disaster Risk Reduction (UNDRR) provides a regional assessment concerning the state of disaster risk reduction and recommendations regarding disaster risk reduction strategies across African countries and policy coherence between disaster risk reduction, climate change adaptation and sustainable development (UNDRR 2020). There are also strategy documents and policies at the regional and sub-regional level that could serve as additional guidance.[22]

Legal and policy frameworks enabling effective environmental protection and natural resource management as well as frameworks pertaining to various relevant sectors including, inter alia, agriculture, coastal management, and urban planning will also be critical. Climate impacts on food crops, livestock, forestry, fish stocks and other aquatic resources would need to be addressed in order to ensure that people can cope with the impacts of climate change if they remain in their habitual places. As human mobility in the context of climate change will likely increase, it will also put more pressure on land. Accordingly, governance arrangements over land and land-based natural resources, including cross border frameworks for land and natural resource access, need to be carefully designed with specific measures targeted at women and indigenous groups. It is important to note, however, that some of these interventions would require technical, institutional, and financial capacity to design and implement relevant policies and actions. Therefore, international cooperation will be key in implementing relevant measures.

Facilitating safe, orderly, and dignified migration is crucial when adapting in place is no longer a sensible and viable option. The adoption of the intergovernmentally-negotiated Global Compact on Safe, Orderly and Regular Migration (Global Compact for Migration) and the Global Compact on Refugees under the auspices of the UN in 2018 has been a significant development. Global Compacts are not legally binding, but they do represent strong political commitments. The Global Compact for Migration in particular, provides entry points for action highlighting collective commitment to improve cooperation on international migration and shared responsibilities. In complementing the Global Compact for Migration, the African Union (AU) adopted the "Common African Position on the Global Compact for Safe, Orderly and Regular Migration" calling for more regular migration pathways that ensure the protection of migrants' rights and providing a reference point for future discourses on migration management and cooperation (Tadesse Abebe 2018). At the international level, governance of international migration has been fragmented (Ferris 2017). There are, however, umbrella principles in human rights law and relevant international labor law instruments that can guide national policy and legislation. Migrants are often subject to further vulnerabilities and discrimination, preventing them from effectively enjoying their human rights (OHCHR and GMG 2018). A particular vulnerability could arise due to the risk of forced labor and human trafficking both prohibited under international law.

It is important to design legal and policy frameworks to complement international human rights law and labor law standards by addressing primarily the issues of admission, conditions of stay, and access to the labor market (Nansen Initiative 2015). At the regional level, there are various instruments that have traditionally facilitated cross-border migration within the region, even though some of these instruments were not initially designed to address the climate-mobility nexus. The AU's Migration Policy Framework and Plan of Action, adopted in 2018, provide a strategic framework to guide AU member States and Regional Economic Communities (RECs) in addressing migration challenges for the continent. In 2018, the AU adopted a Protocol relating to free movement of persons, right of residence, and rights of establishment. Existing agreements at sub-regional levels may also facilitate migration (Wood 2018).

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21. Sendai Framework, in particular, paras 27, 28, 30, 33, and 36.
22. These include the 2017 Programme of Action for the Implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 in Africa in line with the 2004 Africa Regional Strategy for Disaster Risk Reduction which has guided disaster risk reduction strategies in Africa. At the sub-regional level, ECOWAS adopted the 2006 Policy for Disaster Risk Reduction.

Such frameworks may provide access to the territory of the host State, status and rights during stay, and opportunities for lasting solutions. Eligibility to benefit from such free movement agreements, however, is generally accessible to States of the same REC and subject to the discretion of the particular State granting access to its territory. Likewise, status and rights during the stay may also be subject to certain limitations such as administrative and financial requirements, some of which could be supplemented by the existing human rights and labour law standards addressed earlier (Wood 2018).

In the ECOWAS region, there are various instruments that can be potentially applicable in the climate-migration nexus. This includes the 1979 Protocol relating to Free Movement of Persons, Residence and Establishment; 1986 ECOWAS Supplementary Protocol on Right of Residence; and 1990 ECOWAS Supplementary Protocol on Right to Establishment. Practice and stakeholder engagements show that the ECOWAS free movement arrangements have been relatively well implemented but it has not been easy to differentiate drivers of movement, and therefore to identify and address the specific protection needs of vulnerable displaced persons (PDD 2019).

Planned relocation generally within the country's borders and in some cases also across national borders may also need to be considered as a measure of last resort. Both the Kampala Convention and the UN Guiding Principles on Internal Displacement prohibit arbitrary displacement including, among others, displacement emanating from situations where people are evacuated in disaster settings unless their safety and health requires such evacuation. When adverse impacts of climate change are unavoidable, however, governments may need to undertake planned relocations to move people from areas that are particularly exposed to climate stresses to less vulnerable locations (McAdam and Ferris 2015). International law standards require that such measures are conducted in a proportionate and non-discriminatory manner, for a legitimate purpose, in accordance with existing law and the principles of human dignity and liberty.[23]

International law does not provide a legally binding instrument specifically addressing the issue of planned relocation, however, practical tools and policy guidance are available (Brookings Institution, Georgetown University, and UNHCR 2015; IOM, Georgetown University, UNHCR 2017). It is important for countries that are particularly prone to the risk of relocation to plan at legal, policy, and institutional levels. It is recommended that such planned relocation processes adopt a whole-of-government approach and are integrated into national strategies relating to land use, disaster risk management, climate change adaptation, and development initiatives (Brookings Institution, Georgetown University, and UNHCR 2015). Community-driven decision-making mechanisms should be put in place to ensure meaningful consultation with affected communities and policy design that reflects community needs. If prepared adequately, planned relocation has the potential to move people from harm's way (Ferris and Weerasinghe 2018).

Ultimately, despite the efforts to facilitate safe, orderly, and dignified migration, forced displacement at internal and cross-border level may still happen and when this is the case, it is crucial to address protection needs of the displaced and design durable solutions to avoid further displacement. The 1998 UN Guiding Principles on Internal Displacement are particularly applicable to internally displaced persons (IDPs). The UN Guiding Principles on Internal Displacement define IDPs as "people or groups of people who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border (emphasis added)." Although not legally binding in themselves, they are based on well-established standards under international humanitarian law and human rights law including the principle of non-discrimination, the right not to be arbitrarily displaced, right to life, right to liberty and security of person, freedom of movement, and right to an effective remedy, among others. The UN Guiding Principles address all phases of internal displacement including principles relating to protection from displacement, protection during displacement, and principles relating to return, resettlement, and reintegration.

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[23] For a comprehensive analysis on the issue, see see Burson et al. 2018.

At the continental level, the "Kampala Convention"[24] provides a progressive and legally binding framework for the protection of IDPs. Under Article 5(4), Parties are obliged to "take measures to protect and assist persons who have been internally displaced due to natural or human-made disasters, including climate change." The Kampala Convention recognizes the primary duty of the State in preventing internal displacement, protecting, and assisting IDPs and creating conditions conducive to durable solutions. It prohibits discrimination of any kind and requires States to respect the rights of IDPs provided under regional and international human rights treaties to which the State is a party, also recognizing specific circumstances and needs of marginalized and vulnerable groups.[25] Even though the Kampala Convention provides a comprehensive framework for preventing and responding to internal displacement including due to climate change impacts, its ratification and implementation have been slow.

Finally, forced displacement due to climate impacts may still occur at cross-border level. In general, refugee law could apply for people crossing borders due to climate change impacts as long as elements of persecution are also present to meet the "refugee" definition of the 1951 Convention relating to the Status of Refugees.[26] This is particularly important as refugees are entitled to the specific protection regime, including not to be returned to a place where they are subject to a risk of persecution or other serious harm (principle of non-refoulement). Article I(2) of the 1969 Organization of African Unity (OAU) Convention Governing the Specific Aspects of Refugee Problems in Africa broadens the refugee definition of the 1951 Convention, enabling people who cross borders to seek protection to substantiate their claims based on "events seriously disturbing public order," potentially encompassing disaster and climate impacts. Moving forward, to address the multi-causal nature of climate-induced mobility, especially its interaction with considerations around fragility, conflict, and violence, a more nuanced application of the refugee law regime would be needed. Human rights law could also provide protection in this context. The recent ruling of the UN Human Rights Committee in the case of Teitiota v. New Zealand determined that people who flee the effects of climate change and natural disasters should not be returned to their country of origin if essential human rights would be at risk on return (HRC 2020).

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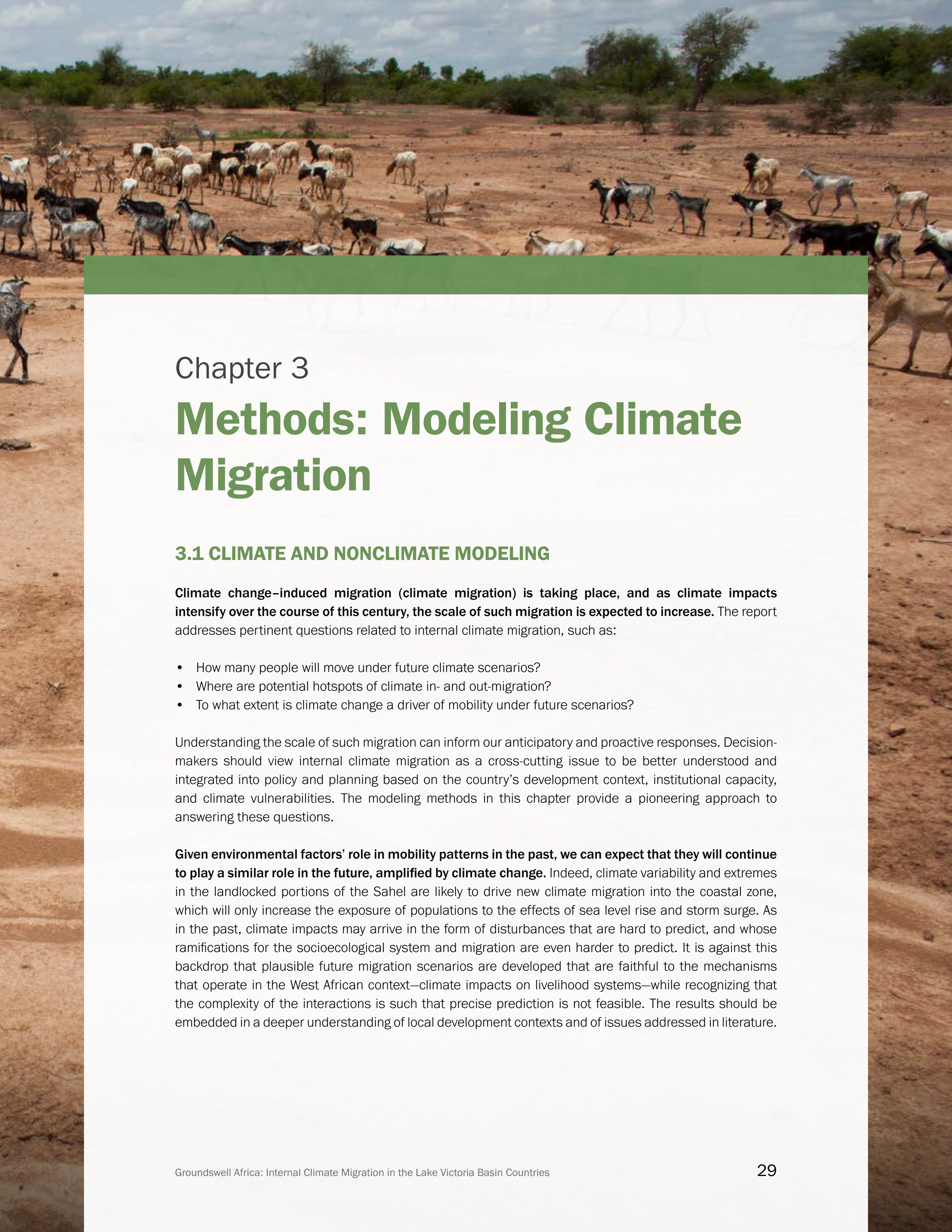
[24] As of June 2020, 40 countries have signed and 31 have ratified the Convention. For the list of countries which have signed and ratified the Kampala Convention, see AU 2020.

[25] Kampala Convention, Art. 3(1)(d) and Art. 9(2).

[26] Convention relating to the Status of Refugees (adopted 28 July 1951, entered into force 22 April 1954) 189 UNTS 137 (Refugee Convention), Article 1A (2).

This study applies an enhanced version of the pioneering 2018 Groundswell model—with a higher level of granularity and under consideration of additional climate and nonclimate factors—to estimate the scale of internal climate migration.

Andrea Borgarello / World Bank



Chapter 3

Methods: Modeling Climate Migration

3.1 CLIMATE AND NONCLIMATE MODELING

Climate change–induced migration (climate migration) is taking place, and as climate impacts intensify over the course of this century, the scale of such migration is expected to increase. The report addresses pertinent questions related to internal climate migration, such as:

- How many people will move under future climate scenarios?
- Where are potential hotspots of climate in- and out-migration?
- To what extent is climate change a driver of mobility under future scenarios?

Understanding the scale of such migration can inform our anticipatory and proactive responses. Decision-makers should view internal climate migration as a cross-cutting issue to be better understood and integrated into policy and planning based on the country's development context, institutional capacity, and climate vulnerabilities. The modeling methods in this chapter provide a pioneering approach to answering these questions.

Given environmental factors' role in mobility patterns in the past, we can expect that they will continue to play a similar role in the future, amplified by climate change. Indeed, climate variability and extremes in the landlocked portions of the Sahel are likely to drive new climate migration into the coastal zone, which will only increase the exposure of populations to the effects of sea level rise and storm surge. As in the past, climate impacts may arrive in the form of disturbances that are hard to predict, and whose ramifications for the socioecological system and migration are even harder to predict. It is against this backdrop that plausible future migration scenarios are developed that are faithful to the mechanisms that operate in the West African context—climate impacts on livelihood systems—while recognizing that the complexity of the interactions is such that precise prediction is not feasible. The results should be embedded in a deeper understanding of local development contexts and of issues addressed in literature.

This study builds on the novel scenario-based model used in the Groundswell report (Rigaud et al. 2018) but includes several enhancements to better inform policy dialogue and action.[27] The enhanced model and refined methods in this study include shorter time steps, higher spatial resolution, more climate impact parameters, and inclusion of nonclimate factors. Table 3.1 provides a summary of the main enhancements.

Table 3.1 Comparison between Groundswell I and West Africa Model

Groundswell I	Modifications in this work
Groundswell used a unique population gravity modeling technique to project future population distributions to the year 2050 based on socioeconomic scenarios known as the SSPs that include assumptions about future urbanization rates.	Applies maximum rural and urban population densities so that unrealistically high urban densities are not produced, as well as information on the age/sex distribution of the population that reflects gender-specific migration rates and the older age structures of urban areas.
Focus on slow-onset factors: the modeling used for the first time actual climate impact models for agriculture and water resources to understand how these would affect future population distributions, as well as sea level rise compounded by storm surge.	Includes another slow-onset impact (ecosystem impacts) and rapid onset events (as flood risk projections); incorporates conflict areas as an additional data layer.
The gravity model is driven by the population as set out in the GPW to estimate future population distribution.	Includes age and sex distribution as nonclimate factors in the gravity model, and affects the results through their relationship with population change (as derived through the spatial autoregressive calibration), and through their interaction with climate drivers.
The three scenarios are based on combinations of socioeconomic development scenarios (SSPs) and emissions scenarios (RCPs): the pessimistic (reference), more inclusive development, and climate-friendly.	Adds a fourth, optimistic scenario that combines low emissions (RCP2.6) and an inclusive development pathway (SSP2).
Scenarios were run in decadal increments from 2010 to 2050, calibrated on data from 1990 to 2010.	Scenarios are run in five-year increments, 2010 to 2050.
The future population projections incorporating climate impact scenarios were compared to future population projections without climate impacts to derive estimates of climate migration for 15-km grid cells (7.5 arc-minute).	Modeling is performed on population data at 1-km resolution (0.5 arc-minute).
Modeling supplemented with peer-reviewed literature and contextualization for illustrative case studies; with in-country consultations.	Supplemented with national, local studies/ data, where available, and validation at a workshop in Accra, Ghana (September 2019); and a virtual multistakeholder regional workshop in March 2021.

Note: GPW = Gridded Population of the World; RCP = Representative Concentration Pathway; SSP = Shared Socioeconomic Pathway.

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[27] For a full description of the Groundswell approach see Groundswell: Preparing for Internal Climate Migration (Rigaud et al. 2018, chapter 3, appendix A, and appendix B).

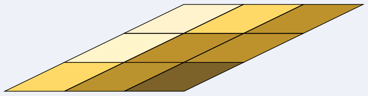
The scenarios combine development scenarios and emissions pathways, implemented in the context of a population gravity model, to estimate the potency of climate to drive internal migration. Box 3.1 summarizes the method.

Box 3.1 Modeling Approach in a Nutshell

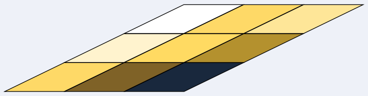
A population gravity model is used to project future population distribution for each country based on two development scenarios: an unequal development scenario representing a divided world with poor development prospects in developing countries, versus a moderate development scenario representing a more equitable future world.

Climate impacts on water availability and crops/pasturage are added to the two development scenarios, which affect the relative attractiveness of regions within countries. Areas projected to see higher water availability and productivity attract people; areas projected to see lower water availability and productivity will tend to repel people. Areas affected by sea level rise are "masked" out in a way that people cannot move into them.

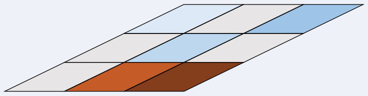
a. No Climate Change Impacts (development only) Scenario



b. Climate Change Impacts Scenario



c. Climate Impacts minus No Climate Impacts Scenario = In-Migration (red) or Out-Migration (blue)



The climate impacts are included with the development scenarios in four combinations: a pessimistic scenario with high emissions and poor development prospects, a more inclusive development scenario with high emissions and more equitable development prospects, a more climate-friendly scenario with low emissions and poor development prospects, and an optimistic scenario with low emissions and equitable development. Panels a–c (in this box) reflect the process for a hypothetical model run for one of the scenarios, in which higher population densities in 2050 are reflected by darker shades. (We produce four model runs per scenario to get a spread around the results.)

Future population projections without climate impacts are subtracted from population projections with climate impacts to yield a map of population differences. Positive differences are assumed to reflect net in-migration and negative differences are assumed to reflect net out-migration due to climate change impacts. The model is calibrated by looking at the relationship between past climate impacts and changes in historical population distributions between 1990 and 2010 (in two 10-year increments), which generates parameter estimates used to project future changes (see appendix B.2).

3.1.1 Shared Socioeconomic Pathways

To create climate change scenarios illuminating possible development pathways, this analysis builds on spatial population projections based on Shared Socioeconomic Pathways (SSPs) as developed by Jones and O'Neill (2016). SSPs represent a set of scenarios—or plausible future worlds—that underpin climate change research and permit the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation (Ebi et al. 2014). They can be categorized by the degree to which the scenarios represent challenges to mitigation (greenhouse gas emissions [GHG] reductions) and societal adaptation to climate change.

The analysis uses SSPs as story lines to guide the development of spatial population projections at 30 arc-second resolution (grid cells of about 1 square kilometers at the equator).[28] The five SSPs developed by O'Neill et al. (2014) span a wide range of possible future development pathways and describe trends in demographics, human development, economy, lifestyles, policies, institutions, technology, the environment, and natural resources. They are the scenario benchmarks used for adaptation planning purposes. Table 3.2 summarizes the SSP narratives; figure 3.1 relates the SSPs to one another. National-level estimates of population, urbanization, and gross domestic product (GDP) have been released for each SSP and are available through the SSP database.[29]

Table 3.2 Shared Socioeconomic Pathway (SSP) Narratives

SSP	Illustrative starting points for narrative	Challenge level
SSP1	Sustainable development proceeds at a reasonably rapid pace, inequalities are reduced, and technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and higher productivity of land.	Low for mitigation and adaptation
SSP2	Intermediate case between SSP1 and SSP3.	Moderate
SSP3	Unmitigated emissions are high because of moderate economic growth, rapid population growth, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.	High for mitigation and adaptation
SSP4	A mixed world, with relatively rapid technological development in low-carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most to global emissions. However, in other regions, development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving them highly vulnerable to climate change with limited adaptive capacity.	High for adaptation, low for mitigation
SSP5	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Economic development is relatively rapid, driven by high investments in human capital. Improved human capital produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.	High for mitigation, low for adaptation

Source: Based on O'Neill et al. 2014.

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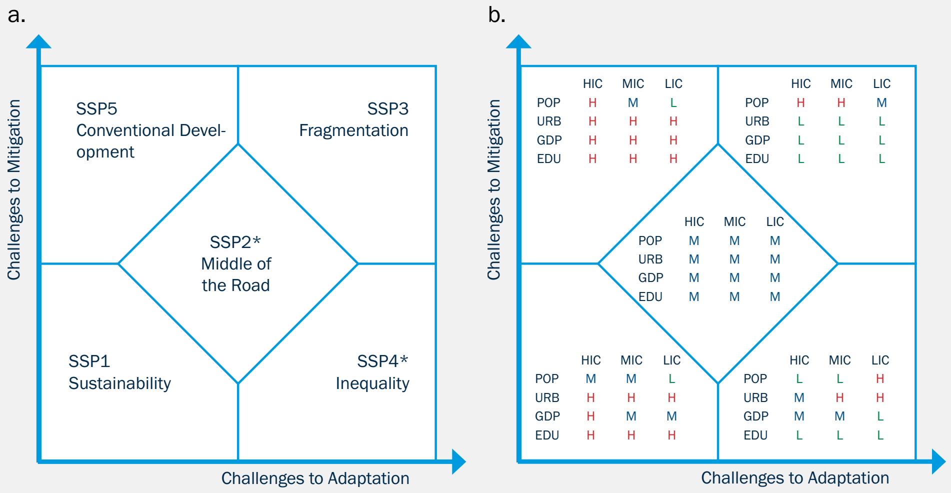
[28] The Groundswell projections were conducted at 7.5 arc-minutes (approximately 15 square kilometers at the equator).

[29] See SSP Database (Shared Socioeconomic Pathways) - Version 2.0 at https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about.

Figure 3.1 Assumptions about Changes in Population, Urbanization, GDP, and Education across Countries of Different Income Groups of the Shared Socioeconomic Pathways



	HIC	MIC	LIC
POP	H	M	L
URB	H	H	H
GDP	H	H	H
EDU	H	H	H

	HIC	MIC	LIC
POP	H	H	M
URB	L	L	L
GDP	L	L	L
EDU	L	L	L

	HIC	MIC	LIC
POP	M	M	M
URB	M	M	M
GDP	M	M	M
EDU	M	M	M

	HIC	MIC	LIC
POP	M	M	L
URB	H	H	H
GDP	H	M	M
EDU	H	H	H

	HIC	MIC	LIC
POP	L	L	H
URB	M	H	H
GDP	M	M	L
EDU	L	L	L

Source: Jiang 2014.

Note: panel a: SSP = Shared Socioeconomic Pathway; panel b: EDU = education; GDP = gross domestic product; H = high; HIC = high-income country; L = low; LIC = low-income country; M = medium; MIC = medium-income country; POP = population; URB = urbanization.

The model in this report builds on SSP2 and SSP4, reflecting more moderate and unequal development pathways. Under the unequal development scenario (SSP4), low-income countries (LICs) and middle-income countries (MICs) follow different pathways. LICs have high population growth rates and urbanization, and low GDP and education levels. MICs have low population growth rates, high urbanization, moderate GDP, and low education levels. Inequality remains high both across and within countries, and economies are relatively isolated, leaving large, poor populations in developing regions highly vulnerable to climate change with limited adaptive capacity. SSP2 is a moderate development scenario between SSP1 ("sustainability") and SSP3 ("fragmentation"), where lower-middle-income countries (LMICs) are characterized by moderate population growth, urbanization, income growth, and education; and have moderate challenges to adaptation. These scenarios were chosen because they represent divergent development pathways. They were also selected for consistency, or the ability to be paired, with the high and low emissions scenarios (Representative Concentration Pathways [RCPs]) used in this report. The high emissions scenario (RCP8.5) can be paired with both SSP4 and SSP2; the low emissions scenario (RCP2.6) can be paired with SSP4.

The development pathways drive population and urbanization trends in a gravity model that distributes population change according to the perceived attractiveness of different locales over time under the low and high emission scenarios as framed by RCPs. Future population distributions are influenced by climate impacts on the water and agriculture sectors, ecosystem impacts, and future flood risk, all of which influence attractiveness. The model estimates the number of climate migrants and their future locations by comparing population distributions that incorporate climate impacts with scenarios based on development trajectories only.

The SSP population projections include international migration, but the modeling conducted in this study was limited to assessing internal climate migration. Because this study builds on the SSPs, by definition, it also includes the bilateral migration flows included in the national-level population projections that correspond to each SSP (KC and Lutz 2014). For both SSP2 and SSP4, these flows are in the middle of the range.[30] They are based on an existing global-level matrix of in- and out-migration (Abel and Sander 2014) and adjusted to reflect assumptions regarding, for example, conflict and political changes and the degree of openness of national borders in each SSP (O'Neill et al. 2014).

3.1.2 Representative Concentration Pathways

The magnitude of future global warming is framed by the RCPs, and the internal climate migration forecasts are based on two emissions scenarios.[31] The lower emissions scenario (RCP2.6) is a world in which temperatures peak at 0.25°–1.5°C above recent baseline levels by 2050 and then stabilize through the end of the century (IPCC 2014). This is the world of the Paris Agreement, in which countries work together to reduce GHG emissions to zero within the next 15 to 20 years (Sanderson et al. 2016). In the higher emissions scenario (RCP8.5), temperatures rise by 0.5°C to 2°C by 2050 and by 3°C to 5.5°C by 2100. It is a future consistent with scenarios of energy-intense development, continued reliance on fossil fuels, and a slow rate of technological development. RCP8.5 implies little to no climate policy. It is characterized by significant increases in CO_2 and CH_4 emissions. These two emission scenarios drive the indicators of water, agricultural, and ecosystem sector change as well as flood risk, which are incorporated in projections of future population distributions.

RCP2.6 scenario is consistent with the extremely rapid adoption of cleaner technologies, slower population growth, strong environmental policies, and well-functioning international institutions that facilitate rapid global integration. To achieve RCP2.6, new technologies would need to be widely deployed over the next five to ten years. The extended RCP2.6 scenario assumes "negative emissions" by 2070, meaning that humans remove more CO_2 and CH_4 from the atmosphere than they release. RCP2.6 is thus consistent with the Paris Agreement, which seeks to limit temperature rise to 2°C.

RCP8.5 is characterized by increasing GHG emissions, leading to high atmospheric concentrations. It is a future consistent with scenarios of energy-intense development, continued reliance on fossil fuels, and a slow rate of technological development. Pathways characterized by rapid population growth and land use intensification (croplands and grasslands) are also consistent with this scenario.

As set out in the Groundswell model, RCP8.5 is intended to be a high-end outlier in the business-as-usual world, and should not be concluded as the only or most likely outcome in a "no policy" world. RCP2.6 was closer and more in line with the Paris Agreement. In the development of the Groundswell methodology, the SSP and RCP combinations were in part driven by their compatibility. There is no perfect combination. Some argue against the plausibility and utility of RCP2.6. Comparing the RCP2.6, however, even as it may be a challenge to achieve it, provides a spread in the model runs and outcomes, to differentiate between a best case "sustainable" scenario (RCP2.6) and a high-end emission scenario (RCP8.5). What is important here is the ranges and plausibility of scenarios as the low and high end.

3.1.3 Scenario Combinations Used in the Model

We examined four plausible future internal climate migration scenario combinations (figure 3.2). For each scenario, the estimate represents an ensemble of model runs using combinations of crop, water, ecosystem, and flood impact models from the Intersectoral Impacts Model Intercomparison Project (ISIMIP). The four scenarios include:

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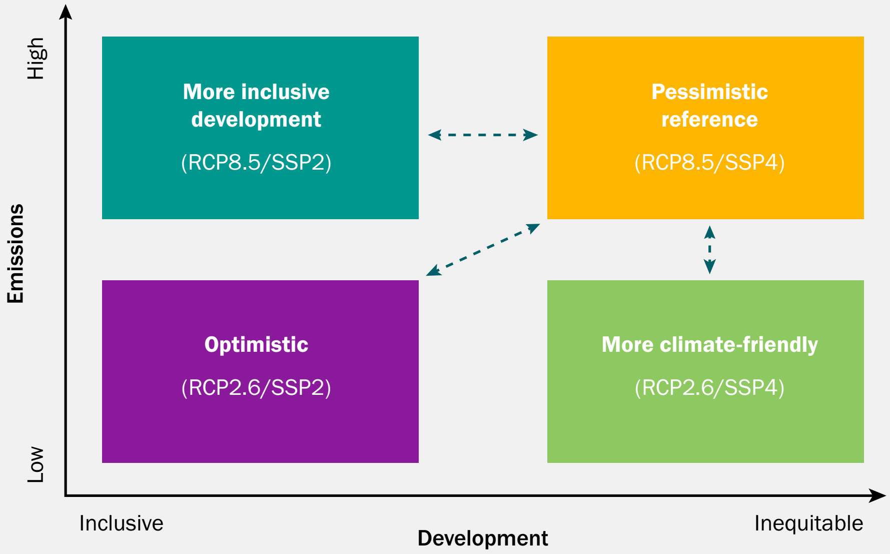
[30] Migration flows are considered medium across all SSPs except SSP3 ("fragmentation"), where they are low, and SSP5 ("conventional development"), where they are high. A more sophisticated set of SSP projections is under development.

[31] The term emissions scenarios is technically not correct, in that the RCPs represent concentration levels of GHGs and other pollutants that warm the Earth's surface. It is used here as shorthand, because emissions contribute directly to concentration levels.

- A pessimistic/reference scenario (SSP4 and RCP8.5), in which LICs reflect continued high emissions and have unequal development and are characterized by high population growth, high rates of urbanization, low GDP growth, and low education levels. Urban growth is poorly planned, and high emissions drive greater climate impacts. This scenario poses high barriers to adaptation because of the slow pace of development and isolation of regional economies.
- A more climate-friendly scenario (SSP4 and RCP2.6), with lower emissions that reduce climate impacts, but holds the development scenario consistent with the pessimistic scenario.
- A more inclusive development scenario (SSP2 and RCP8.5), which retains high emissions because they are in the pessimistic scenario, but provides a development scenario that is more optimistic and the potential for adaptation is higher than under SSP4. Population and urban growth are lower than in SSP4 for LICs and higher for MICs, while progress in education and GDP are higher than in SSP4.
- An optimistic scenario (SSP2 and RCP2.6), which combines the lower emission scenario that reduces climate impacts and provides a development scenario that is more optimistic.

Figure 3.2 Projecting Internal Climate Migration under Four Plausible Scenarios



Source: Adapted from Rigaud et al. 2018

Note: RCP = Representative Concentration Pathway; SSP = Shared Socioeconomic Pathway.

We calibrated the model based on the historical sensitivity of past shifts in population distribution to the effects of deviations in water availability, crop productivity, and net primary productivity (NPP) from long-term baselines. Because of limitations in the underlying historical population data, only three countries had population data that met the criteria needed to undertake the calibration: Mauritania, Guinea, and Sierra Leone. The coefficients were averaged across the three calibration results for every country in the region, meaning that these countries serve as stand-ins for the other countries in the region (see appendix B.2 for details).

There are inherent uncertainties in the way climate impacts will play out in a given locale. At higher resolutions, these will affect the magnitude and patterns of climate-induced migration, including through intervening opportunities that can work in either direction depending on how climate and nonclimate factors interact (see box 3.2).

3.1.4 Climate Impacts Addressed in the Model

A key innovation of the Groundswell methodology—applied to this study—is that it incorporates actual climate impacts on critical primary sectors: water, agriculture, and ecosystem services (NPP), as well as future flood risk. Most studies seeking to understand the effects of climate change on mobility have used climate variables such as temperature and precipitation rather than actual climate impacts on different sectors.

The Groundswell model used the ISIMIP database of state-of-the-art computer model simulations of biophysical climate impacts. This climate-impact modeling initiative—aimed at contributing to a quantitative and cross-sectoral synthesis of the differential impacts of climate change, including uncertainties—offers a framework for consistently projecting the impacts of climate change across affected sectors and spatial scales.

The analysis for this study used outputs of the ISIMIP Fast Track modeling effort, which covers 1970–2010, as well as projections for 2010–50 (Piontek et al. 2013).[32] Under the Fast Track, the future sectoral impact models are driven by a range of general circulation models. This project used two general circulation models that provide a good spread for the temperature and precipitation parameters of interest: the HadGEM2-ES climate model developed by the UK Met Office Hadley Centre for Climate Change and the IPSL-CM5A-LR climate model developed by the Institut Pierre Simon Laplace Climate Modeling Center, in France (see appendix A for details).

The ISIMIP sectoral models of global crop, water, and ecosystem simulations—at a relatively coarse spatial scale (0.5 degrees, or roughly 55 kilometers at the equator)—are an advance over purely climate model–based indicators of rainfall and temperature, because they represent actual resources of relevance to development. The flood impact model is at 500-meter resolution and is based on projected flood depth. These climate impacts were selected because the literature shows that water scarcity, declining crop yields, declines in pasturage, and flood impacts are among the major potential climate impacts facing LICs, and these impacts will be important drivers of migration.[33] Finally, sea level rise is included as a spatial mask that does not permit people to live in areas likely to experience inundation. Each of these input layers is described in greater detail below.

The models are better at assessing long-term trends rather than individual extreme events such as drought or extreme rainfall. As devastating as they may be for rural livelihoods, brief, fast-onset events are not directly included. That said, the five-year time step in this report captures successive extremes better than the original 10-year time step used in Groundswell, in which extremes in either direction are more likely to counterbalance each other over the course of a decade. To further assess the impact of extremes, we included flood impacts (described below) in this improved model.

Water and Crop Models Used in the Gravity Model

Data on water availability and crop production were integrated into the gravity model using the following approach. The water sector model outputs represent river discharge, measured in cubic meters per second in daily and monthly time increments. The crop sector model outputs represent crop yield in tons per hectare on an annual time step at a 0.5° x 0.5° grid cell resolution. Crops include maize, wheat, rice, and soybeans; for regions with multiple cropping cycles, yield reflects only the major crop production period.[34] The data were converted to five-year average water availability and crop production (in tons) per grid cell.[35] An index was then calculated that compares those values with the 40-year average for water availability and crop production for 1970–2010 (equation 3.1):

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[32] See ISIMIP Fast Track at https://www.isimip.org/gettingstarted/fast-track-simulation-protocol.

[33] Water availability is influenced by rainfall and rising temperatures. Crop production is a function of rainfall, temperature, CO_2 concentrations, irrigation, and other management practices that are incorporated in the ISIMIP models.

[34] The ISIMIP models seek to assess the risk that climate change will have on the potential for agriculture in a location. For this purpose, the relative changes in average yield potential are useful.

[35] The models report "pure crop yields" in tons per hectare (that is, they assume that a given crop is grown everywhere, irrespective of growing conditions or where crops are actually grown). These yields were multiplied by observations-based growing areas (in 2005), separately for rainfed and irrigated yields, to obtain grid cell–level production (in metric tons) (Portmann, Siebert, and Döll 2010).

$$Index = (D_{avg} - B_{avg}) / B_{avg} \tag{3.1}$$

where D_{avg} is the five-year average crop production/water availability and Bavg is the baseline average crop production/water availability for the 40-year period, 1970–2010. The indexes for water availability and crop production represent deviations from the long-term averages (0.2 indicates 20 percent above the baseline average, 1 represents a doubling, and –0.6 indicates 60 percent below the baseline average). To reduce the effect of extremes on the gravity model, increases greater than index values of 2 (meaning a tripling of yields) were capped at 2.

The ISIMIP crop and water model outputs are based on combinations of climate, crop, and water models. Applying the combinations—two global climate models driven by two emissions scenarios, which in turn drive two sets of sectoral impact models (described below)—provides a range of plausible population projections. It also gives a sense of the level of agreement across scenarios. Because the population modeling process is time consuming and computationally intensive, it was important to work with a reduced set of ISIMIP inputs.[36] The modeling employed the HadGEM2-ES and IPSL-CM5A-LR global climate models, which drive combinations of the two water models and two crop models: the LPJmL water and crop models, the WaterGAP2 water model, and the GEPIC crop model. The crop and water models were selected based on several criteria, including model performance over the historical period, diversity of model structure, diversity of signals of future change, and availability of both observationally driven historical (ISIMIP2a) and global climate model–driven historical and future (ISIMIP fast-track) simulations. Table 3.3 presents the combinations of crop and water models used. Appendix A provides detailed information on model selection.

Table 3.3 Matrix of Global Climate Models and Crop and Water Model Combinations

	Crop simulation			
Water simulation	**HadGEM2-ES, LPJmL (crop)**	**HadGEM2-ES, GEPIC**	**IPSL-CM5A-LR, LPJmL (crop)**	**IPSL-CM5A-LR, GEPIC**
HadGEM2-ES, LPJmL (water)	Model 1			
HadGEM2-ES, WaterGAP2		Model 2		
IPSL-CM5A-LR, LPJmL (water)			Model 3	
IPSL-CM5A-LR, WaterGAP2				Model 4

Note: Where crop production does not take place; ecosystem (NPP) models are used to gap-fill the LPjML and GEPIC crop models, respectively. NPP = net primary productivity.

Ecosystem Productivity Models Used in the Gravity Model

Including ecosystem productivity in the gravity model was driven by two considerations. First, it is an important measure for pastoral livelihoods, just as crop production is an important metric of farm-based livelihoods. A large portion of the Sahel is inhabited by pastoralists who engage in livestock herding, and this livelihood is very climate sensitive. Ecosystem productivity is critical for this livelihood. When the original Groundswell modeling work (Rigaud et al. 2018) was done, ISIMIP ecosystem productivity models were not available.

The second reason was to fill gaps where there is no crop production. Crop production results in Groundswell were reported only for areas where the four major crops—wheat, maize, rice, and soybeans—are produced, leaving gaps in the coverage of the crop production change metrics and areas in which water stress was the sole climate-related indicator. The solution was to fill the gaps in those crop production results with the ecosystem productivity data, which are areas more likely to encompass pastoral livelihoods. Even so, in this study, ecosystem productivity is applied in the model only to those areas lacking crop productivity, since there is high spatial co-linearity between the crop and ecosystem metrics.[37]

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[36] Feeding all potential ISIMIP water and crop model outputs into the gravity model would have yielded 12,500 model runs: 2 RCPs * 5 GCMs * 25 crop model outputs * 50 water model outputs = 12,500.

[37] This means that adding ecosystem impacts would only repeat information contained in the ISIMIP crop production impacts.

Ecosystem productivity is measured in terms of the NPP. The ecosystem models simulate the natural growth of several plant functional types, including grasses. The NPP simulated by these models thus serves as an estimate of the productivity of a location's natural biome, including grassland biomes. The NPP index is calculated in the same way as the crop and water indexes (see equation 3.1). The index used for this report are from two models: the LPJmL and VISIT models. The former is used with the LPJml crop production and water availability models (table 3.3, models 1 and 3), while the latter is used with the GEPIC crop and WaterGAP water models (table 3.3, models 2 and 4).[38] The models were driven by the same GCMs using the same RCPs as in the original Groundswell report.[39]

Flood Models Used in the Gravity Model

The original Groundswell modeling did not include flood hazards. We added flood hazards for West Africa because of their important impact on displacement, even if the impacts are highly localized. The flood hazard layer is based on projected flood depth simulated by a global flood model CaMa-Flood (Yamazaki et al. 2011) ver. 3.4.4. It primarily represents riparian (along rivers) flooding, not coastal, although it does capture rivers emptying into the ocean. Potential coastal flooding is better captured by the sea level rise mask (below). The input required by this global flood model is daily runoff simulated by multiple global hydrological models participating in the ISIMIP2b (Frieler et al. 2017) project. These hydrological models are forced by four bias-corrected climate models that include standard outputs (temperature, precipitation, radiation, etc.) from the Coupled Model Intercomparison Project phase 5 (CMIP5) (Taylor, Stouffer, and Meehl 2012). Appendix A describes the climate models, global hydrological models, and global flood model in this modeling chain.

The flood hazard data were used to calibrate the model by establishing a baseline relationship between the return rate of 100-year flood event and spatial patterns of observed population change (along with multiple additional drivers). This relationship contributed to projections of future spatial population change.

Sea Level Rise Augmented by Storm Surge

Sea level rise augmented by storm surge is not considered a driver of migration, but rather is inserted as a spatial mask in the modeling work—representing a loss of habitable land—to move populations out of inundated areas. The figures in table 3.4 represent the lower-, middle-, and upper-bound sea level rise, including storm surge, by 2030 and 2050, as reported by the Intergovernmental Panel on Climate Change (IPCC) (Church et al. 2013). Two scenarios meant to represent changes in sea level by 2050, associated with RCP2.6 and RCP8.5, were adapted by adding an increment to reflect storm surge on top of the estimates (table 3.4). According to Dasgupta et al. (2007, 6), "Even a small increase in sea level can significantly magnify the impact of storm surges, which occur regularly and with devastating consequences in some coastal areas." A comprehensive assessment of the likely levels of storm surge for all the coastal areas covered by this report was beyond the scope of this project. Nor were we able to find data on coastal erosion that cover enough of the coastline consistently. However, the coastline of Senegal (particularly Saint-Louis and Sine Saloum) and the Gulf of Guinea are among the most vulnerable to erosion because of sea level rise, whereas portions of the coast from Guinea to Liberia, along with a good portion of the Ghanaian coast, tend to rise steeply. The omission of erosion may mean that our coastal climate migration numbers are underestimated. Further details on projected sea level rise by 2050 and 2100 for a few (West Africa Coastal Areas) WACA countries are in World Bank (2020).

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[38] The ecosystem models are used to gap-fill the LPjML and GEPIC crop models, respectively.

[39] See chapter 3 and appendix A of the Groundswell: Preparing for Internal Climate Migration report (Rigaud et al. 2018).

Table 3.4 Projected Sea Level Rise under Low and High RCPs, West Africa, 2030 and 2050

	Meters above current mean sea level					
	RCP2.6			RCP8.5		
Year	*Lower*	*Middle*	*Upper*	*Lower*	*Middle*	*Upper*
2030	0.092	0.127	0.161	0.098	0.132	0.166
2050	0.157	0.218	0.281	0.188	0.254	0.322
Storm surge increment	0.85–0.9			1.68–1.85		

Source: Church et al. 2013; CIESIN database, 2013 (storm surge).

Note: RCP = Representative Concentration Pathways.

Both the 1- and 2-meter sea level rises are based on NASA Shuttle Radar Topography Mission data, as modified by the Center for International Earth Science Information Network for the Low Elevation Coastal Zone (LECZ) ver. 2 dataset (CIESIN 2013b). Processing coastal elevation over large areas is time consuming, so using the global LECZ data expedited this work. That said, there is strong scientific grounding adding the increments (Dasgupta et al. 2007; Hallegatte et al. 2011).

In the model, the proportion of each grid cell at or below sea level is calculated for 2010 and under the projection to 2050 (for both the 1-meter and 2-meter sea level rise), and the amount is linearly interpolated for each five-year time step in between. As described in section 3.2, the model implements sea level rise by progressively removing land from occupation, thereby reducing the population that will be accommodated in a coastal grid cell over time. A supplementary analysis was conducted for coastal countries on the population movements into or out of the 5-kilometer coastal strip (because of sea level rise and other climate impacts), using the 1-kilometer grid cell model outputs (that is, not outputs aggregated to 15-kilometer grids as for the other analyses).

3.1.5 Population Data

For the population baseline, we used the 2010 baseline in the Center for International Earth Science Information Network (CIESIN) Gridded Population of the World ver. 4 (GPWv4) (CIESIN 2016). For a representation of the population distribution of West Africa based on GPWv4 for 2015 see figure 2.7). The gravity model was calibrated twice, first based on population change estimates for 1990–2010 derived from GPWv3 (CIESIN, CIAT, and FAO 2005), and second for 2000–10 from GPWv4. GPWv3 and v4 model population distribution on a continuous global surface were based on the highest spatial resolution census data available from the 2000 and 2010 rounds of censuses, respectively. We used population count grids adjusted to national-level estimates from the UN World Population Prospects reports. GPWv3 and v4 are gridded data products with output resolutions of 2.5 arc-minutes (a square approximately 4 kilometers on a side at the equator) and 30 arc-seconds (a square approximately 1 kilometer on a side at the equator), respectively. Calibration was run at two resolutions: 2.5 arc-minutes for 1990–2010 (in two decadal time steps) and 30 arc-seconds for 2000–10 to check for any variation in outcomes that might result from alternative resolution (specifically comparing 2000–10) at different resolutions. The decision to take an exploratory approach to calibration reflects the resolution at which the model was applied for future projections (1 kilometer), and the maximum number of historic periods against which to fit the model (more details below).

Uncertainties in GPWv4 2010 population count grid relate to the timeliness and accuracy of the underlying census data and to the input resolution of the census units. In West Africa, the census year ranges from 2004 in Sierra Leone to 2014 in Côte d'Ivoire, and the mean size of the input units ranges from 191 square kilometers in São Tomé and Príncipe to more than 112,000 square kilometers in Niger (table 3.5). Further uncertainties in the year 2000 estimates relate to the lowest common denominator spatial units that match between the years in GPWv3 and GPWv4, or for which growth rates are available. These units apply consistent rates of change across all subunits. So, for example, if only admin 1 units (state or province) match between censuses, population is backcast from 2010 to 2000 by using consistent rates of change across those units, even if GPWv3 and GPWv4 included population count data for 2010 at a significantly higher resolution (i.e. admin2 or admin3). This affects the confidence in the decadal population change grids used for model calibration. For

West Africa, populations for 2000 were backcast at admin 0 (country level) for Senegal and admin 1 for Liberia and Nigeria (table 3.5). All other countries had matching admin 2 or 3 units across both versions of GPW, which provided higher levels of confidence in backcast population distributions. Because of corresponding admin 3 units over each census time step, calibration of the model was performed using historical ISIMIP index values with population data from Mauritania, Guinea, and Sierra Leone.

Table 3.5 Population Data Inputs by West African Countries for GPWv4

Country	Census year	Admin level	Mean unit size (km^2)	Growth rate: start	Growth rate: end	Growth rate: admin level at which GR is applied
Benin	2013	2	3,456.1	2002	2013	2
Burkina Faso	2006	3	1,448.7	1996	2006	3
Cabo Verde	2010	2	314.2	2000	2010	2
Chad	2009	2	7,0637.4	1993	2009	1
Côte d'Ivoire	2014	4	1,226.9	1998	2014	3
Gambia, The	2013	2	536.2	2003	2013	2
Ghana	2010	2	2,923.6	2000	2010	2
Guinea	2014	3	1,315.8	1996	2014	3
Guinea-Bissau	2009	2	1,219.2	1991	2009	2
Liberia	2008	2	1,228.9	1984	2008	1
Mali	2009	4	79,610.4	1998	2009	3
Mauritania	2013	3	74,902.9	2000	2013	3
Niger	2012	2	112,392.1	2001	2012	2
Nigeria	2006	2	2,898.3	1991	2006	1
São Tomé and Príncipe	2012	2	191.1	2001	2012	2
Senegal	2013	2	8,458.2	2002	2013	0
Sierra Leone	2004	3	773.1	1985	2004	2
Togo	2010	2	2,846.9	2000	2010	2

Note: Admin level refers to governmental level. 0 = country, 1 = state/province, 2 = county (or equivalent), with levels 3 through 6 representing progressively smaller units such as local government areas or villages

Though modeling for West Africa was carried out at the original 1-kilometer spatial resolution of the GPWv4 data (30 arc-seconds), they were aggregated to approximately 15-kilometer grid cells (7.5 arc-minutes), consistent with Groundswell report. This distance better reflects attribution to migration, and the data analysis and visualization methods are appropriate only at this coarser resolution. This is primarily because the resolution at which analysis is undertaken, by proxy, defines what qualifies as a migration. This work assumes that differences between models that include and exclude climate change impacts are driven by migration. Realistically it is not possible to speak of differences at 1-kilometer resolution being due to migration, but at 15-kilometer resolution (the modeling resolution used in the original Groundswell results) these differences can feasibly be attributed to migration.[40] Similarly, at higher spatial resolution we would always obtain higher levels of migration, because aggregate differences across grid cells will be higher if the total number of grid cells is higher. Thus, it is important to balance spatial resolution with a realistic definition of the distance that constitutes a migration. Here, although we run the model at higher

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[40] Definitions of migration generally carry with them some minimum distance. According to the UN (1970), "A migration is (…) operationally defined as a change of residence from one civil division to another, and the volume of migration is to a considerable degree a function of the size of areas chosen for compilation." If the smallest civil division is a village or town, then in much of the world 15 kilometers is the approximate distance between settlements.

resolution than in the original Groundswell report, we aggregate to the same spatial resolution because it represents a reasonable definition of meaningful human movement. Note, however, that for analyses of the population movements into or out of the 5-kilometer coastal strip (because of sea level rise and other climate impacts) of interest in the WACA context,[41] the 1-kilometer resolution data are used.

3.1.6 Nonclimate Factors

In the West Africa modeling, we applied three additional spatial data layers to the climate impact and no-climate impact model runs. These included data on conflict occurrence over the past decade and data on the age and sex structure of the population.

Conflict

Spatial data on conflict occurrence was obtained from the Armed Conflict Location & Event Data (ACLED) database (Raleigh et al. 2010) and interpolated through spatial kriging.[42] A spatial layer was developed of the point locations of every conflict event for the 10 years spanning 2009 to 2018, and the values at each point were the number of fatalities. Spatial kriging (a form of interpolation) created a continuous surface to fill in the gaps between points, yielding a surface where each 1-kilometer pixel has a value associated with the relative amount of conflict fatalities. This surface was applied in model calibration to identify the impact of conflict on spatial population patterns and derive the coefficients (see appendix B.2 for details on the calibration results).

Demographic Characteristics—Median Age and Sex

Spatial data on the age and sex distribution per grid cell were obtained from the GPWv4.10 Basic Demographic Characteristics (CIESIN 2017). Data on median age and the sex ratio (males as a percentage of female population) calibrated the model by establishing the relationship between spatial population change and demographic characteristics of the population.

In this report the model was run at 30 arc-second (approximately 1-kilometer) resolution but aggregated to 7.5 arc-minutes for analysis and the production of maps and statistics. All modeling in the previous Groundswell report was conducted at a 7.5 arc-minute (approximately 15-kilometer) resolution, which was the original resolution of the National Center for Atmospheric Research-CUNY Institute for Demographic Research (NCAR-CIDR) model. The higher resolution reflects the spatial needs of the global change community for which the model was originally developed. In general, this resolution is adequate for spatial projections of, for example, patterns of emissions or exposure to climate hazards for applications at the global or regional scale. However, at the subnational level, it can overly generalize patterns of population change. Nevertheless, aggregation to 7.5 arc-minutes is needed, because, as noted above, at higher resolution it becomes difficult to attribute observed differences in outcomes between the climate and nonclimate scenarios to climate-induced migration.

The Groundswell report does not assume or apply any maximum population density in rural areas before they either reached carrying capacity or became urban. However, research suggests such limits may exist. In Kenya, for example, densities beyond a threshold of 500–600 persons per square kilometer resulted in no further intensification and in declining household income per adult (Muyanga and Jayne 2014), and other evidence suggests that thresholds may be reached in subsistence agricultural systems of Africa (Jayne, Chamberlin, and Headey 2014). Based on an assessment of population densities in rural areas of Africa, using each 1-kilometer grid cell of GPWv4 as a unit and identifying rural and urban areas using CIESIN's GRUMP v1 data set (CIESIN 2011), we evaluated population densities across all grid cells. See table 3.6.

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[41] Note that there is no universally accepted definition of the coastal zone. In Denmark, the Planning Act (1991) defines the landward boundary of the coastal zone as a 3-kilometer inland from the coast, and the seaward boundary as the shoreline, but in Spain, under the Shores Act (1988), the landward is up to 200 meters from the inland limit of the shore. Lavalle et al. (2000) adopt a definition of 10 kilometers. Our definition represents a middle ground that accounts for the modeling resolution of 1 kilometer, and assumes that livelihood activities tied to the coast are likely to be within the first 5 kilometers.

[42] See The Armed Conflict Location & Event Data Project at https://acleddata.com.

Table 3.6 Population Density of Rural and Urban Areas

Rural Population Density	Urban Population Density
Maximum: n.a. 99 percentile: 614 SD: 149 Mean: 77	Maximum: 80,500 99 percentile: 11,366 SD: 2,625 Mean: 1,011

Note: n.a. = not available, SD = standard deviation.

Based on these statistics, a threshold for maximum rural population densities of 1,000 persons per square kilometer were applied, and a threshold of 50,000 person per square kilometer for urban areas. These thresholds were applied to groups of 15-square-kilometer pixels, so that while any one 1-kilometer pixel may exceed the level, on average the threshold could not surpass 1,000 persons (rural) or 50,000 persons (urban) per square kilometer.

3.1.7 Coefficients

The enhanced model includes model coefficients that show the influence of the variable on the observed deviation between observed and projected population change (spatial shifts) based on historical calibration of climate signal from 1990–2000 and 2000–10. The variables are crop production, water availability, NPP, median age, sex ratio, conflict-related fatalities, and flood risk. Crop productivity and NPP are not included in the calibration for urban populations because these are not hypothesized to have an impact in those areas (their populations are not directly dependent on cropping or animal husbandry).

The coefficients for the West African countries in table 3.7 represent the average of the coefficients across the two decades for Mauritania, Guinea, and Sierra Leone. These are the only countries whose population data met the criteria for the calibration. Note that sea level rise is not a driver of migration, but rather is inserted as a spatial mask in the modeling work to move populations out of inundated areas.

Table 3.7 Coefficient Values for West African Countries

Predictor	(Parameter) coefficient		Units
	Urban	Rural	
Crop production	n.a.	0.400	5-year deviation from historic baseline
Water availability	1.696	1.071	5-year deviation from historic baseline
Net primary productivity[a]	n.a.	0.380	5-year deviation from historic baseline
Median age	0.617	0.078	Median age of the population in years
Sex ratio	0.024	0.006	Males/females
Conflict-related fatalities	−0.025	−0.003	Number of recorded fatalities
Flood risk	0.147	0.020	5-year likelihood of flood event

Note: Data represent an average of the calibrations based on Mauritania, Guinea and Sierra Leone data. n.a. = not applicable.

a. Net primary productivity, which is intended to reflect impacts on pastoral populations, is included in the model only when crop production is not present.

Among the climate impacts, water availability is the strongest factor, particularly in urban areas, and positively correlated with population change. Therefore, increasing water availability results in increasing attractiveness, and vice versa. The coefficient for water availability in rural areas is around 2.7 to 2.8 times higher than that of either crops or NPP. Other things equal, areas with better water availability (as measured by the deviation from historic baseline) are projected to have relatively large positive population changes. In rural areas, larger values in crop yields or NPP are positively correlated with larger population change.[43] The magnitude of the coefficient is smaller, so its effect is not as strong as water availability. (As mentioned, crop production and NPP are not used to calibrate urban grid cells.)

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[43] Crop production is not used to calibrate urban grid cells.

Demographic variables of median age and sex (gender) distribution, introduced in this study's enhanced model, affect the climate migration projections through their relationship with population change (as derived through the spatial autoregressive calibration), and through their interaction with the climate drivers). In West Africa, the demographic variables mitigated or dampened climate migration. Results imply that while high median age tends to draw migrants to urban areas, which offer better economic opportunities, declines in water availability repel migrants, thereby offsetting each other. In short, when demographic effects are working against climate impacts, there are fewer migrants in West Africa. In contrast, in the Lake Victoria Basin (LVB) countries, the alignment between these factors means that they amplify the impact of climate (Rigaud et al. 2021a).

Flood risk is positively associated with population change, and once again, the effect is larger in urban areas by an order of magnitude. Clearly, floods do not attract populations; rather it is likely that this reflects the location of many urban areas in coastal areas and flood plains, which are prone to flooding.

3.2 POPULATION MODELING METHODS

Climate impacts on crop production, water availability, ecosystem productivity, and flood depth and extent affect the population potential of locations in the gravity model. The modeling work is based on a modified version of the NCAR-CIDR gravity model (Jones and O'Neill 2016).[44] Technical details on the model specification are in appendix B.1, and results of calibration of each input layer against changes in historical population during the 1990–2010 time period are in appendix B.2.

3.2.1 Gravity Model

The NCAR-CIDR model uses a modified form of population potential, a distance-weighted measure of the population taken at any point in space that represents the relative accessibility of that point (for example, higher values indicate a point more easily accessible by a larger number of people). Population potential is a measure of the influence that the population at one point in space exerts on another point. Summed over all points within an area, population potential represents an index of the relative influence that the population at a point within a region exerts on each point within that region, and can indicate the potential for interaction between the population at a given point in space and all other populations (Rich 1980). This potential will be higher at points closer to large populations; thus, potential indicates the relative proximity of the existing population to each point within an area (Warntz and Wolff 1971). Such metrics are often used as a proxy for attractiveness, under the assumption that agglomeration is indicative of the socioeconomic, geographic, political, and physical characteristics that make a place attractive.

3.2.2 Adding Climate Impacts

The calculation of potential was modified primarily by adding variables that describe local conditions, including climate impacts, and weighting the attractiveness of each location (grid cell) as a function of the historic relationship between these variables and observed population change. Figure 3.3 shows modeling steps; boxes in red show the addition of climate impacts (or results incorporating climate impacts), demographic characteristics, and conflict-related fatalities. Population potential is, conceptually, a relative measure of agglomeration, indicating the degree to which amenities and services are available. In the original model, this value shifts over time as a function of the population; assumptions regarding spatial development patterns (for example, sprawl compared to concentration); and certain geographic characteristics of the landscape. In this expanded version of the model, the agglomeration effect is enhanced or muted as a function of the characteristics discussed above that differentiate between places. In any given grid cell, the drivers may either act in concert, reinforcing one another (for example, rural grid cells with crop production and water availability declines), or they may offset each other (for example, flood risk may increase but water availability declines).

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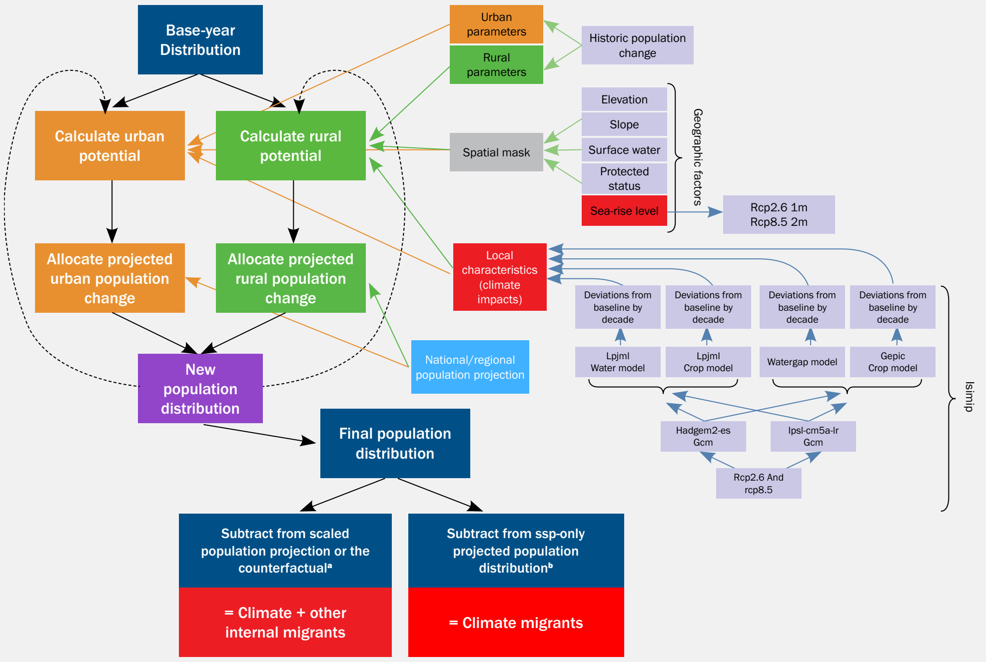
[44] Data for the original SSP-only population projections are available for download via the NASA Socioeconomic Data and Applications Center (SEDAC) at https://doi.org/10.7927/H4RF5S0P. These projections are produced using a baseline 2010 population of GPWv3 rather than GPWv4, as used here.

Figure 3.3 Modeling Steps



Note: Boxes in red represent the addition of climate impacts into the modeling framework or results that reflect climate impacts. SSP = Shared Socioeconomic Pathway.

a. The counterfactual population projection simply scales the population distribution in 2010 to country-level population totals appropriate to each SSP.

b. The no climate impacts population projection represents the population projection without climate impacts (that is, based only on the development trajectories embodied in the SSPs and the conflict and age and sex characteristics of the baseline population).

Beginning with the 2010 gridded urban-rural population distribution for each country,[45] the modeling for this report incorporated the influence of climate impacts on relative attractiveness in the following manner:

1. Calculate an urban population potential surface (a distribution of values reflecting the relative attractiveness of each grid cell).
2. Calculate a rural population potential surface.
3. Allocate projected urban population change to grid cells proportionally based on their urban potentials.
4. Allocate changes in the projected rural population to grid cells proportionally based on their rural potential.
5. Because the allocation procedure can lead to some redefinition of population from rural to urban (for example, rural population allocated to a cell with an entirely urban population is redefined as urban), this step entails redefining population as urban or rural as a function of density and contiguity of fully urban-rural cells to match projected national-level totals.

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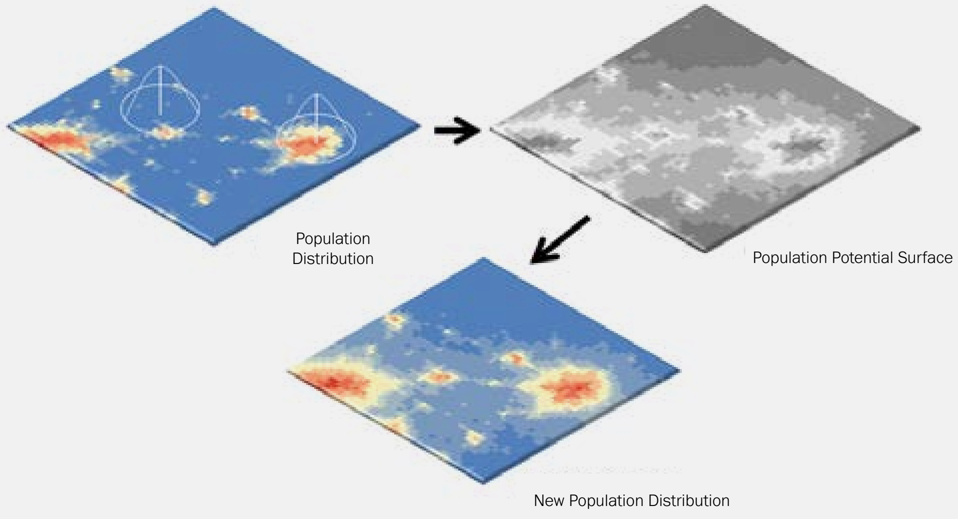
[45] Urban and rural population change need to be calculated separately because the factors that influence growth of urban and rural areas are distinct. Data on the evolution of population distributions show that historically urban and rural populations exhibit very different patterns of spatial population change (Jones and O'Neill 2013). The former tends toward agglomeration over smaller geographic areas that can take several different forms (for example, dispersion/concentration), while the latter occurs over larger geographic areas, varies across a wider range of patterns (including uniform and proportional) than urban populations, and is subject to periods of substantial population decline. Further, in fitting the model to historical data we find substantial variation in many parameters driving spatial population change. These two factors suggest that modeling urban and rural populations as separate but interacting components of the total population is advantageous compared to considering the entire population as a single entity.

These steps are then repeated for each decadal time interval. Figure 3.4 illustrates steps 3 and 4 for a hypothetical population distribution. Population potential surfaces, urban and rural, are continuous across all cells; each cell may thus contain urban and rural populations.

Figure 3.4 Hypothetical Example of Gravity-Based Population Projection Model for Single Time Step (Step 3 and 4 of the Modeling Exercise)



Based on the modified NCAR-CIDR population potential (vi) is calculated as a parametrized negative exponential function (equation 3.2):

$$v_i = A_i l_i \sum_{j=1}^{m} P_j^{\alpha} e^{-\beta d_{ij}}$$

Where:

A_i = Local characteristics

l_i = Spatial mask

a = Population parameter etc.

P = Population

β = Distance parameter

d = Distance

(3.2)

It is weighted by a spatial mask[46] (l) that prevents population from being allocated to areas protected from development or unsuitable for human habitation, including areas likely affected by sea level rise between 2010 and 2050. P_j is the population of grid cell *j*; *d* is the distance between two grid cells. The distance and population parameters (α and β) are estimated from observed patterns of historical population change (for the urban and rural populations, separately). The β parameter is indicative of the shape of the distance-density gradient describing the broad pattern of the population distribution

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46. Spatial masks are used in geospatial processing to exclude areas from consideration. The effect is that the algorithm is not applied in these areas. Examples would include protected areas or places where the terrain is too rugged to inhabit.

(for example, sprawl compared to concentration), typically a function of the cost of travel (with lower costs leading to residential patterns more indicative of sprawl). The α parameter captures returns on agglomeration externality, interpreted as an indicator of the socioeconomic, demographic, and political characteristics that make a place attractive or not.

The SSPs include no climate impacts on aggregate total population, urbanization, or the subnational spatial distribution of the population. We modified the NCAR-CIDR approach by incorporating spatial data including the ISIMIP sectoral impacts, demographic characteristics, and the distribution of conflict-related fatalities, all of which would likely affect population outcomes. The index A_i is a weight on population potential calibrated to represent the influence of these factors on the agglomeration effect that drives changes in the spatial distribution of the population. Data are incorporated into the model as 1-kilometer gridded spatial layers. The ISIMIP data represent five-year deviation from long-term baseline conditions, the demographic data are observed median age and sex ratio, and conflict-related fatalities are interpolated from point data. The value A_i is calculated as a function of these indicators. Numerically, it represents an adjustment to the relative attractiveness of (or aversion to) specific locations (grid cells), reflecting current water availability, crop yields, and ecosystem services relative to “normal” conditions, as well as the population’s demographics and the likelihood of dangerous conflict. The model is calibrated over two decadal periods (1990–2000 and 2000–2010) of observed population change relative to observed climatic and demographic conditions as well as safety (for example, conflict-related fatalities).
Details on the modeling methodology, including the methods used for calibration, and drivers of migration discovered during the calibration process, are in appendix B.

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3.2.3 Characterizing the Model

This modeling provides credible, spatially explicit estimates of changes in the population distribution (and indirectly migration) as a function of climate, demographic, and development trends. It is important to understand what the model does and does not do. Gravity models, in their simplest form, can reconstruct and quantify past evolutions of population distributions based on observed agglomeration effects over large geographic regions, under varying conditions, and at alternative spatial scales. They can also be refined and expanded to incorporate additional details, such as environmental parameters that affect the relative attractiveness of locations, typically improving the capacity of the model to accurately replicate past trends and thus, theoretically, project into the future.

Gravity models do not directly model internal migration. Instead, internal migration is assumed to be the primary driver of deviations between population distributions in model runs that include climate impacts (in our model crop production, ecosystem productivity, water availability, and flood risk) and the development-only (also referred to as the SSP, or no climate, models that include only the demographic and conflict metrics). Both types of models include the agglomeration effect. Migration is a “fast” demographic variable compared with fertility and mortality; it is responsible for much of the decadal-scale redistributions of population. Without significant variation in fertility or mortality rates between climate-migrant populations and nonmigrant populations, it is fair to assume that differential population change between the climate impact scenarios and the development-only scenarios occur as a function of migration. The model assumes that fertility and mortality rates are relatively consistent across populations in a locale. Note that the model does not provide any information about the directionality of migration. In other words, it cannot be inferred that migrants are moving from a given area of out-migration (for example, a hotspot of climate out-migration) to a given area of in-migration. Rather, the model reflects broader changes in the spatial distribution of population because of climate impacts, with the distribution changing incrementally with each time step.

For each climate migration scenario, the model produces a range of estimates that reflect variation in the underlying inputs to the model, which in turn reflect scientific uncertainty over likely future climate projections and impacts and development trajectories (box 3.2). In any scenario, outcomes are a function of the global climate models and the sectoral impact models that drive climate impacts on population change. For each of the four scenarios, there are four models, consisting of different global climate model/ISIMIP combinations. The ensemble mean (or average) of the four models is reported as the primary result for each scenario. Uncertainty is reflected in the range of outcomes (across the four models) for each grid cell and at different levels of aggregation. While some may prefer to have just one figure, in a complex issue such as climate-related migration, a scenario-based approach of plausible outcomes is preferable. It would be desirable to have even more scenarios to better assess the uncertainty (or conversely confidence) in the results. However, time and resource constraints prevented more than four realizations for the model per climate-development combination.

Box 3.2 Sources of Uncertainty in Modeling Climate Migration

The climate migration modeling results incorporate five main sources of uncertainty that can affect the estimated number of internal climate migrants or the differences between the four scenarios and the development-only scenario.

ISIMIP impacts vary across models. The differences result in different effects in the gravity model; models with the highest negative impacts repel more people from affected areas than those projecting fewer extreme outcomes. Similarly, in isolated cases (a small number of grid cells) different ISIMIP models can disagree on the positive or negative nature of changes, leading one model to attract population and the other to repel.

Variations between the two global climate models—HadGEM2-ES and IPSL-CM5A-LR—can amplify the ISIMIP differences. The global climate models were selected in part because their future precipitation trends differ substantially in magnitude, and partly even in sign (see appendix A). This variance in precipitation affects the water, crop, and NPP models.

The modeling has a temporal component that can influence population distribution trajectories. Stronger sectoral impacts early in the 40-year projection period will have greater influence than the same impacts later in that period, because those early impacts affect the gravitational pull of locations, creating "temporal" momentum over which later climate impacts may have less influence. Similarly, the timing of population change (growth or decline) projected by the SSPs relative to the development of sectoral impacts can influence outcomes. For example, for most countries in the study, projected population growth is greatest during the first decade. If conditions are predicted to deteriorate severely during that period, the impact on migration will be greater than if the deterioration occurred during a more demographically stable period.

If the no climate impacts model finds that a place is relatively attractive and the sectoral climate impacts are positive or neutral (relative to other areas that see negative impacts), it will reinforce the attractiveness of that area. Conversely, in remote areas experiencing population decline and negative climate impacts, "push" factors will be reinforced. This phenomenon creates spatial momentum.

Model parameterization affects the results. The model was calibrated using actual population changes and actual climate impacts (represented by ISIMIP model outputs) for two periods, 1990–2000 and 2000–10. This calibration was done using the two separate sets of model combinations: the LPJmL water and crop models and the WaterGAP water and GEPIC crop models (supplemented by the LPJml and Visit NPP models). Different parameters correspond to the different models. If the parameter estimates are close across the crop or water models, there will be less variation in the population distribution projected by each model. The uncertainty around the ensemble mean (measured using the coefficient of variation) will therefore be lower. Conversely, if parameter estimates are not close, there will be greater uncertainty around the ensemble mean.

The model is analyzed at spatial and temporal scales that capture migration well. With grid cells of about 15 square kilometers at the equator, population shift can be a form of short-distance migration. The temporal scale of five-year increments from 2010 to 2050 is adequate to capture the longer-term shifts in population caused by changes in water availability, crop conditions, ecosystem productivity, and flood risk. The five-year temporal resolution of the model corresponds to the temporal resolution most national censuses consider when attempting to capture and quantify migration trends.[47] The model does not capture shorter-term and seasonal migration.

The focus is on the 30 years between 2020 and 2050, which represent a meaningful planning horizon, especially considering the social dimension of migration. Chapter 4 of Rigaud et al. (2018) considers water and agriculture sector impacts beyond 2050 by examining ISIMIP outputs for 2050–2100. The authors suggest that, if anything, the climate signal will become far stronger toward the end of the 21st century. Appendix C of this report provides those projections for West Africa. Under RCP8.5, the western portions of the region (Senegal, The Gambia, parts of Guinea-Bissau, and southern Mali) and in some cases the southern portions (from Côte d'Ivoire in the west to Benin and even Nigeria in the east) are projected to get much drier by the end of the century. If these projections materialize, they will amplify further the impacts on migration.

The model cannot forecast all future adaptation efforts, conflicts, or cultural, political, institutional, or technological changes. Discontinuities are likely to arise because of political events and upheavals that can heavily influence migration behavior. Armed conflict may have nonlinear links to climate variability and change, but models are generally not sophisticated enough to forecast the changing nature of armed conflict or state failure with any precision. The scenario framework is not designed to predict shocks to any socioeconomic or political system, such as large-scale war or market collapse. The models cannot anticipate new technologies that may dramatically affect adaptation efforts to the degree that climate impacts become negligible. The SSPs, as well as output from the global climate model and ISIMIP, reflect plausible futures that span a wide range of global trajectories, with the caveat that extremely unpredictable or unprecedented events are explicitly excluded. The SSPs assume certain levels of adaptation and a continuation of the business as usual, and the projected scale of migration is not cast in stone. The scenario-based results in the study should be seen as a plausible range of outcomes rather than precise forecasts to spur policy and action to counter distress-driven climate migration.

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47. Migration data are sporadic in national censuses, but when present, they are typical based on a "five-year question," which prompts respondents to indicate where they lived five years ago.

Water availability—in both rural and urban areas—will be the strongest driver of internal climate migration in West African countries.

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Chapter 4

Modeling Results: Climate Impact Projections

This chapter presents the modeling results of the projected climate impacts on water availability, crop production, net primary productivity (NPP), and flood risk (derived on the basis of the Intersectoral Impacts Model Intercomparison Project [ISIMIP] simulation models) and for sea level rise compounded by storm surge. Results are presented relating to the nonclimate factors: demographic (including median age and sex) and conflict. These climate and nonclimate impact results form the basis of the modeling outcomes of the plausible future climate migration scenarios presented in chapter 5.

4.1 CLIMATE IMPACT MODELS

Panels in figures 4.1 to 4.3 present the average projected changes in water availability, crop production, and NPP for the 2010–50 time period, respectively. NPP is used to gap-fill areas where there is no crop production. These projections represent the inputs for estimated future population shifts induced by climate change as a proxy of climate migration.[48]

4.1.1 Water, Crop, and Ecosystem Productivity

Water availability is the strongest factor that will influence migration in West Africa over the next few decades. The water models project drying in the western Sahel (Senegal into western Mali) and wetting in the eastern Sahel (Burkina Faso and Niger), consistent with patterns in the Coupled Model Intercomparison Project phase 5 (CMIP5) archive (Biasutti 2019, see also Chapter 2.3). Figure 4.1 depicts the average index values across the model runs for the 2010–50 period for the water models. The extreme values in the northern Sahel and into the Sahara Desert are a function of extremely low baselines. Appendix C has projections from 2050–2100. The maps show the same patterns, but with accentuated impacts in the western Sahel, but also the south under the IPSL-CM5A-LR global climate model, especially under Representative Concentration Pathway 8.5 (RCP8.5).

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[48] Since NPP is used in the migration model only to gap-fill areas where there is no crop production in rural areas, this does not apply to Nigeria because there is no part in the country without crop production.

The water modeling results vary considerably among West African countries. The climate models project that by 2050 Senegal is almost certain to become drier in the western and coastal areas, and that under some models the whole country will become drier, in some cases significantly (for example, for the WaterGAP models under RCP8.5). Ghana will see modest wetting in the north and drying across several models in the south. Drying may be high: up to 50 percent to 70 percent reductions in water availability in the Accra metropolitan area under the IPSL-CM5A-LR global climate model (GCM) coupled with WaterGAP by 2050. Results suggest that Mauritania will become drier in the western and coastal areas under the Had-GEM2-ES GCM, and that water availability will more than triple in some of the arid interior areas, but against a very low baseline such that changes may not be that significant from a livelihoods' perspective. Côte d'Ivoire will see an increase in water availability between now and 2050 under most model runs. Only under the IPSL-CM5A-LR GCM is there some drying in the eastern portion of the country.

The projections for crop models are more nuanced than for the water models. Figure 4.2 depicts the average index values for the crop models for the 2010–50 period. The LPJmL crop model projects more widespread decreases of 10 percent to 30 percent across much of the region (except Sierra Leone and Liberia and the northern Sahel), whereas the GEPIC model produces a patchwork of mostly increases with some decreasing crop production. Appendix C has projections from 2050–2100. The maps show the same patterns, but with accentuated impacts, especially under RCP8.5.

Model runs show mixed crop production among the countries. In Nigeria, by 2050 the LPjML model shows 10 percent to 30 percent declines in the middle belt of the country (away from the river basins), and GEPIC shows more mixed results, including areas with increases in crop production. The notable increase in water availability in the north and northeast reflects increases in crop production, particularly under the GEPIC models. In Côte d'Ivoire, agriculture is largely stable or there are increasing yields for staple crops, though with patches of decline. In the south of Mauritania, crop production declines under most model runs.

In rural areas, high values in crop yields and NPP are positively correlated with larger population change. Ecosystem productivity models—enhancements to the original Groundswell modeling work (Rigaud et al. 2018) —are important measures for pastoral livelihoods. A large portion of the Sahel is inhabited by pastoralists who engage in livestock herding, and this livelihood is very climate sensitive. Ecosystem productivity or NPP models are used only in areas lacking crop productivity data, since there is high spatial co-linearity between crop and ecosystem metrics.[49]

Generally, the wetting in climate models used to assess NPP suggests great increases in plant biomass in the northern Sahel and into the Sahara, but these are against a very low baseline productivity (figure 4.3). For example, the dramatic changes in NPP in Mauritania, similar to precipitation patterns, are against a very low baseline, and should be interpreted in this light (figure 4.3). In some cases, the NPP model outputs are shown only for information purposes (because there are very limited parts of the countries without crop production, for example, Nigeria).

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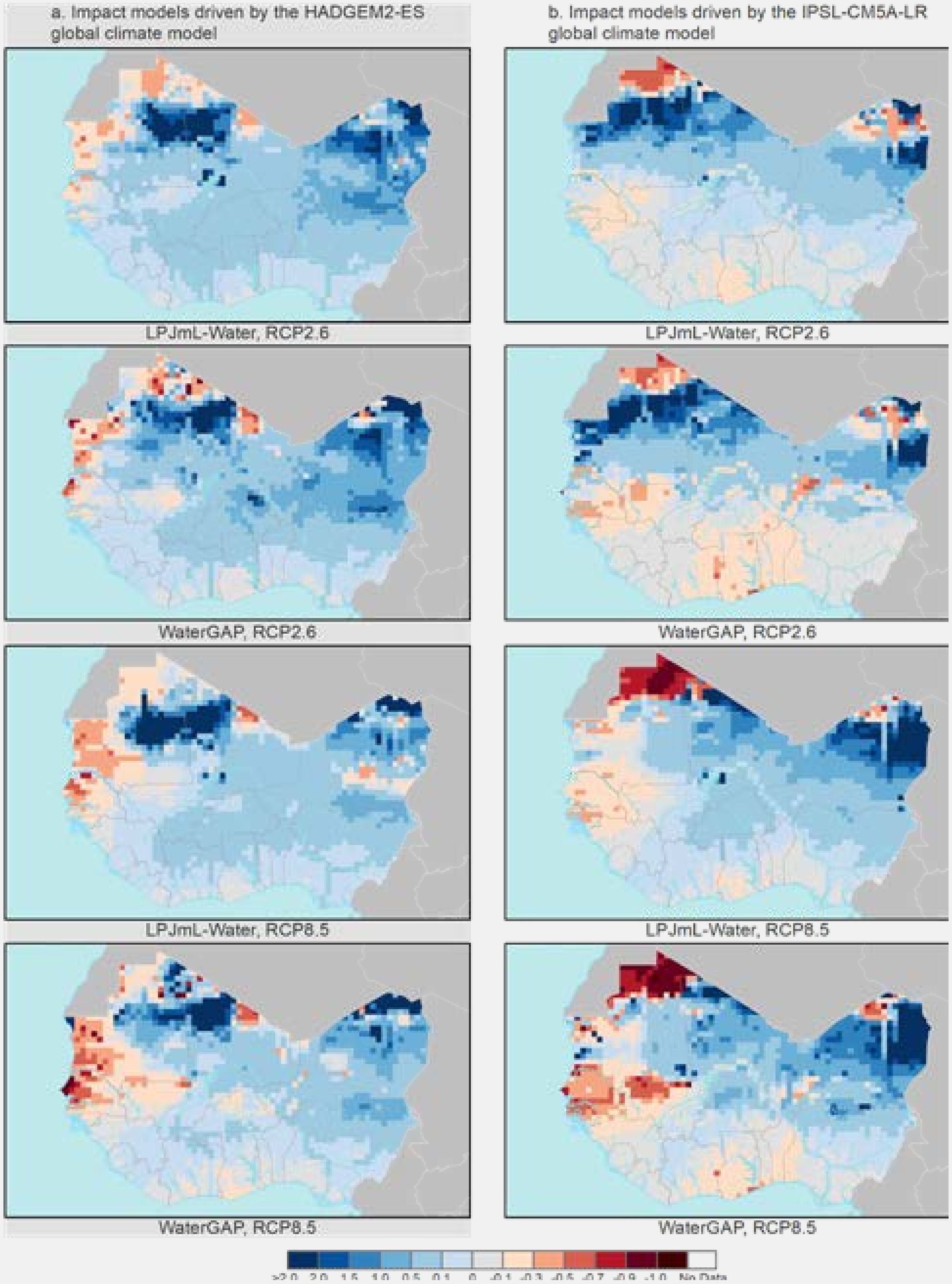
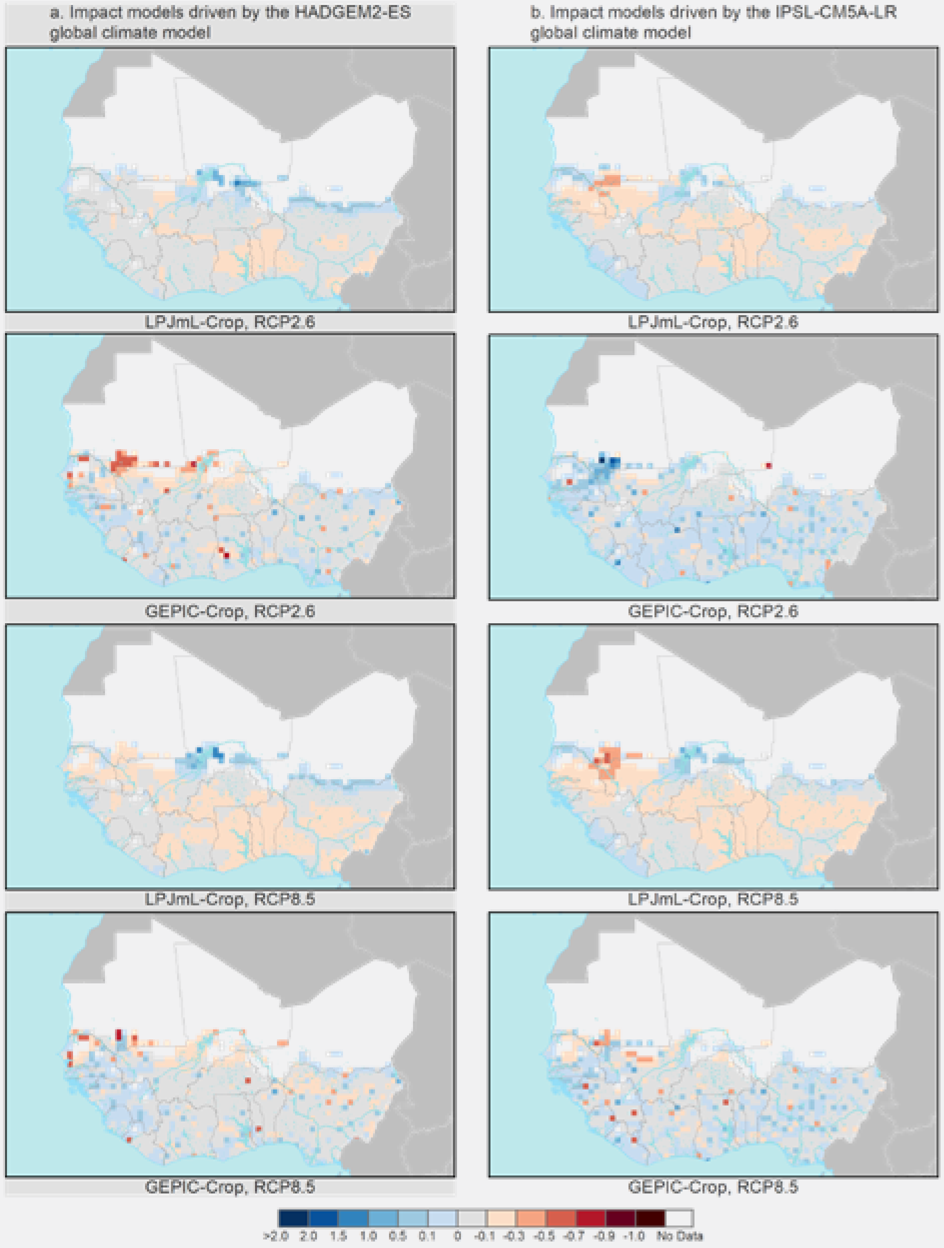
49. This means that adding ecosystem impacts would only repeat information in the ISIMIP crop production impacts.

Figure 4.1 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, West Africa, 2010–50



Note: Data calculated against 1970–2010 baseline for water availability from HadGEM2-ES (panel a) and IPSL-CM5A (panel b) climate models, with RCP2.6 model runs in the top four maps and RCP8.5 model runs in the bottom four maps. Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

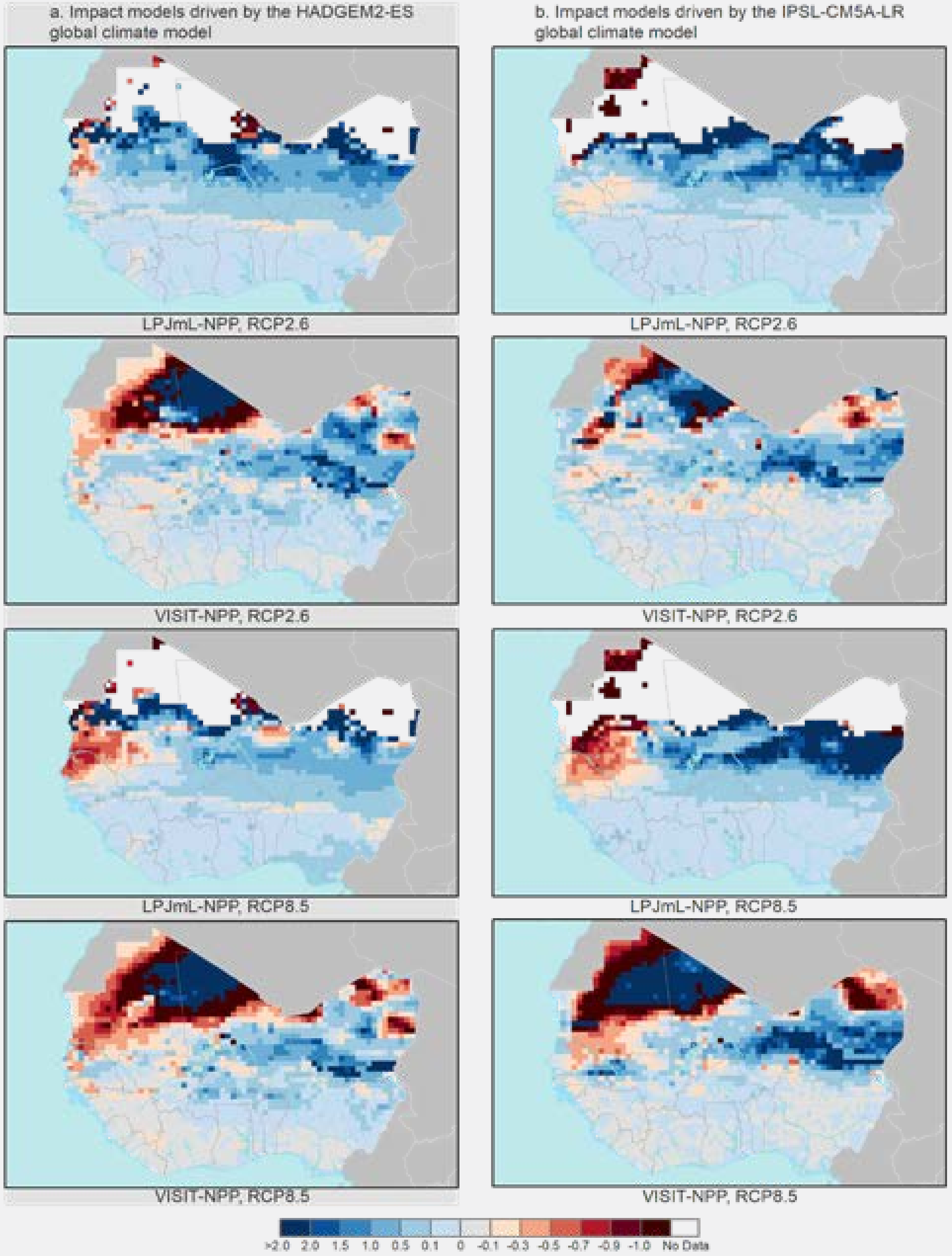
Figure 4.2 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, West Africa, 2010–50


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A-LR global climate model

Note: Data calculated against 1970–2010 baseline for crop production, driven by the HadGEM2-ES (panel a) and IPSL-CM5A (panel b) climate models, with RCP2.6 model runs in the top four maps and RCP8.5 model runs in the bottom four maps. Blue areas indicate crop production increases relative to the historical baseline, and gray to tan to red areas indicate crop production decreases. White areas do not grow the four major crops: these gaps were filled with projections of ecosystem productivity.

Figure 4.3 ISIMIP Average Index Values against 1970–2010 Baseline for Ecosystem NPP, West Africa, 2010–50



a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A-LR global climate model

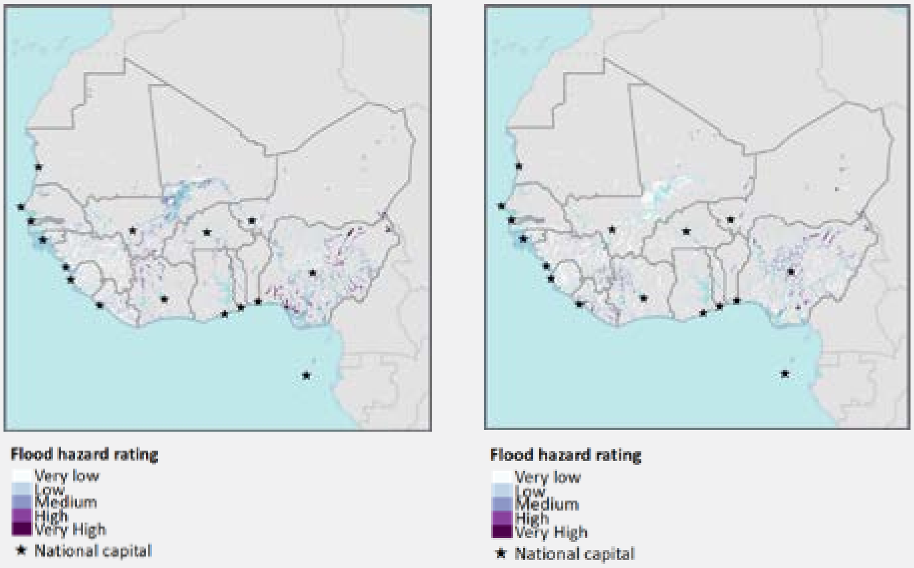
Note: Data calculated against 1970–2010 baseline for ecosystem NPP, driven by the HadGEM2-ES (panel a) and IPSL-CM5A (panel b) climate models, with RCP2.6 model runs in the top four maps and RCP8.5 model runs in the bottom four maps. Blue areas indicate higher NPP relative to the historical baseline, and tan to red areas indicate lower NPP. These projections were used to gap-fill areas without crop production projections. Extreme index values under the VISIT model in the Sahara are against very low baselines. NPP = net primary productivity.

4.1.2 Flood Models Used in the Gravity Model

Flood risk is positively associated with population change, and the effect is larger in urban areas by an order of magnitude. Figure 4.4, panels a and b, depicts flood risk data for West Africa under RCP2.6 and RCP6.0, representing low and high emission scenarios, respectively. Flood hazards are higher and more extensive under higher emissions—along main rivers—including the Niger River Basin from Mali through to Nigeria, Sasandra River in Côte d'Ivoire, and the Lake Faguibine system in Mali, which experiences seasonal flooding. The model runs for RCP2.6 were used in the climate-friendly and optimistic scenarios, and the model runs for RCP6.0 were used in the more inclusive development and pessimistic scenarios.

Paradoxically, flooded areas tend to attract population in the gravity model, because riparian areas have been historically more accessible and often host urban areas. Thus, flood risk will tend to attract new migrants rather than repel them; and this is consistent with the literature on flood risk in developing countries. For example, Jongman et al. (2012) state that "over the period 1970–2010 the number of people exposed to flooding globally has increased by 2.7 percent more than total population growth. Developing countries have, conjoint with general high population growth, experienced the strongest increase in exposed relative to total population." In addition, there is the well-documented trend in migration toward, and consequently population growth in, low-lying and flood-prone coastal areas (de Sherbinin et al. 2011; Neumann et al. 2015).

Figure 4.4 Projected Flood Hazard Rating, West Africa, 2040, RCP2.6 and RCP 6.0



a. RCP2.6

b. RCP 6.0

4.1.3 Sea Level Rise

The analysis considers sea level rise projections from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, augmented by an increment for storm surges. Under RCP2.6, the increment for storm surge was 0.85–0.9 meters, for a total of 1 meter; under RCP8.5, the increment was 1.68–1.85 meters, for a total of 2 meters. These assumptions are applied to all coastlines. They represent the loss of habitable land because of sea level rise plus storm surge in each coastal grid cell.

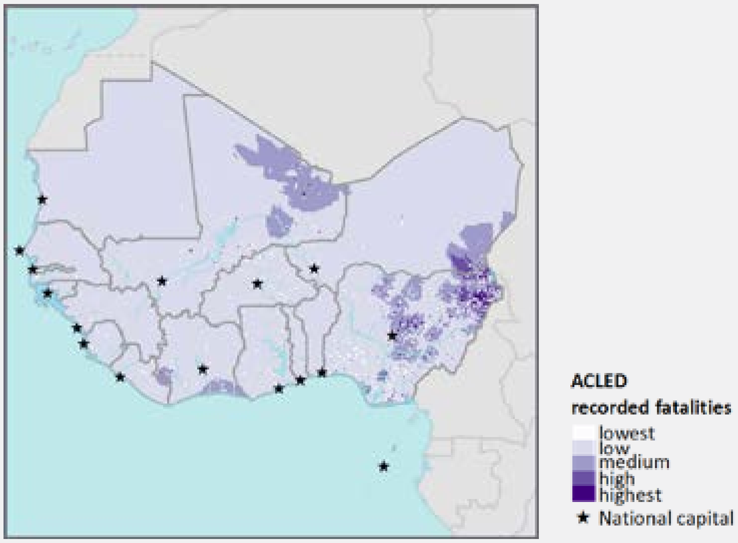
4.2 NONCLIMATE FACTORS

4.2.1 Conflict

Conflict hotspots tend to be associated with slow or declining rural population growth and slightly more rapid urban growth because when civil conflicts break out people tend to flee rural areas in search of protection in urban areas. Conflict-related fatalities are moderately negatively correlated with population change, decreasing attractiveness, again with a stronger effect in urban areas. However, the coefficients are small.

Spatial kriging (a form of interpolation) created a continuous surface to fill in gaps between points, yielding a surface where each 1-kilometer pixel has a value associated with the relative amount of conflict fatalities (figure 4.5). This surface was applied in model calibration to identify the impact of conflict on spatial population patterns. Spatial data on conflict occurrence was obtained from the Armed Conflict Location & Event Data Project (ACLED) database. A spatial layer was developed of the point locations of every conflict event between 2009 and 2018, and the values at each point were the number of fatalities.

Figure 4.5 Interpolated Conflict Surface, West Africa, 2009–18



Source: Adapted from CIESIN interpolation of Armed Conflict Location & Event Data (ACLED) for 2009-18.

Note: The fatality levels across the 10 years for each of these classes are as follows: lowest = 0, low = 1–34, medium = 35–102, high = 103–270, highest = 270–8,600.

4.2.2 Demographic Characteristics

Data on median age and the sex ratio (males as a percentage of female population) were used to calibrate the model by establishing the relationship between spatial population change and demographic characteristics of the population. The coefficient on median age used to calibrate the model was high in the West Africa region (table 3.6), meaning that it was influential. The reason is that urban areas typically have higher median ages than rural areas (figure 4.6) because of higher fertility rates in rural areas and patterns of rural-to-urban migration that typically syphon off working age adults from rural areas, adding them to the population of urban areas. The strong signal on a nonclimate-related parameter in West Africa may have contributed to the lower number of estimated climate migrants relative to the original Groundswell work (Rigaud et al. 2018). For example, the attractiveness of higher median age in urban area, as an underlying demographic pattern in West Africa, dampened the effects of water stress, which would otherwise drive climate out-migration. This is observed in the coastal areas of Senegal and Bight of Benin region from Côte d'Ivoire to Nigeria. Similarly, conflict-related fatalities are negatively correlated with population change, decreasing attractiveness of localities, with a stronger effect in urban areas, but here the coefficient is small. This is discussed further in appendix D. See figure 4.7, panels a and b.

In most regions, because of the propensity of youth to migrate to urban areas, rural areas would typically have higher median age. Also, lower sex ratios (more females than males) would typically be associated with rural areas (Siegel and Swanson 2004), and areas with higher sex ratios (more males per females) would typically be associated with urban areas. For future projections we assume that variability in the sex ratio and median remain constant over space.

Figure 4.6 Median Age, West Africa, 2010

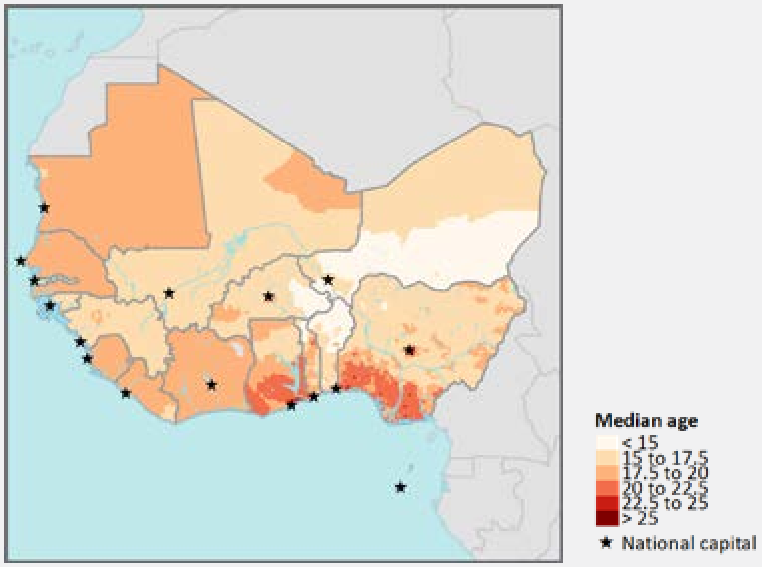
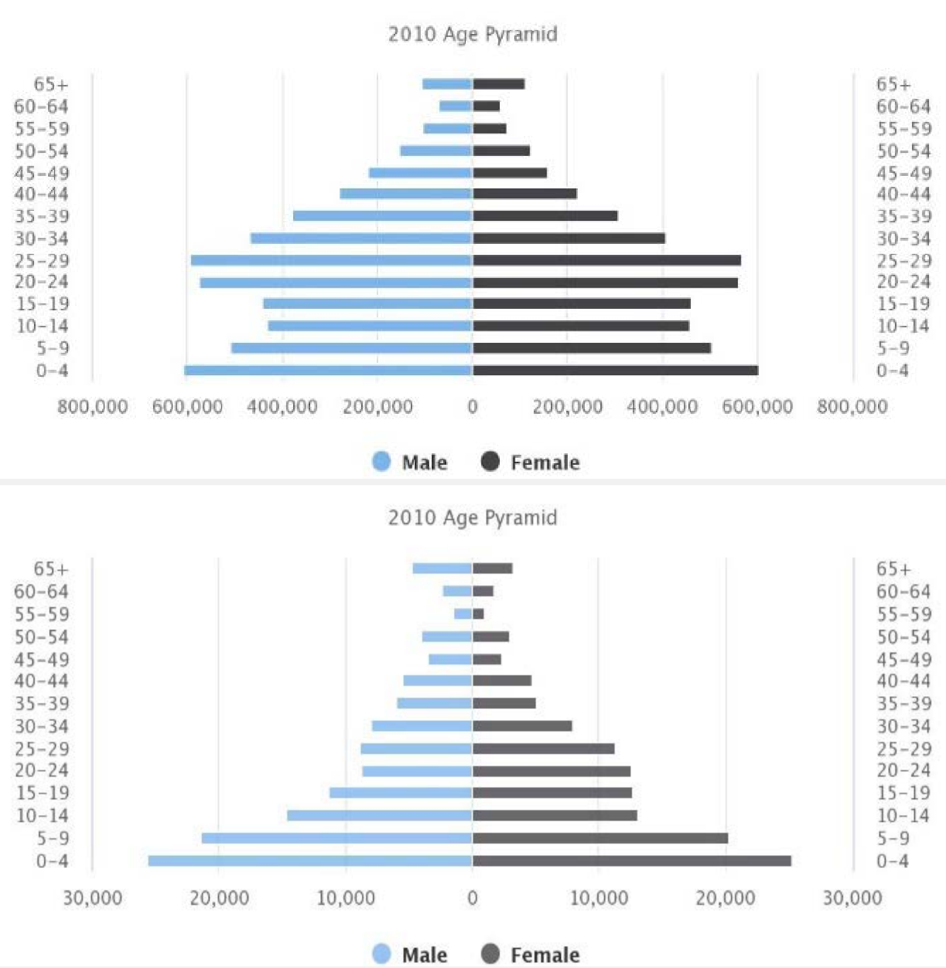
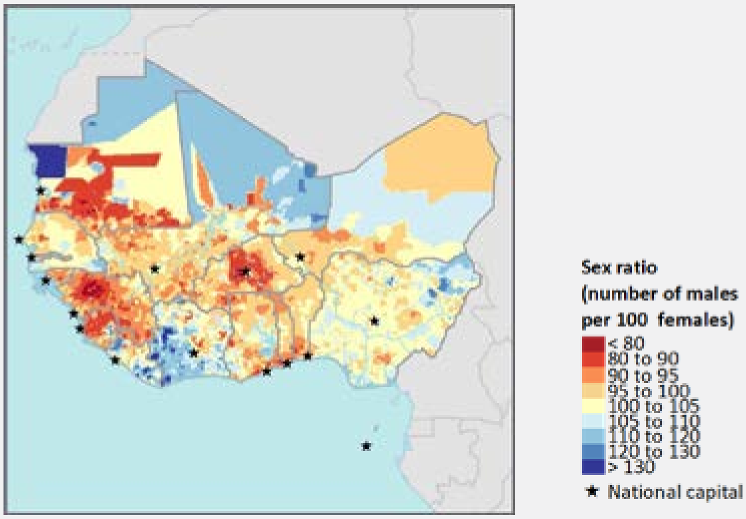


Figure 4.7 Age Pyramid for Lagos Area (top) and Rural Northern Nigeria (bottom), 2010



Source: CIESIN 2018a.

Figure 4.8 Sex Ratio, West Africa, 2010



West African countries will see an upward trajectory of Internal climate migration between 2025 and 2050—increasing up to five-fold. Early and concrete climate and development action could reduce this scale by 60 percent by 2050.

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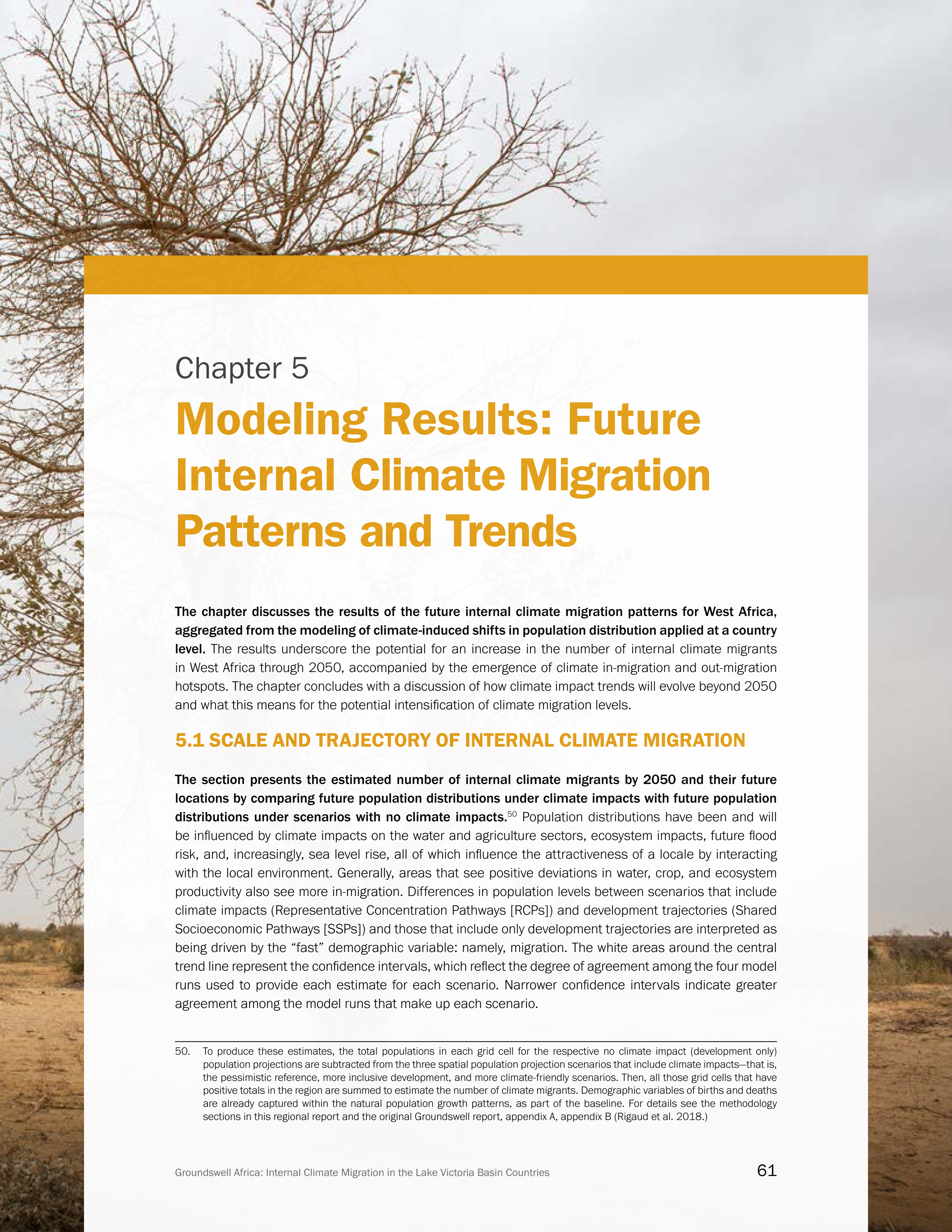

Chapter 5

Modeling Results: Future Internal Climate Migration Patterns and Trends

The chapter discusses the results of the future internal climate migration patterns for West Africa, aggregated from the modeling of climate-induced shifts in population distribution applied at a country level. The results underscore the potential for an increase in the number of internal climate migrants in West Africa through 2050, accompanied by the emergence of climate in-migration and out-migration hotspots. The chapter concludes with a discussion of how climate impact trends will evolve beyond 2050 and what this means for the potential intensification of climate migration levels.

5.1 SCALE AND TRAJECTORY OF INTERNAL CLIMATE MIGRATION

The section presents the estimated number of internal climate migrants by 2050 and their future locations by comparing future population distributions under climate impacts with future population distributions under scenarios with no climate impacts.[50] Population distributions have been and will be influenced by climate impacts on the water and agriculture sectors, ecosystem impacts, future flood risk, and, increasingly, sea level rise, all of which influence the attractiveness of a locale by interacting with the local environment. Generally, areas that see positive deviations in water, crop, and ecosystem productivity also see more in-migration. Differences in population levels between scenarios that include climate impacts (Representative Concentration Pathways [RCPs]) and development trajectories (Shared Socioeconomic Pathways [SSPs]) and those that include only development trajectories are interpreted as being driven by the “fast” demographic variable: namely, migration. The white areas around the central trend line represent the confidence intervals, which reflect the degree of agreement among the four model runs used to provide each estimate for each scenario. Narrower confidence intervals indicate greater agreement among the model runs that make up each scenario.

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[50] To produce these estimates, the total populations in each grid cell for the respective no climate impact (development only) population projections are subtracted from the three spatial population projection scenarios that include climate impacts—that is, the pessimistic reference, more inclusive development, and more climate-friendly scenarios. Then, all those grid cells that have positive totals in the region are summed to estimate the number of climate migrants. Demographic variables of births and deaths are already captured within the natural population growth patterns, as part of the baseline. For details see the methodology sections in this regional report and the original Groundswell report, appendix A, appendix B (Rigaud et al. 2018.)

For West Africa,[51] and notwithstanding variations in confidence intervals, all the scenarios display an upward trend in internal climate migration, with increases highest under the high emissions scenarios (RCP8.5). Although the climate migration modeling work was performed at country level, it is possible to piece the country results together to develop a regional picture. Table 5.1 shows the results for total climate change–induced internal migration for the region by 2050. Numbers are highest under the pessimistic scenario, with an average of 19.3 million migrants for the four model runs, and a low of 8.7 million and high of 32.0 million,[52] based on the confidence intervals, by 2050. The more inclusive development scenario is the next highest, followed by the more climate-friendly and the optimistic scenario, which projects the lowest number of climate migrants by 2050. This low estimate is highly unlikely given the evolution of the climate system of West Africa described in this report. The higher scale of internal climate migration under higher emissions scenarios (pessimistic and more inclusive) underscores the importance of achieving emissions reductions through early action. Lower emissions can reduce the average number of climate migrants significantly. While climate migrants as a percentage of population remain relatively low—averaging from 1.09 percent to 2.44 percent across the scenarios—it makes up a significant proportion of all migration, particularly under the high emissions scenarios (figure 5.1).

Table 5.1 Projected Total Climate Migrants for West Africa by 2050

	Scenario							
	Pessimistic (reference)		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	19.3		14.8		11		7.4	
Min. (left) and max. (right) (millions)	8.7	32	4.9	27	2.5	22.7	0.9	16.9
Internal climate migrants as a share of pop. (%)	2.44		2.18		1.39		1.09	
Min. (left) and max. (right) (%)	1.1	4.06	0.72	3.99	0.31	2.87	0.14	2.5

Note: The countries included in the regional totals include the coastal countries of Mauritania, Senegal, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and São Tomé and Príncipe, and the inland countries of Mali, Burkina Faso, and Niger. The lower bound does not include the higher resolution estimates of coastal displacement; if the displacement found in the 1-kilometer data were counted, the lower bound numbers would be higher.

The number of climate migrants in the region is expected to increase over the next 30 years, reflecting the growing potency of climate change impacts as factors driving future migration. Figure 5.1, panels a–d, shows the number of climate migrants for West Africa by scenario and by decade from 2020 to 2050. For the scenarios based on the more equitable development pathway (SSP2) (left-hand panels in figure 5.1), the increase is relatively consistent over time, whereas under the more inequitable development pathway (SSP4) (right-hand panels in figure 5.1), there is a slight upward inflection from 2040–50.

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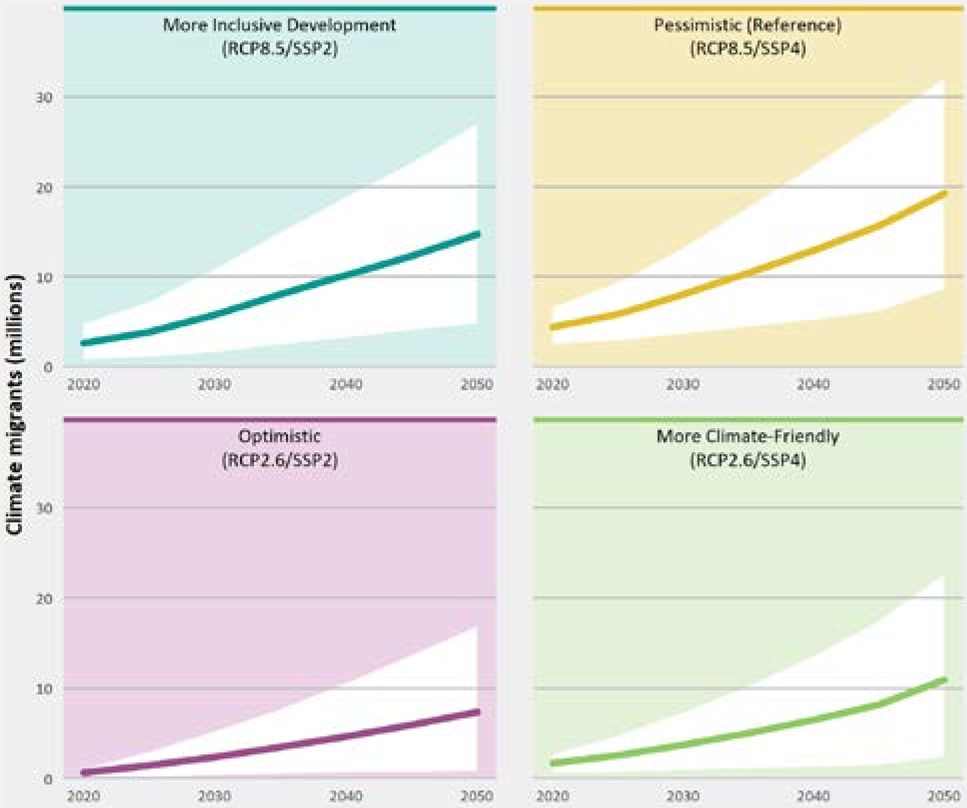
[51] The countries in the regional totals include the coastal countries of Mauritania, Senegal, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and São Tomé and Príncipe, and the inland countries of Mali, Burkina Faso, and Niger.

[52] While numbers for the region are lower than reported by Groundswell (Rigaud et al. 2018), the results are not directly comparable because of the different modeling resolution and new input layers (see box 5.1), and methodology.

Figure 5.1 Projected Total Internal Climate Migrants and Corresponding Confidence Intervals, by Scenario, West Africa, 2020–50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050
%	0.69	1.22	1.77	2.18

2020	2030	2040	2050
1.12	1.58	2.03	2.44

Year	2020	2030	2040	2050
%	0.18	0.51	0.82	1.09

2020	2030	2040	2050
0.44	0.74	1.02	1.39

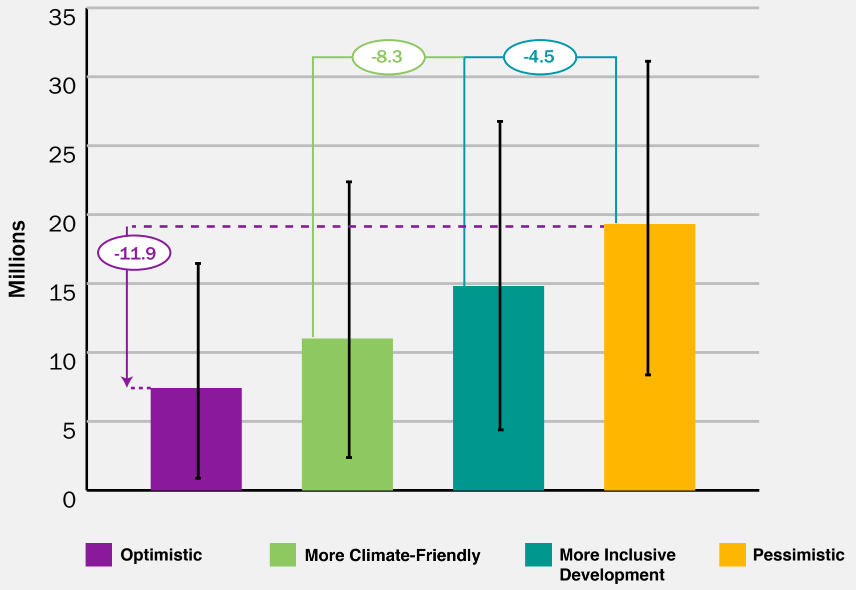
Note: The projected total population for the SSP2 and SSP4 pathways are different.

Box 5.1 Comparing Groundswell 2018 and Groundswell West Africa 2021 Results

The results under this Groundswell Africa model range from 2.5 million to 32.0 million (0.31 percent to 4.06 percent of the population, respectively) (excluding the optimistic scenario) compared to the Groundswell results, which range from 11.1 million to 64 million (2.27 percent to 6.87 percent of the population, respectively). Direct comparisons between the model results are difficult because of the substantial number of enhancements. It is widely recognized in the modeling community that refinements to models will affect results, often substantially. Despite the lower range in numbers, the relative order of magnitude of the scenarios is the same, and the trends and spatial patterns of change are similar. The good news is that the newly included optimistic scenario shows that the scale of distress-driven climate migration can be further reduced through intervening opportunities. The numbers here include only the coastal sea level rise–induced migration based on the aggregated/coarser resolution. If the displacement found in the 1-kilometer data were counted, the numbers would be higher. For more details, see appendix D.

Both inclusive development and low emissions are important for modulating the scale of climate migration, with greatest gains through early action. The more inclusive development scenario is projected to reduce the average internal climate migration by 4.5 million by 2050 compared to the pessimistic scenario. The climate-friendly scenario reduces average internal climate migration by 8.3 million (figure 5.2). Greatest gains are made when pursuing the optimistic scenario (low emissions and inclusive development), with reductions of 11.9 million; even so, the lock-in to climate migration cannot be ignored (at an average of 7.4 million, 1.1 percent). The patterns are different in each country. In Nigeria, which has the highest population in the region, more equitable and climate-friendly policies under the optimistic scenario can reduce the scale of internal climate migration by more than 80 percent: from 8.3 million to 1.2 million. A similar trend is observed in Senegal. These scenarios are not cast in stone: they provide a roadmap to chart out urgent and concerted action characterized by inclusive development and climate-friendly policies to reduce the adverse consequences of climate migration. Without collective global responsibility and action to meet the Paris targets, some of these gains may become more difficult to realize.

Figure 5.2 Reduction in Scale of Internal Climate Migrants from Pessimistic Reference Scenario, West Africa, by 2050



5.2 INTERNAL CLIMATE MIGRANTS COMPARED TO OTHER INTERNAL MIGRANTS

Other internal migrants include individuals who move internally within their countries due to changes in population growth, urbanization, income, and education (as set out in the SSP pathways). We calculated the projected number of other migrants by comparing projected population distribution under the SSP-only 2050 development scenarios (no climate) to a counterfactual in which the population in each grid cell is scaled according to the 2010 population distribution. The counterfactual is a world in which the population changes, but people remain in place. The difference between these two scenarios is considered development or "other" internal migrants.

The number of internal climate migrants compared to other internal migrants is projected to increase across scenarios and decades (figure 5.3, panels a–d). Under the high emission scenarios (pessimistic and more inclusive development), the scale of climate migrants remains close to that of other migrants at the high end of the projections by 2050.

Climate migrants will make up a high proportion of all migration by 2050 (figure 5.4). Climate migrants could account for one third of all internal migrants as early as 2030 under the pessimistic scenario. Nigeria, as the demographically most significant country in the region (51 percent of the total regional population), drives the levels and trends of climate migration.

Figure 5.3 Estimates of Internal Climate Migrants Compared to Other Internal Migrants, West Africa, 2020-50

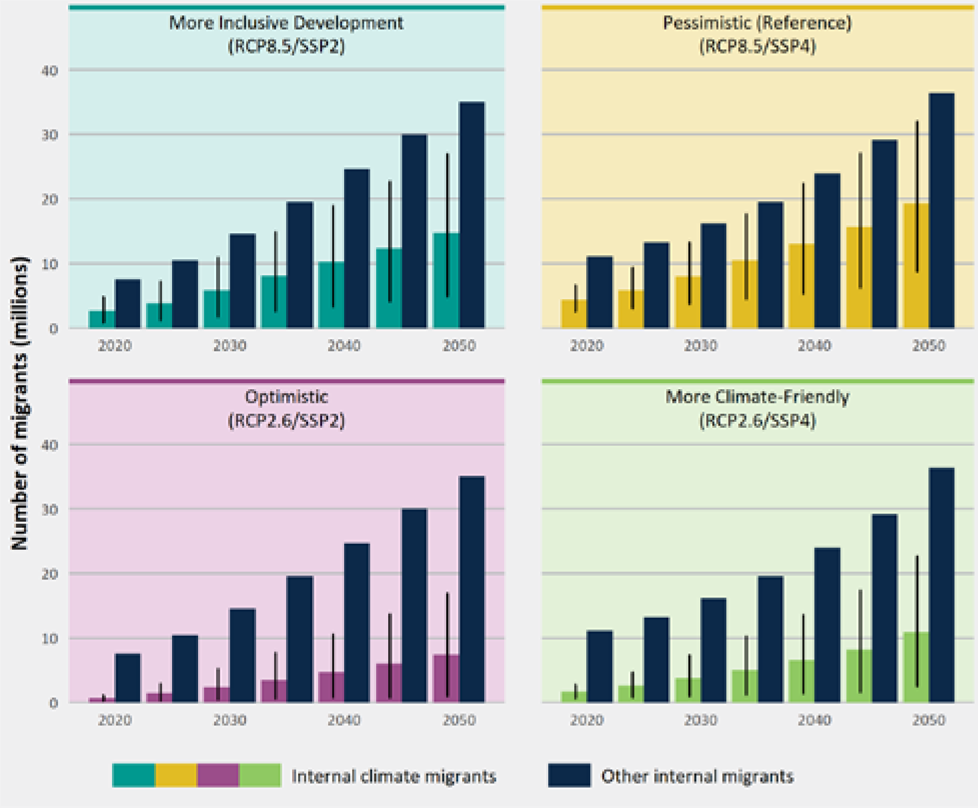
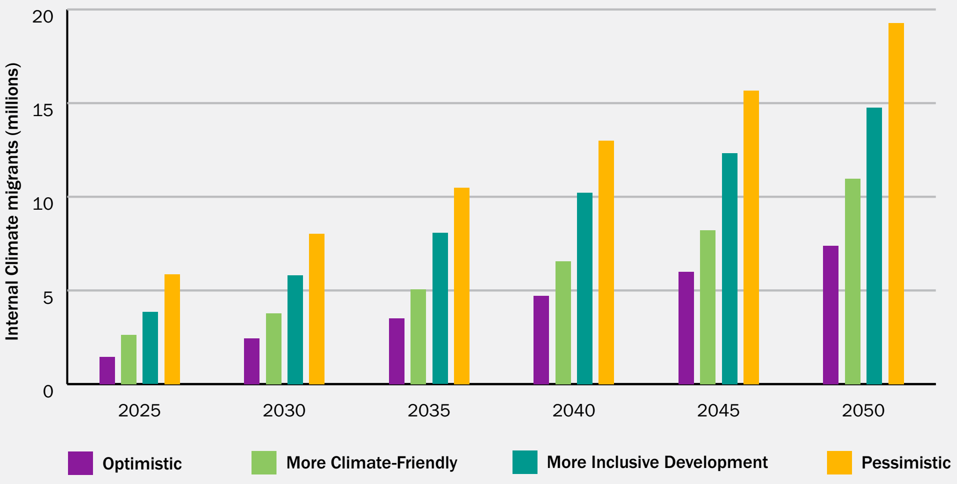


Figure 5.4 Trends in Climate Internal Migrants as a Share of Total Internal Migrants, West Africa, 2020–50



5.3 CLIMATE IN- AND OUT-MIGRATION HOTSPOTS

Climate migration hotspots reflect areas of high certainty (with agreement across the scenarios at the top 5th percentile) in which the largest spatial populations will shift into (climate in-migration) or out (climate out-migration) of a grid cell over time.[53] Climate out-migration will occur in areas where livelihood systems are increasingly compromised by climate impacts, and climate in-migration will occur in areas with better livelihood opportunities. These reflect movements from less viable areas with lower water availability and crop productivity and from areas affected by rising sea level and storm surges to areas with better opportunities. Climate in-migration hotspots reflect better climatic conditions for agriculture as well as cities able to provide better livelihood opportunities. Confidence levels are assigned based on the number of scenarios that agree. When all four scenarios agree, it is a high certainty hotspot. When three out of four scenarios agree, that is a medium certainty hotspot, and when only two out of four scenarios agree, that is a low certainty hotspot.

Impacts of climate change and other drivers are not uniform across the region, so a spatial dimension is important. Figure 5.5 presents a regional hotspots map for 2050, which represents a compilation of the country-level hotspots. Figure 5.6 presents similar maps for 2030 (panel a) and 2040 (panel b). These maps visualize how the spread, intensity, and number of hotspots increase over the decades. Because hotspots are measured in terms of absolute differences in population under climate and no climate scenarios, more densely settled areas with higher population numbers are more likely to be hotspots. These maps show that many coastal areas are likely to see climate out-migration because of sea level rise and increasing flood hazard. Flood displacement has occurred in coastal areas of Senegal (Alex and Gemenne 2016), and that trend is likely to continue. Coastal Nigeria is likely to be affected by sea level rise, flooding, and more frequent extreme events (Werz and Conley 2012).

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[53] The highest positive differences represent high levels of in-migration for a given scenario, and the highest negative differences represent high levels of out-migration for a given scenario, representing the top 10 percent highest movement grid cells, positive or negative, across the distribution (5 percent at both ends of the distribution). To be consistent across the time series, we apply the 2050 5th percentile population difference thresholds for 2030 and 2040. This gives a sense of the progression of hotspots over time.

These hotspots occur against a backdrop of population increase and reflect amplified growth rates (climate in-migration) or reduced growth rates (climate out-migration) because of climate impacts. Given the rapid population growth in West African countries, very few areas will decline in population numbers. First, even though an area may represent an out-migration hotspot (in blue), that does not mean that its population will decline. Rather, these out-migration hotspots reflect shifts in population distribution away from certain areas because of habitability declines. Second, while these hotspots represent areas of convergence across the models, addressing internal climate migration could require action in areas outside these hotspots, through concerted climate and development solutions, to ensure that the hotspots do not increase in extent and as stress areas.

Changes in water availability, crop productivity, and net primary productivity (NPP) result in a mix of in- and out-migration hotspots inland. Inland areas that see net climate in-migration (red spots, figures 5.5 and 5.6) tend to be where the impact models project higher water availability and, in the northern Sahel, increases in NPP that would be advantageous for pastoralists. A few in-migration hotspots near border areas persist over time, including the Mali–Burkina Faso border and the area north of Kano, Nigeria. Major climate out-migration hotspots appear on the Mali-Mauritania border and in southern Niger. The shifts in Niger from southwest to eastern areas are mostly because of more favorable climatic conditions projected for the eastern portions of the Sahel, and should be viewed with caution, since the region is relatively inhospitable. Many coastal areas are likely to see attenuated population growth, or growth that is lower than it would have been in the absence of climate impacts.[54]

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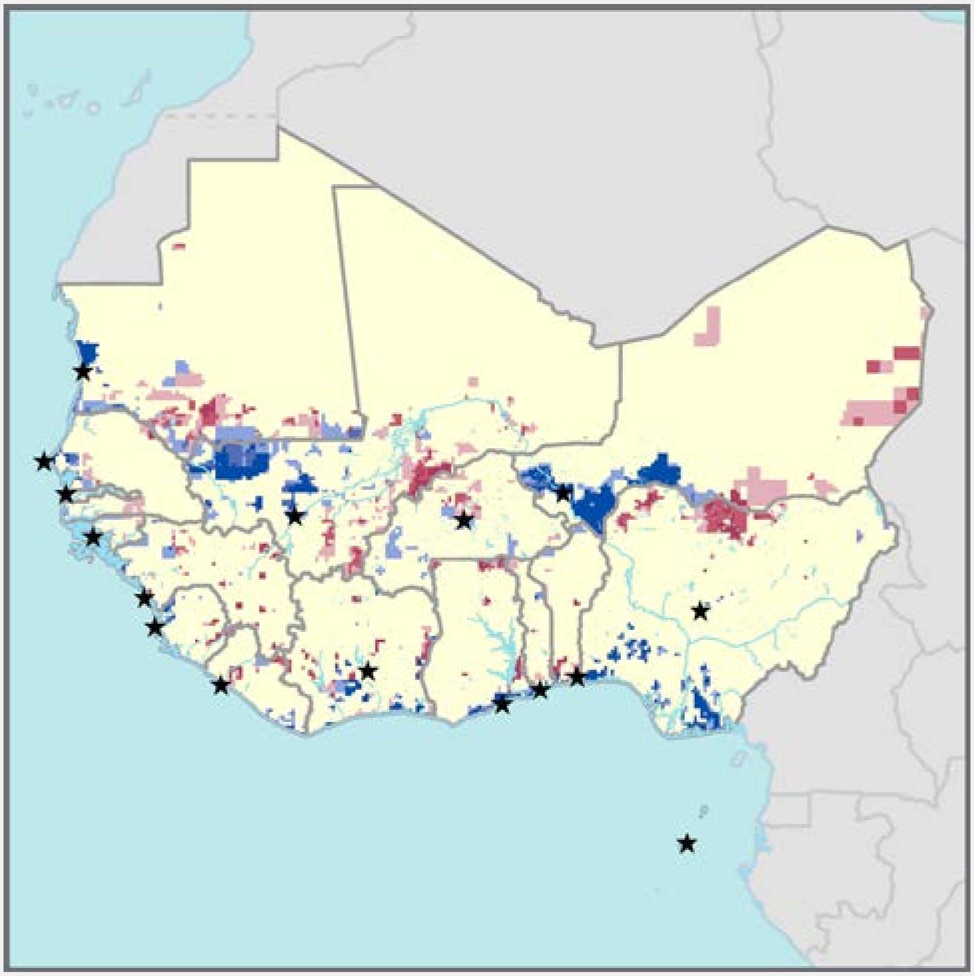
[54] The modeling approach produces apparently anomalous in-migration hotspots on the southern fringes of the Sahara, including parts of Mauritania and eastern Niger. This is an artifact of very high positive index values for water availability and NPP, particularly in the eastern portions of the region. These index values make these sparsely populated zones more attractive and may indeed support higher population densities, but they are unlikely to be major growth polls—especially if conflict in some of these regions were to remain high.

Figure 5.5 Projected hotspots of Internal Climate In- and Out-Migration, West Africa, by 2050 based on Country-level Compilation



IN-MIGRATION

🟥 High certainty in high levels of climate in-migration

🟥 Moderate certainty in high levels of climate in-migration

🟥 Low certainty in high levels of climate in-migration

OUT-MIGRATION

🟦 High certainty in high levels of climate out-migration

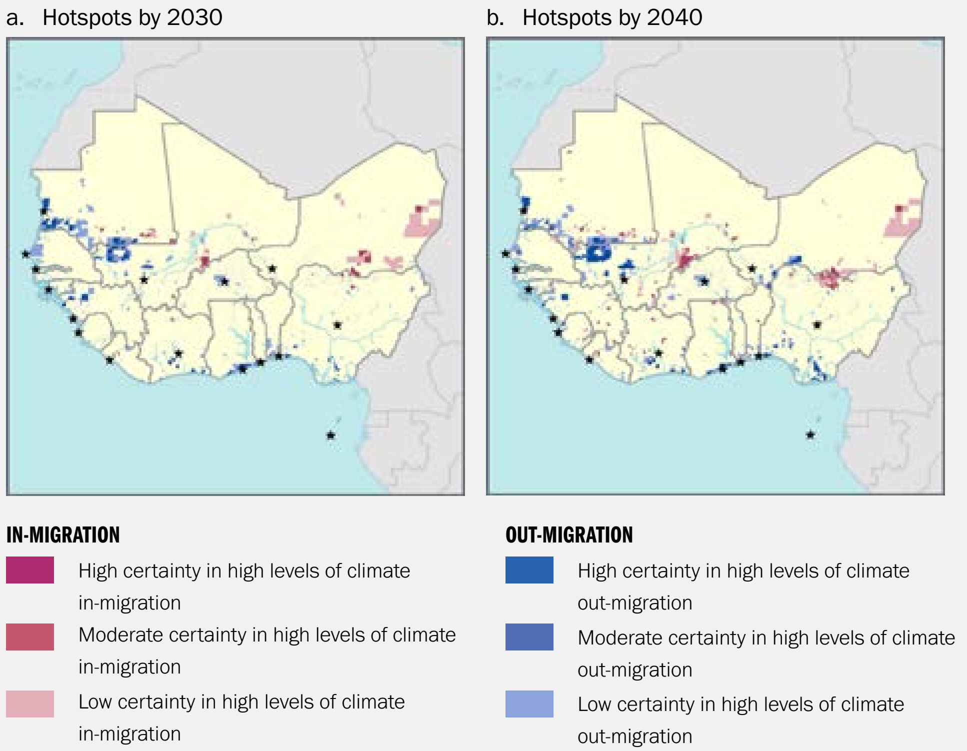
🟦 Moderate certainty in high levels of climate out-migration

🟦 Low certainty in high levels of climate out-migration

Note: Data based on compilation of country results using top and bottom 5 percent highest differences between the climate and no climate impact scenarios by country.

> West Africa’s coastal areas could see the emergence of climate out-migration hotspots as early as 2030. Early action to fortify coastal assets with green and gray infrastructure and participatory planned relocation are key parts of green, resilient, and inclusive development.

Figure 5.6 Projected Hotspots of Internal Climate In- and Out-Migration, West Africa, by 2030 and 2040 based on Country-level Compilation



a. Hotspots by 2030

b. Hotspots by 2040

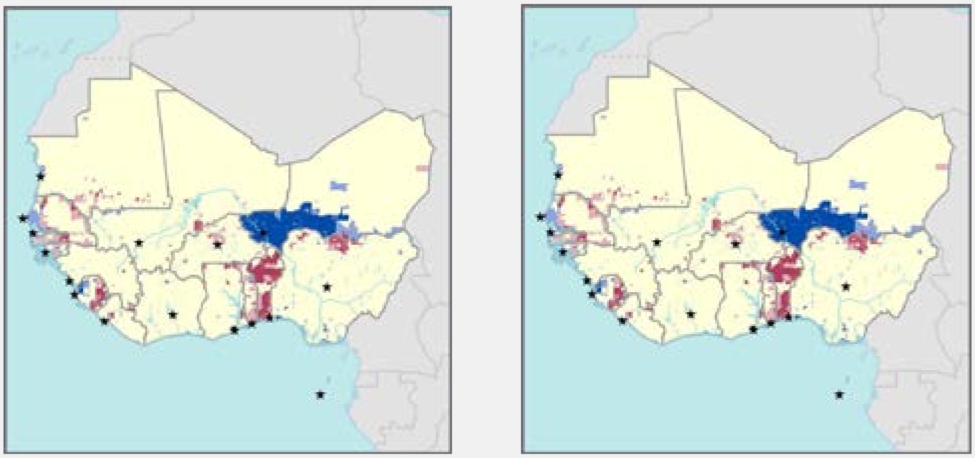
Note: Data based on compilation of country results using top and bottom 5 percent highest differences between the climate and no climate impact scenarios by country.

Alternative representations of the hotspots, based on normalizing for population and on regional aggregation, give prominence to different hotspots but with some level of consistency across approaches. In figure 5.7, panels a–c, the population difference between the climate and the no climate impacts scenarios for each grid cell is normalized (divided) by the country population total in that year for that Shared Socioeconomic Pathway (SSP), and the top fifth percentile in the distribution on a regional basis is mapped. This provides representation of hotspots in demographically smaller countries, with Benin, Sierra Leone, Senegal, and Mauritania showing up with more positive and negative hotspots. Conversely, Nigeria diminishes in importance regionally as a hotspot for both in-migration (in the north) and out-migration (in the south). Figure 5.8, panels a–c, shows the hotspots calculated at the regional level. These are the top fifth percentile highest and lowest differences in population between the climate and no climate scenarios regionally. This gives preference to the two countries with the largest projected populations in 2050, Nigeria and Niger, which dominate the hotspots map, whereas countries with smaller populations barely register. Regardless of the approach, most of the maps reveal climate out-migration from the coastal zone. Again, this does not mean that the populations in these areas will decline, but they will grow at a slower rate than otherwise might be expected because of factors such as sea level rise and flood risk.

Figure 5.7 Projected Hotspots of Climate In- and Out-Migration, Weighted by Total Population, West Africa, 2030, 2040, 2050

a. Hotspots by 2030

b. Hotspots by 2040



c. Hotspots by 2050

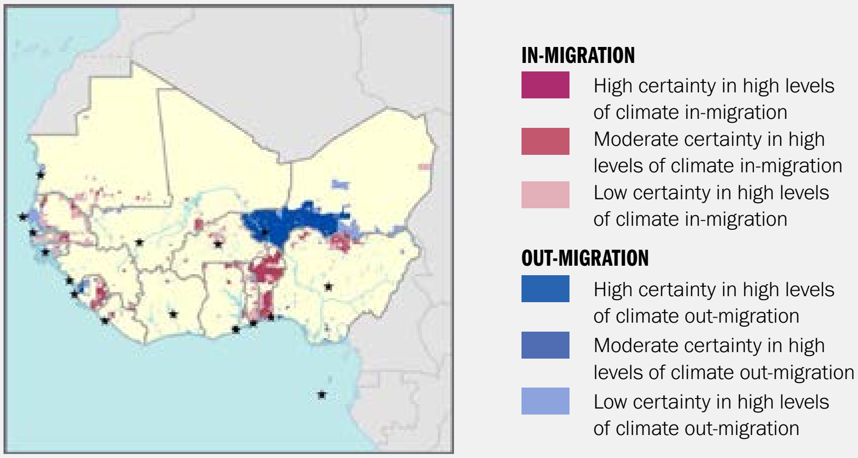
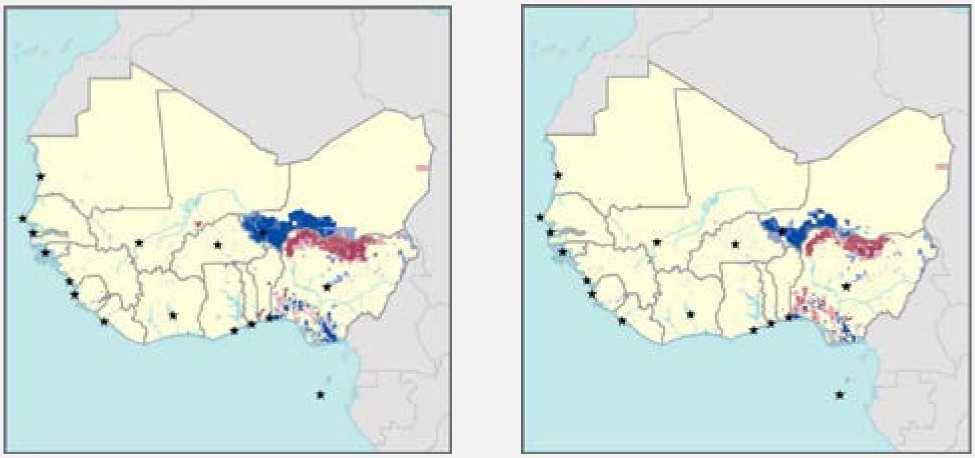


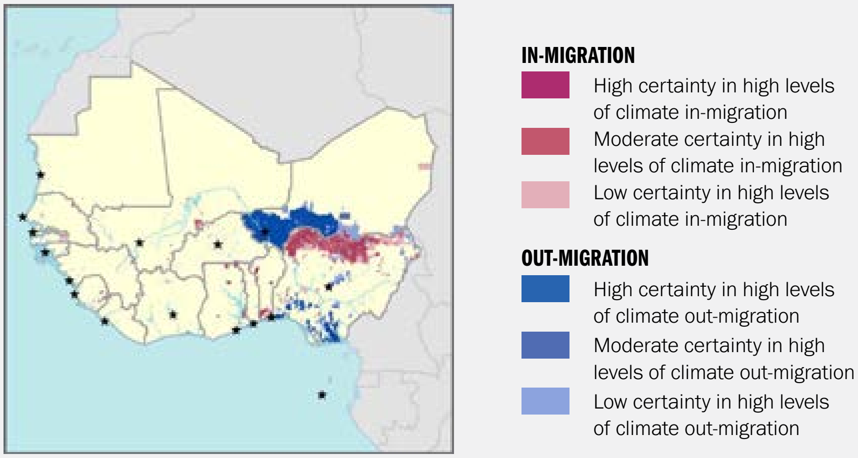
Figure 5.8 Projected Hotspots of Climate In- and Out-Migration, West Africa, on a Regional Basis (2030, 2040 and 2050)



a. Hotspots by 2030

b. Hotspots by 2040

c. Hotspots by 2050



Note: Data results reflect top and bottom 5 percent highest differences between the climate and no climate impact scenarios for the region as a whole.

5.4 SPECIAL FOCUS ON THE COASTAL ZONE

Coastal areas will become less attractive because climatic factors such as rising sea levels and storm surges will lead to climate out-migration.[55] Figure 5.9, panels a–d, shows projected out-migration from the 5-kilometer band along the coast (the coastal zone) based on the 1-kilometer resolution model outputs. It reveals that under the higher emissions RCP8.5 (with a 2-meter sea level rise) out-migration will reach a low and high level of 1.0 million to 2.2 million people in 2050, whereas under RCP2.6 (with a 1-meter sea level rise) it will be between number is between 300,000 and 800,000 people. As a share of the populations in the coastal zone, the ranges are from 0.88 percent at the low end of the optimistic and 5.4 at the high end of the pessimistic one. The rank order of countries by current populations in the low elevation coastal zone of 0–5 meters elevation include Nigeria, with more than 6 million people, followed by Senegal (1 million), Mauritania and Benin (0.8 million each), Côte d'Ivoire (0.7 million), Ghana (0.6 million), and Togo (83,000).[56]

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[55] The migration numbers for the special focus on the coastal zone are not part of the regional totals.

[56] See Low Elevation Coastal Zone Urban-Rural Population and Land Area Estimates (1990, 2000, 2015) Version 3 at CIESIN and CIDR 2021.

Figure 5.9 Projected Coastal Displacement from 5-Kilometer Coastal Zone, West Africa, 2020–50

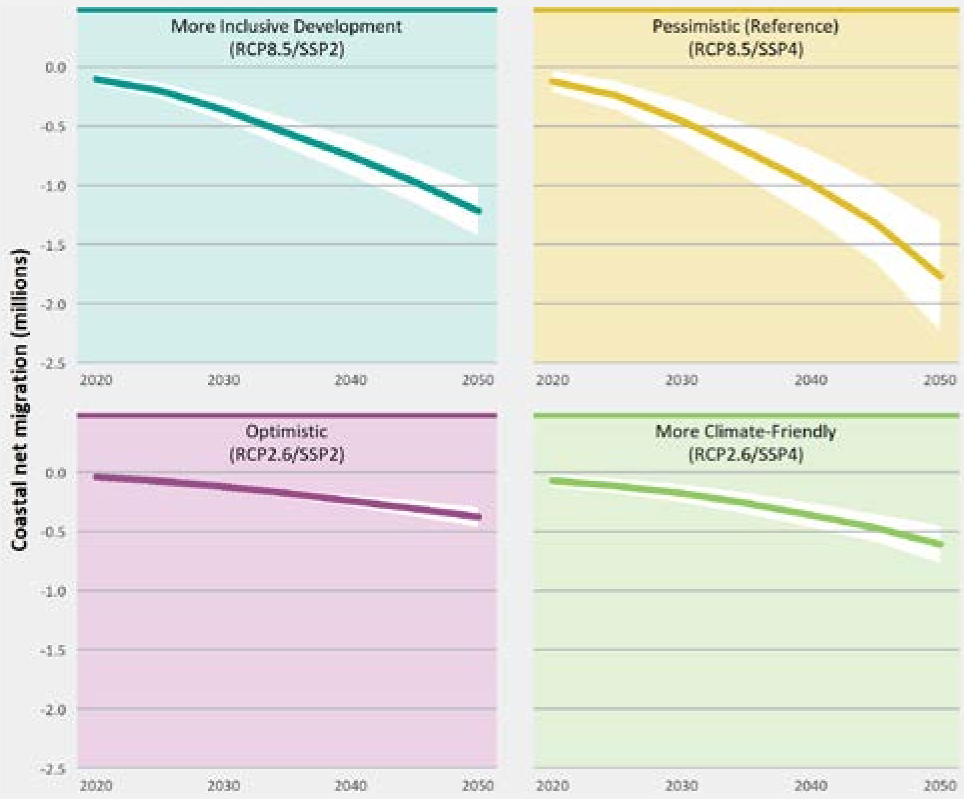


Table 5.2 Total Climate Displacement from the Coastal Zone for West Africa by 2050

	Scenario							
	Pessimistic/ Reference (RCP8.5; SSP4)		More Inclusive Development (RCP8.5; SSP2)		More Climate-friendly (RCP2.6; SSP4)		Optimistic (RCP2.6; SSP2)	
Average number of coastal displacement by 2050 (millions)	-1.8		-1.2		-0.6		0.4	
Min. (left) and max. (right) (millions)	-2.2	-1.3	-1.4	-1.0	-0.8	-0.4	-0.5	-0.3
Coastal displacement as a share of pop. in the 5-km coastal zone (percent)	-4.28		-3.67		-1.43		-1.11	
Min (left) and max. (right) (percent)	-3.17	-5.38	-3.04	-4.30	-1.06	-1.81	-0.88	-1.35

Note: The countries in the regional totals include the coastal countries of Mauritania, Senegal, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and São Tomé and Príncipe.

Senegal and Benin are vulnerable because their capitals, Dakar and Cotonou, respectively, are just above sea level, and Mauritania will see the highest relative sea level rise over the course of this century because of coastal subsidence. Parts of Nouakchott, Mauritania, are already prone to flooding from seawater intrusion and rising groundwater. In Senegal's Saint-Louis, coastal erosion has become an existential threat for the city, and planned relocation is happening. Groups of people have been relocated (box 5.2). Major climate out-migration hotspots are in coastal Senegal and along the entire coastline of the Gulf of Guinea. In Nigeria, climate out-migration is projected for the south and southeast and coastal states such as Lagos, Ogun, Rives, Ondo, Delta, Bayelsa, Rivers, and Akwa. Coastal urban areas will still gain population because of the attraction of jobs and amenities, but climate impacts are likely to shift populations slightly inland.

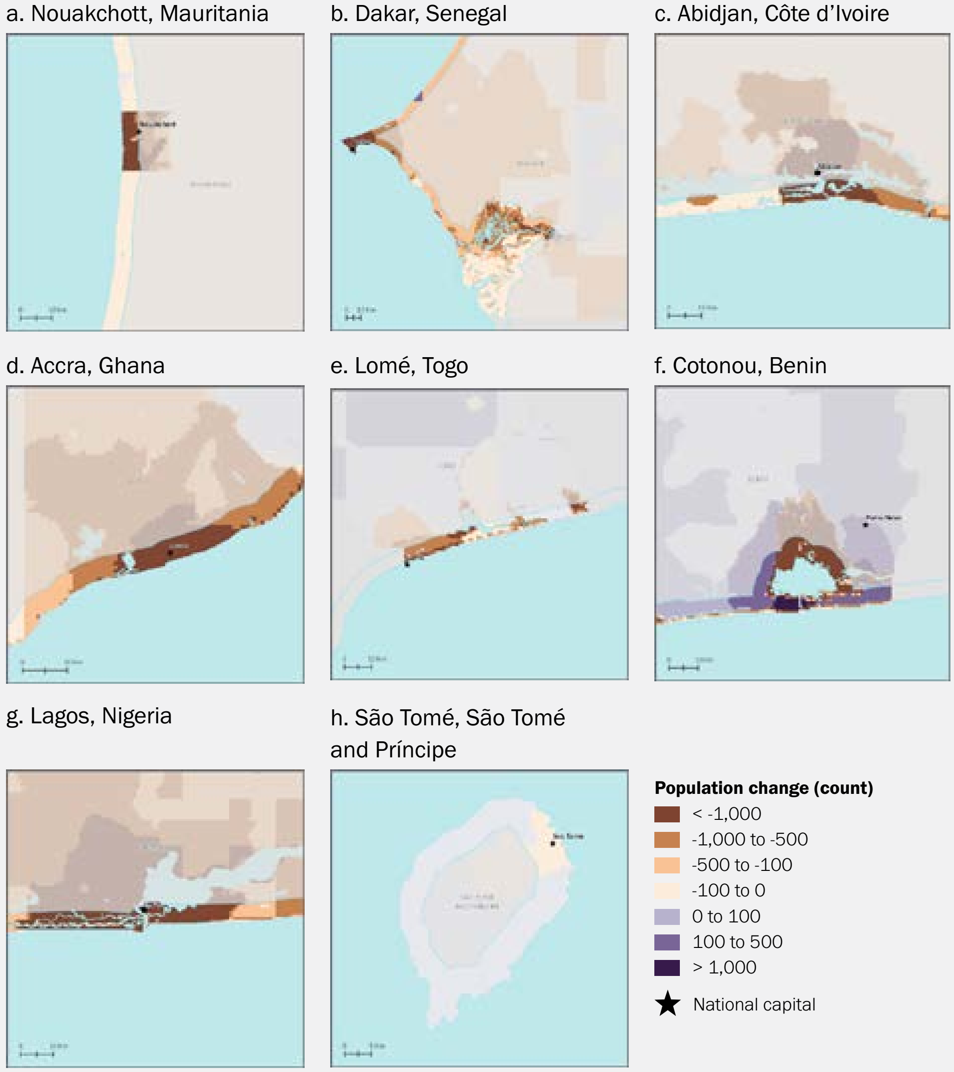
Box 5.2 Coastal Erosion in Saint-Louis, Senegal

In Saint-Louis, Senegal, approximately 80,000 people reside in densely populated fishing neighborhoods, more than 9,000 of which live in a high-risk zone under constant attack from flooding and erosion. More than 2,000 people have lost their homes in the last two years. The World Bank is financing the US$30 million Saint-Louis Emergency Recovery and Resilience Project to reduce the vulnerability of 10,000 people threatened by flooding and coastal erosion and strengthen urban and coastal resilience planning. Coastal erosion along the Langue de Barbarie, a thin, sandy peninsula along the Atlantic Ocean, has accelerated in recent years, with up to 5–6 meters of beach loss per year.

The patterns and trends of exposure and vulnerability of West Africa's coastal activities, livelihoods, and habitability to climate change risks will reverse conventional migration to coastal cities. By 2050, Senegal will have up to 443,000 coastal climate out-migrants under the high end of the distribution for the pessimistic scenario (5.8 percent of the coastal population in that year), while Benin will have up to 154,000 (5 percent of the coastal population). Nigeria will have the greatest number of coastal climate out-migrants, with close to 1 million by 2050 under the high end of the distribution for the pessimistic scenario. By contrast, Côte d'Ivoire is projected to have only 25,600 climate out-migrants (1 percent of the coastal population).

The out-migration hotspots along the coast seem entirely plausible. While large cities such as Dakar, Abidjan, Accra, and Lagos will continue to grow because they provide economic opportunities to those from more economically depressed areas, the population growth will be dampened. The population change by 2050 under the pessimistic scenario for major coastal cities of the focus countries is in figure 5.10, panels a–h. Most cities are dominated by brown shades, indicating areas of coastal displacement in which future population scenarios that include sea level rise and surge impacts are lower relative to the scenarios without climate impacts. The analysis reveals that the confluence of the attractiveness of higher median age in urban areas in West Africa (in the coastal areas of Senegal and Bight of Benin region from Côte d'Ivoire to Nigeria) dampens the effects of water stress, which would repel migration. Early, inclusive reinforcement of these coastal areas with green and gray infrastructure, where appropriate, and farsighted zone planning are essential.

Figure 5.10 Projected Population Change Because of Climate Migration for Selected Coastal Zones, West Africa, 2050


a. Nouakchott, Mauritania
b. Dakar, Senegal
c. Abidjan, Côte d'Ivoire
d. Accra, Ghana
e. Lomé, Togo
f. Cotonou, Benin
g. Lagos, Nigeria
h. São Tomé, São Tomé and Príncipe

Note: Calculations based on per square kilometer under the pessimistic scenario.

5.5 REGIONAL SUMMARY OF COASTAL WEST AFRICAN COUNTRIES

Every country in West Africa has a future projected increase in climate migration, but there are differences between countries. The scale and trajectory of climate migration depends heavily on the demographic, economic, and climate trends in each country. Table 5.3 summarizes results for West Africa Coastal Areas Management Program (WACA) countries. Chapter 6 presents the individual country results in much greater detail than provided in the regional overview. Two stand-alone deep dive reports are available for Nigeria and Senegal.

Migration is such an integral part of life in the region, and the flows are so varied and changeable, that the shifts described in this report could happen subtly over the coming decades without eliciting much notice. In that sense there is continuity with the past. Climate migrants as a percentage of each country's population reach a high of 15 percent in Niger by 2050 under the more inclusive development scenario, but in general the levels for other West African countries are in the neighborhood of 0.2 percent to 2 percent of the population across all scenarios. Although our focus here is on internal migration, the current pattern of regional cross-border migration in West Africa suggests that climate impacts in the Sahel may provide additional incentives for migrants from that zone to migrate to the humid tropical climate zones to the south.

Table 5.3 Summary of Results by Country, Coastal West Africa (Part 1)

Result	Senegal	Mauritania	Côte d'Ivoire	Ghana
Pop. in 2050 compared to 2025	Increases to 24.3 million from 17.2 million (in SSP2) or 30.5 million from 18.4 million (in SSP4)	Increases to 7.1 million from 4.7 million (in SSP2) or 6.2 million from 4.8 million (in SSP4)	Increases to 30.6 million from 24.7.2 million (in SSP2) or 37.3 million from 26.2 million (in SSP4)	Increases to 46.3 million from 33.1 million (in SSP2) or 54.1 million from 34.3 million (in SSP4)
Total pop., baseline (2010)	13.0 million	3.7 million	20.1 million	24.3 million
Number of climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 0.6 million (1.98% of projected pop.)	Highest in more inclusive development scenario, with average projection of 0.1 million (1.6% of the pop.)	Highest in pessimistic (reference) scenario, with average projection of 0.1 million (0.31% of projected pop.)	Highest in pessimistic (reference) scenario, with average projection of 0.3 million (0.61% of projected pop.)
Trajectory	Under a high emissions scenario, climate migration steadily increases, with a steeper inflection from 2045 to 2050 for pessimistic scenario but with low confidence; low climate migration under the low emissions scenario with high confidence	Similar to that of Senegal but with a steeper inflection upward under the more inclusive development scenario; medium to high confidence for all but the more inclusive development scenario	Trajectory arcs upward under all scenarios, with mostly high confidence (medium confidence for the pessimistic scenario) but low percentages of pop. (0.1% to 0.3% of pop.)	Trajectory arcs upward modestly under all but the optimistic scenario, which is flat; high confidence under all scenarios except the pessimistic, which has lower confidence
Climate in-migration hotspots	Matam town on the Senegal River (Mauritania border), near Zinguinchor (Guinea-Bissau border)	Assaba and Gorgol regions, especially the towns of Kiffa and Kaedi	Around Yamoussoukro and Bouake (central region)	Around Kumasi (south-central) and eastern banks of the Volta Reservoir
	Eastern Diourbel and western Kafrine, and south of the border near The Gambia	Area west of Nema	Near Korhogo in the north and several towns in the west	Northeastern and northwestern corners

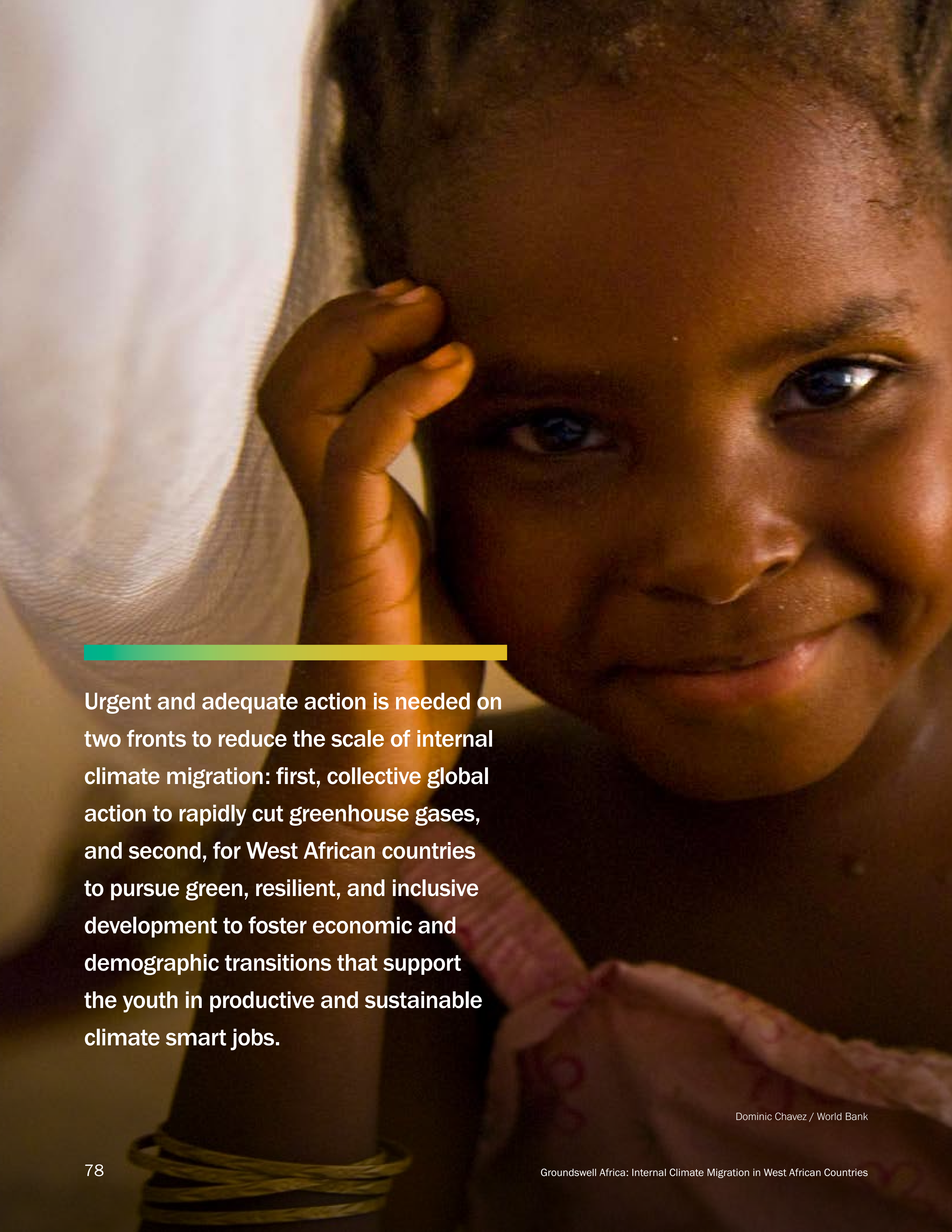
Result	Senegal	Mauritania	Côte d'Ivoire	Ghana
Climate out-migration hotspots	Dakar-Diourbel-Touba corridor	Area north of the capital of Nouakchott	Abidjan and the area around Lagune Aby in the southeast	Coastal areas in the south
	Low-lying coastal areas: north of Dakar and the Saloum Delta region	Southwestern Mauritania (Trarza region and Rosso town)	Southwest of Yamoussoukro near Gagnoa	n.a.
Climate migration in/out of rural livelihood zones	In-migration: pastoral and rangelands, seminatural and wildlands	In-migration: pastoral and rangelands	In-migration: rainfed croplands, including cocoa plantations	In-migration: rainfed croplands, including cocoa growing areas and rice-growing areas
	Out-migration: rainfed croplands, including the peanut basin	Out-migration: dense settlements (coastal)	Out-migration: seminatural and wildlands	Out-migration: n.a.
Climate migrants compared to other migrants by 2050	0.6 million climate migrants compared to 1.1 million other internal migrants in pessimistic (reference) scenario	0.1 million climate migrants compared to 0.39 million other internal migrants in the more inclusive development scenario	0.1 million climate migrants compared to 1.2 million other internal migrants in pessimistic (reference) scenario	0.3 million climate migrants compared to 1.1 million other internal migrants in pessimistic (reference) scenario

Note: SSP2 represents a moderate development pathway, and SSP4, an unequal development pathway. n.a. = not applicable; SSP = Shared Socioeconomic Pathway.

Table 5.4 Summary of Results by Country, Coastal West Africa (Part 2)

Result	Togo	Benin	Nigeria	São Tomé and Príncipe
Pop. in 2050 compared to 2025	Increases to 10.3 million from 7.9 million (in SSP2) or 11.1 million from 8.0 million (in SSP4)	Increases to 19.2 million from 12.9 million (in SSP2) or 13.2 million from 11.7 million (in SSP4)	Increases to 371.7 million from 226.2 million (in SSP2) or 431.1 million from 234.5 million (in SSP4)	Increases to 211,000 from 192,000 (in SSP2) or 240,000 from 199,000 (in SSP4)
Total pop., baseline (2010)	6.4 million	9.5 million	159.3 million	171,000
Number of climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 74,600 (0.67% of projected pop.)	Highest in pessimistic (reference) scenario, with average projection of 0.3 million (1.62% of projected pop.)	Highest in pessimistic (reference) scenario, with average projection of 8.3 million (1.93% of projected pop.)	Highest in pessimistic (reference) scenario, with average projection of 177 people (0.02% of projected pop.)
Trajectory	Pessimistic scenario arcs upward with medium confidence; others are flat with high confidence	All scenarios arc upward with very high confidence; pessimistic scenario has greatest inflection	Low emissions scenarios mostly flat; high emissions scenarios inflect upward; medium to high confidence across all scenarios	Given the small population and different modeling resolution (1 km), trajectories are jagged and should be interpreted with caution
Climate in-migration hotspots	Northwest corner by the border with Burkina Faso	South region, outside the lower elevation areas	North (Kano area)	Parts of Príncipe Island
	South-central region close to Benin border (city of Tohoun)	n.a.	Northwest corner	Near the capital of São Tomé Island
Climate out-migration hotspots	Low-lying coastal areas, including the metropolitan area of Lomé	Low-lying areas along the coast	Southeast coast	Southern part of Príncipe Island
	Northeast of Kara region		Southwest coast	
Climate migration in/out of rural livelihood zones	In-migration: rainfed croplands	In-migration: rainfed croplands, seminatural and wildlands	In-migration: rainfed croplands	n.a.
	Out-migration: seminatural and wildlands	Out-migration: n.a.	Out-migration: rice-growing areas	n.a.
Climate migrants vs. other migrants by 2050	74,600 climate migrants compared to 529,000 other internal migrants in pessimistic (reference) scenario	0.3 million climate migrants compared to 0.4 million other internal migrants in pessimistic (reference) scenario	8.3 million climate migrants compared to 20.3 million other internal migrants in pessimistic (reference) scenario	177 climate migrants compared to 13,000 other internal migrants in pessimistic (reference) scenario

Note: SSP2 represents a moderate development pathway, and SSP4, an unequal development pathway. n.a. = not applicable; SSP = Shared Socioeconomic Pathway.



Urgent and adequate action is needed on two fronts to reduce the scale of internal climate migration: first, collective global action to rapidly cut greenhouse gases, and second, for West African countries to pursue green, resilient, and inclusive development to foster economic and demographic transitions that support the youth in productive and sustainable climate smart jobs.

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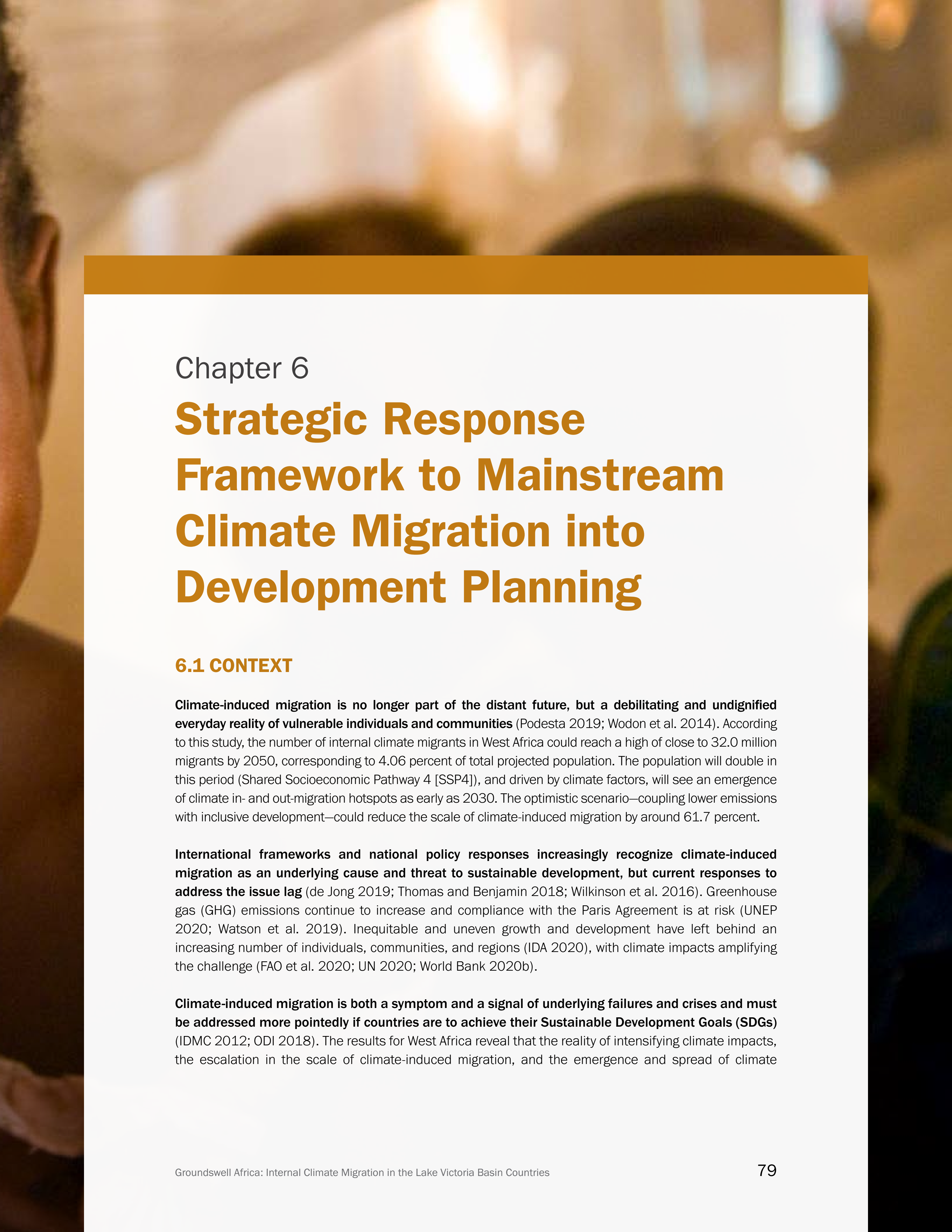


Chapter 6

Strategic Response Framework to Mainstream Climate Migration into Development Planning

6.1 CONTEXT

Climate-induced migration is no longer part of the distant future, but a debilitating and undignified everyday reality of vulnerable individuals and communities (Podesta 2019; Wodon et al. 2014). According to this study, the number of internal climate migrants in West Africa could reach a high of close to 32.0 million migrants by 2050, corresponding to 4.06 percent of total projected population. The population will double in this period (Shared Socioeconomic Pathway 4 [SSP4]), and driven by climate factors, will see an emergence of climate in- and out-migration hotspots as early as 2030. The optimistic scenario—coupling lower emissions with inclusive development—could reduce the scale of climate-induced migration by around 61.7 percent.

International frameworks and national policy responses increasingly recognize climate-induced migration as an underlying cause and threat to sustainable development, but current responses to address the issue lag (de Jong 2019; Thomas and Benjamin 2018; Wilkinson et al. 2016). Greenhouse gas (GHG) emissions continue to increase and compliance with the Paris Agreement is at risk (UNEP 2020; Watson et al. 2019). Inequitable and uneven growth and development have left behind an increasing number of individuals, communities, and regions (IDA 2020), with climate impacts amplifying the challenge (FAO et al. 2020; UN 2020; World Bank 2020b).

Climate-induced migration is both a symptom and a signal of underlying failures and crises and must be addressed more pointedly if countries are to achieve their Sustainable Development Goals (SDGs) (IDMC 2012; ODI 2018). The results for West Africa reveal that the reality of intensifying climate impacts, the escalation in the scale of climate-induced migration, and the emergence and spread of climate migration hotspots as early as 2030 will act across the region. These trends will likely accelerate beyond 2050 with worsening climate change. The deepening nature of this crisis, and the entrapment of the most impoverished, mean that action has to be taken. Current policies and strategies must understand and address the climate-migration-development nexus.

The international law on human mobility in the context of climate change continues to evolve. The 24th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP24) Decision calls for approaches to avert, minimize, and address displacement related to the adverse impacts of climate change as outlined in the *Warsaw International Mechanism* report (UNFCCC 2018). The Global Compact for Safe, Orderly, and Regular Migration, adopted in 2018, recognizes the need to strengthen joint analysis and sharing of information to better map, understand, predict, and address migration movements, including those that may result from rapid- and slow-onset natural disasters and the adverse effects of climate change, as well as develop adaptation and resilience strategies that consider potential implications on migration (IOM 2018). The Sendai Framework highlights the significance of incorporating considerations relating to disaster-induced displacement to improve disaster preparedness and disaster risk governance. The International Organization for Migration's (IOM) continued focus on migration and environmental change and that of the Platform on Disaster Displacement as a state-led initiative working toward better protection for people displaced across borders in the context of disasters and climate change guide international processes.

Migration as an adaptation strategy can be a pathway out of poverty (Adger et al. 2003; Barnett and O'Neill 2012; Elllis 2003). Under certain circumstances, voluntary migration can be a desirable form of adaptation, not a reflection of failure to adapt (Black et al. 2011; McLeman and Smit 2006; Tacoli 2011). However, migration must be addressed holistically and embedded in development policies and planning through inclusive and participatory approaches. Strengthening adaptive capacities and increasing readiness in the face of climate change (Rigaud et al. 2018; Warner et al. 2009) can create an enabling environment for the positive effects of migration to manifest.

The urgency for transformative and farsighted planning and action on climate migration cannot be postponed, with 2030 a critical year. The increasing number of extreme events and displacements raises an alarm bell (UN and World Bank 2018; UNHCR 2019b). The latest IPCC report finds that the global average temperature increase will likely exceed 1.5°C within the next two decades, and could potentially surpass 2°C by the end of the century if carbon-intensive human activities continue at the current rate (IPCC 2021). Climate impacts will continue to deepen existing vulnerabilities and lower capacities, leading to poverty, fragility, conflict, and violence. Already, the number of internal displacements attributed to disasters in Sub-Saharan Africa stands at 4.3 million (IDMC 2021).

Governments have the opportunity to harness climate migration as a factor of growth, jobs, and economic transition within countries, which to date has remained untapped (Scheffran, Marmer, and Sow 2012; World Bank 2018a). A unified approach to addressing climate migration must deliver on the core development needs—food, water, environment—and priorities to deliver on the countries' SDGs and the World Bank's poverty goals. Climate migration will play out against a backdrop of other megatrends of population growth, urbanization, and biodiversity loss as well as technological innovation, digital revolution, and broader economic transitions to low carbon pathways. The plausible climate migration scenarios in this report are not cast in stone but provide an opportunity—through proactive global and local to national action—to not just reduce the scale of climate migration but also to harness opportunities for growth and jobs as part of the transition to resilient and low carbon economies in the pivotal 2020s. This chapter proposes a strategic response framework for mainstreaming climate migration into development policy and planning.

6.2 MIGRATION AND CLIMATE-INFORMED SOLUTIONS (MACS) FRAMEWORK

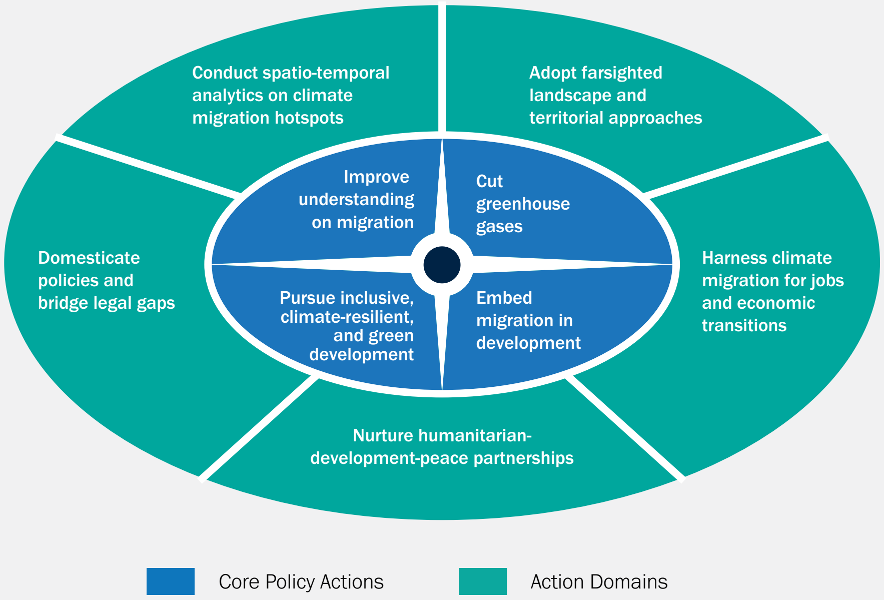
Climate migration is a reality, and as a cross-cutting issue it has to be addressed through policy-informed actions that are farsighted in their approach and execution. Unless concerted climate and development action is taken now, the scale of climate migration will ramp up by 2050, and hotspots of climate in- and out-migration will spread and intensify. These trends will likely accelerate beyond 2050 with worsening climate change.

The World Bank's Groundswell report underscores the need for bold and transformational action to address climate-induced migration through four lines of policy action (Rigaud et al. 2018):

- Cut greenhouse gases now.
- Pursue inclusive and climate-resilient development policies.
- Embed climate migration in development planning.
- Invest in an improved understanding.

These policy directions must be buttressed with a core set of action domains to ensure durable and sustainable development outcomes with respect to distress-driven climate migration (figure 6.1).

Figure 6.1 Migration and Climate-informed Solutions (MACS) Framework



The Migration and Climate-informed Solutions (MACS) framework (figure 6.1) allows us to make connections across time and space that have been missing and cope with future uncertainties and disruptions. It seeks to ensure that vulnerable communities are well prepared to confront current and future climate risks, and that the country economies are braced not only for the challenges but also for the opportunities of climate migration.

MACS stems from the growing interest within the World Bank and the wider community to better understand the implications of climate induced migration and mainstream this phenomenon into development plans, programs, and policies. The Groundswell report (Rigaud et. al. 2018) introduced slow-onset climate impacts (water stress, crop failure, sea level rise) into a model of future population distribution—and established four core policy actions central to the MACS framework: (i) cut greenhouse gases now; (ii) pursue inclusive and climate-resilient development policies; (iii) embed climate migration in development planning; and (iv) invest in an improved understanding (Figure 6.1).

The findings from Groundswell Africa paved the way for domains of action to bolster the delivery of core policy directions set within MACS to reduce, avert, and minimize distress-driven internal climate migration. The framework identified five domains of action (i) conduct spatio-temporal analytics to understand the emergence of climate migration hotspots; (ii) adopt farsighted landscape and territorial approaches; (iii) address and harness climate induced migration as an opportunity; (iv) nurture development-humanitarian-peace partnerships; and (v) bridge the gap in legal mandates and frameworks (Figure 6.1). The results contextualized and localized the Groundswell findings on the basis of literature review of the current and historic mobility patterns and stakeholder consultations. This analysis was further supplemented by the examination from the design features of 165 World Bank projects operating at the climate-migration-development nexus with commitments amounting to US$197.5 billion between 2006-2019 (Rigaud et. a. 2021d).

The MACS framework underscores the need for anticipatory approaches. While the core policies offer high-level forward looking strategic directions, the domains of action are grounded in reality, linked to sectoral interventions, and speak to different group of actors in an inclusive way and along the entire development-climate-humanitarian spectrum. MACS provides a holistic yet flexible set of proposed interventions to ensure durable and sustainable development outcomes with respect to distress-driven climate migration.

MACS is designed to be flexible, based on the premise that climate migration is linked to broader development challenges across spatial scales. Paramount to this premise is the need for country leadership and bottom-up engagement to set out policy and embed action in concrete investment projects backed with the right operational instrument. MACS is not restricted to any single country or region nor is there one formula or pre-determined sequence of actions to operationalize it. It provides a holistic yet flexible set of domains of action that can be applied and sequenced, at different stage of planning, in response to the local, country or regional context and migration patterns. It was developed with vital contributions from World Bank staff and a group of internal and external peer reviewers. Stakeholders' inputs from civil society, government institutions, and academia, as well as regional and international organizations and donors were also integrated during the course of consultations.

The MACS framework speaks to both policymakers and practitioners as it offers critical information and insights with regards to trends, timelines, development and policy implications of climate-induced internal migration. It is intended to inform the preparation of strategic and sectoral development plans and is targeted to national and local level planners, who are in the frontline of future climate migration trends. From the World Bank's perspective, MACS offers inputs to the core diagnostic tools—including the new the Country Climate and Development Report (CCDR)—that inform country engagement and helps to pinpoint areas that may become hotspots of climate in- or out-migration in both rural and urban areas, and across vital landscapes, and key coastal and livelihood zones. In addition, the framework is geared to inform international actors along the humanitarian-development-security continuum. Donors and development partners can use MACS to leverage concrete instruments to finance investments and design new projects, which tackle climate migration as a cross-sectoral issue and address challenges faced by climate-driven migrants and host communities, in particular, in fragile environments.

6.2.1 Core Policy Directions

Action across four major policy areas could help reduce the number of people forced to move in distress due to climate change.

(i) Cut GHGs now to reduce climate pressure on people's livelihoods and the associated scale of climate migration.

Rapid reductions in global emissions can reduce the scale of climate migration and movements under distress. Lower global emissions reduce climate pressure on ecosystems and livelihoods and broaden the opportunities for people to stay in place or move under better circumstances. Under the optimistic reference scenario, the number of migrants could decline from a high of 32.0 million at the high end of the pessimistic reference scenario to an average of 7.4 million in the optimistic scenario by 2050.

Stringent global climate action would be needed to adhere to the Paris Agreement and limit future temperature increases to less than 2°C by the end of this century, close to the more climate-friendly scenario in this report. According to UNEP (2020), the world is moving toward a temperature rise in excess of 3°C this century, and could increasingly foreclose some of the options for reducing climate-induced migration. Increased ambition in the next round of Nationally Determined Contribution (NDC) submissions, especially for the high emission countries, must have emboldened and comprehensive mitigation policies and include carbon pricing, urban and land use planning, and innovations in performance standards. Mitigation policies must be inclusive and pro-poor to guard against potential blowback of mitigation measures.

(ii) Pursue inclusive and climate-resilient development policies with targeted investments to manage the reality of climate migration.

Climate migration demands anticipatory development policies that respond to the scale of the issue over the medium to long term. Internal climate migrants by 2050 could be up to 4.06 percent of the population, and could make up a significant proportion of all migration, particularly under the pessimistic scenario.

(iii) Embed climate migration in development planning for all phases of migration and across time scales.

Countries need to integrate climate migration for all phases and patterns of migration across time scales into national development plans and policy. Most regions have poorly prepared strategies, policies, plans, and laws to deal with people moving from areas of increasing climate risk into areas that may already be heavily populated. Policy focus on the full migration life cycle—adapt in place, enable mobility, and after migration—will ensure the presence of the adequate ecosystem to avert, minimize, and address climate-induced migration in response to current and future climate risks and impacts.

Adapt in place ensures help to communities to stay in place when local adaptation options are viable and sensible. Components of successful local adaptation include investing in climate-smart infrastructure, diversifying income-generating activities, and building responsive financial protection systems for vulnerable groups, including women.

Enable mobility facilitates movement of people away from unavoidable climate risks when the limits of local adaptation and viability of ecosystems are reached. Governments should facilitate safe, orderly, and dignified migration (or, as a last resort, planned relocation) toward areas of lower risk and higher opportunity by providing skills training, information, and legal support. Enable mobility offers a risk management strategy that reduces vulnerability—especially of poor populations living in informal areas who have limited access to basic services like water, sanitation, and electricity (Olarinoye et al. 2020).

In after migration, sending and receiving areas, and their people, are well-connected, socially cohesive and adequately prepared for the medium and longer term. Policy makers should develop and implement migration preparedness plans for the immediate and longer-term population growth from migration. Secondary cities can become growth poles to support large, active domestic markets and be focus areas for tertiary manufacturing while strengthening rural to urban linkages by providing access to markets. Plans should include viable livelihood opportunities, skills training, critical infrastructure and services, registration systems for migrants (to access services and labor markets), and the inclusion of migrants in planning and decision-making.

(iv) Invest now to improve understanding of internal climate migration.

More investment is needed to better contextualize and understand climate migration, particularly at scales ranging from regional to local, in which climate impacts may deviate from the broader trends identified in a global analysis. There are inherent uncertainties in the way climate impacts will play out in each locale, and this will affect the magnitude and pattern of climate change–induced movements. Studies as the ones conducted for this report provide insights on the scale of the issue. As more data become available on climate change and its likely impacts on water availability, crop productivity, and sea level rise, the scenarios and models need to be updated. Increasing the modeling resolution and improving data inputs to produce more spatially detailed projections are among the possible future applications of the approach used in this report.

Building country-level capacity to collect and monitor relevant data can increase understanding of the interactions among climate impacts, ecosystems, livelihoods, technological change, and mobility and help countries tailor policy, planning, and investment decisions. Including climate-related and migration questions in national census and existing surveys is a cost-effective way to advance understanding. Decision-making techniques under deep uncertainty need to be further developed and applied for policy making and development planning. Evidence-based research complemented by country-level modeling are vital. In support of this, new data sources—including from satellite imagery and mobile phones—and advances in climate information can improve the quality of information about internal migration. The West Africa Coastal Areas Management Program (WACA) is assessing coastal challenges and potential areas of interventions in Nigeria, and Senegal is strengthening its coastal observation and early warning systems. In these efforts, the privacy of personal data needs to be protected, and human rights need to be respected.

6.2.2 Domains of Action to Drive Planning and Action at Scale

Four domains of action can bolster the delivery of the core policy direction to reduce, avert, and minimize distress-driven internal climate migration. They are presented below.

(i) Conduct spatio-temporal analytics to understand the emergence of climate migration hotspots.

Climate-induced migration is not uniform within West Africa; its impacts vary across space and time. As a result, it poses distinct spatial challenges that necessitate spatially aware long-term planning that can avert, minimize, and reduce the negative impacts of climate migration. While internal climate migrants as a percentage of population remain relatively low—averaging from 1.09 percent to 2.44 percent across the scenarios by 2050, reaching a high of 4.06 percent under the pessimistic scenario—they will make up a significant proportion of all migration. Climate migrants will account for one third of all internal migrants by 2030 under the pessimistic scenario. As early as 2030, most West African countries will see climate in- and out-migration hotspots emerging, which will intensify and spread by 2050. Expanded and more granular modeling and analysis undertaken in this study—including a focus on water stress, crop productivity, net primary productivity (NPP), sea level rise compounded by storm surge, floods, and conflict—would benefit from local data, tailored assessments, and on-site interviews. These findings have important policy implications and require greater scrutiny and analysis. It is imperative to develop climate migration hotspots maps for each country and identify spatial climate risks and impacts to secure resilience.

Policy makers need to drive early, proactive, and informed action aided by state-of-the-art models on the current and future trends of mobility. Investing in evidence-based research at the national level and mobilization of new data sources—including from satellite imagery and mobile phones—can help better contextualize and understand climate migration (particularly at local scales) where climate impacts may deviate from the broader regional or global trends. The results from this study demonstrate that climate migrants will move from less viable areas with lower water availability and crop productivity and from areas affected by rising sea level and storm surges. These trends and the emergence of hotspots of climate migration will have major implications on conceiving effective responses. For example, Nigeria and Senegal are projected to see climate out-migration from areas with lower poverty incidence, such as in Lagos, Ogun, Rivers, Ondo, Delta, Bayelsa, Rivers, Akw (in Nigeria) and Dakar, Thies, Fatick, and Kaolack (in Senegal). Climate in-migration hotspots are projected to emerge in areas of high poverty, such as in the north and northeast of Nigeria (Kano, Katsina, Sokoto) and near the town of Matam on the Senegal River (border with Mauritania), and near Ziguinchor on the Guinea-Bissau border, in eastern Diourbel and western Kaffrine, and south of the border near The Gambia in Senegal. Differential strategies are needed to address climate-induced migration and greater development efforts, investments, and focus to adequately prepare the countries' states for the projected influx of climate migrants. The suite of policy actions to embed resilience in hotspots should include investments and economic opportunities in green industry, environmental safeguards, institutional strengthening and coordination, and the creation of health, sanitation, and energy infrastructure.

(ii) Enable and embrace landscape and territorial approaches for farsighted planning to avert, minimize, and address climate-induced migration.

Climate change impacts and other socioeconomic trends could change the desirability of land and natural resources, varying uses, and shift the comparative advantage of locations across the landscape (Childress, Siegel, and Törhönen 2014). According to the Next Generation Africa Climate Business Plan (World Bank 2020b), slow-onset climate factors will adversely affect water and land resources and food systems. These changes affect migration patterns, which necessitate deeper engagement with land uses and their interactions with broader forces. Protecting the underlying ecological foundation becomes crucial to achieve a resilient rural economy (World Bank 2020b). The West African coast is particularly vulnerable to climate change and extreme events yet has high population densities and economic growth. More than 6 million Nigerians live in the low elevation coastal zone, followed by Senegal (1 million), Mauritania and Benin (0.8 million each), Côte d'Ivoire (0.7 million), Ghana (0.6 million), and Togo (83,000) (CIESIN and CIDR 2021). The capital or larger cities of Benin, Côte d'Ivoire, Ghana, Mauritania, Nigeria, Senegal, São Tomé and Príncipe, and Togo are on the coast and are projected to be climate out-hotspots by 2050. Analysis of climate change impacts on landscape, terrestrial and marine ecosystems, and natural habitats with community-focused planning are a step forward. Local Integrated Coastal Zone Management (ICZM) plans and analysis of adaptation options are good entry points for communities to address the delicate balance between the coastline and riverine estuaries and potentially avoid the loss of land and livelihoods due to severe marine erosion.

Placing the landscape approach within larger territorial approaches enables planning across spatial and time scales through a focus on the full migration life cycle (before, during, and after). It considers the underlying causes of distress-driven migration, and addresses both slow- and rapid-onset climate factors and their interlinkages. It offers a pathway to site-specific planning for climate-induced migration with an expanded and integrated view of land that can support local priorities and natural resource uses. Unlike sector-oriented planning, it allows deeper understanding of human-natural ecosystems and how they affect migration through land management, natural resource management, livelihoods, and ecosystem integrity. The World Bank's Sahel Irrigation Initiative Support Project illustrates climate-smart approaches to natural resource management.

(iii) Address and harness climate-induced migration as an opportunity for jobs and economic transitions.

Migration affects the well-being of the migrant, the household, and the sending and receiving community (World Bank 2019b). Incremental, low regrets measures will not be sufficient to counter the magnitude of climate impacts (Kates et al. 2012). Sequences of flexible, incremental adaptation should be explored alongside more transformational adaptation to secure resilience over longer time scales (Kates et al. 2012; Pal et al. 2019). Good management of demographic transitions and investment in human capital can reduce adverse impacts of climate migration. For example, Côte d'Ivoire is projected to see climate out-migration from Abidjan, the country's economic capital and largest city, with around 20

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percent of the total population, and 80 percent and 90 percent of formal jobs and businesses, respectively (Coulibaly 2015). Other fast-growing cities, such as Korhogo, Bouake, and the capital, Yamoussoukro, are projected to see climate in-migration as early as 2030. To tap the demographic dividend, demographic transitions from and toward urban cities need to be accompanied by policies to absorb larger working age populations into productive and climate-resilient labor markets—and to ensure that they have good access to health care, employment, and education. The World Bank's Youth Employment and Skills Development Project (P172800) in Côte d'Ivoire aims at facilitating youths' access to skills and vocational training to facilitate their access to the labor market. This program can underscore the importance of creating and facilitating access to climate-resilient labor markets.

Driven by climate change over longer time scales, good migration management can produce positive momentum for such shifts (World Bank 2019b). Climate-smart urban transitions provide win-win opportunities to invest in the next generation of skills to foster green and resilient jobs, and secure cities as engines of growth. For instance, sea level rise compounded by storm surge will affect vibrant cities in West Africa, such as Dakar, Cotonou, Accra, Nounakchott, São Tomé, and Lomé. Early action to fortify coastal assets through green and gray infrastructure must be optimized through adapt-in-place options, while considering participatory planned relocation as part of longer-term solutions. Anticipatory planning through a focus on climate in-migration to secondary cities or peri-urban areas could lay their foundation as growth poles instead of sprawling slums steeped in poverty. Combining these opportunities with climate-smart urban transitions that nurture and build skills, talent, and workforce to harness the youth bulge through a focus on energy efficient, green, and resilient urban infrastructure and services would present win-win and leapfrogging opportunities.

(iv) Nurture development-humanitarian-peace partnerships for end-to-end action at the national and local levels.

Migration should be part of humanitarian-development-peace efforts, working with national and local stakeholders. While this report does not focus specifically on cross-border migration, the modeling identifies numerous migration hotspots in areas close to national borders. Climate change can be an inhibitor or a driver of cross-border migration, depending on factors that propel individuals to decide to move. Countries must deploy holistic strategies to deal with the facets and actors of mobility in the face of climate change. In the past, humanitarian efforts were followed by development efforts that operated with different objectives, counterparts, instruments, and logic (Guinote 2019). Cooperation and stepped-up action by development, humanitarian, security, and disaster communities across the mobility continuum could greatly assist countries in pursuing more holistic and durable solutions to climate-induced migration and displacement (World Bank 2019b) in support of regionwide peace, stability, and security.

Climate change is causing novel challenges and dilemmas that undermine the humanitarian, development, and peace agenda. Unplanned migration and an absence of policies and strategies to integrate different communities can exacerbate social tensions and faultlines into a downward spiral leading to conflicts (Thoha 2020). The increased frequency and intensity of extreme events, including drought and floods, will plague the region, which, compounded by competition for scarce resources and social inequalities and tension, can lead to or amplify the possibility of conflict. In West Africa, with water becoming increasingly scarce, farmers are expanding their fields into pastoral regions and transhumance corridors even as pastoralists leave their villages with their herds earlier in the year to deal with drought, thus leading to increased tensions between migrant herders and sedentary farmers.

Treating migration as a nexus of the humanitarian-development-peace frameworks implies overcoming structural barriers and internal divisions around sources of funding, coordination mechanisms, and project timelines (OCHA 2017). This approach can benefit from actors' comparative advantage to strengthen local capacity (OCHA 2017). Ultimately, this approach should reduce humanitarian need, risk, and vulnerability through well-aligned short-, medium- and longer-term contributions by humanitarian and development actors (OCHA 2017). The linkages need to happen in a contiguum[57] (simultaneously) to secure peace, address the humanitarian objectives to save lives, alleviate human suffering, and achieve the development priority to alleviate poverty.

(v) Bridge the gap in legal mandates and frameworks on climate-induced migration.

There is an absence of comprehensive and coherent legal architecture to address climate induced mobility (Leighton 2010; World Bank 2020). Adequate protections under international law are generally not afforded to those moving primarily due to environmental factors (World Bank 2020). As the impacts of climate change intensify, there will be more migrants and displaced people uncovered by law. The Groundswell report posits that West Africa could become more attractive under climate change because of its higher elevation and more stable and plentiful rainfall.

A well-defined and implemented legal architecture brings clarity, protects affected individuals and communities, and reconciles international funding and local decision-making (Mayer 2011). It can pave the way for migrants to demand and seek assistance; ensure meaningful consultation about relocation; secure tenure at the new location; restore, if not improve their livelihoods; disadvantaged and vulnerable individuals and communities receive special attention (World Bank 2020).

Collaboration between various different actors including development actors and other organizations with humanitarian aid mandate within and across international borders is essential. World Bank financing instruments and other technical support modalities have been used to support climate migrants, and there is potential scope for further support focusing on development opportunities and policies for the safe movement of people and provide viable options for in situ adaptation. Integrating climate-related human mobility early on into development planning and project design would be helpful in addressing the adverse impacts of climate change in this context (Kuusipalo et al. 2020).

6.3 CALL TO ACTION

The development vision and plans of countries and World Bank projects in West Africa provide multiple entry points to mainstream climate-induced migration. The plausible scale of internal climate migration and spread of climate migration hotspots in West Africa require holistic responses aligned with the MACS framework and the National Development Plans (NDPs), Country Partnership Frameworks (CPFs), and Systematic Country Diagnostics (SDCs).

Enhancing productivity and equitable and sustainable outcome must be underpinned by structural and spatial transformation buttressed in sound natural resource management. Embedding climate migration into territorial and spatial planning can foster growth and sustainable outcomes. Governments need a farsighted focus on climate out-migration hotspots—in centers of economic growth—to embed resilience and preparedness in the face of sea level rise and storm surges. They can pursue diverse strategies such as gray and green infrastructure and institutional transformations for better service delivery.

We are not starting from zero: insights and lessons from past and ongoing projects can inform action and scale up work to address climate-induced migration (box 6.1). As an example, the Regional Sahel Pastoralism Support Project for the countries of Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal (P147674), supported trans-boundary migration as an adaptation strategy for pastoralists threatened by droughts and conflict. This was done by providing: (1) improved sub-regional infrastructure for migration corridors; (2) markets for regional trade in livestock products; (3) shared water points for livestock and people; (4) building capacity for regional collaboration; and (5) coordination to prevent and manage shocks affecting livestock, including drought and disease.

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[57] "*Contiguum* means, more realistically, that development and change, all hazards and their impacts, all 'disasters' of whatever magnitude, and all stages of post-disaster response, are operating at the same time in overlapping juxtaposition. Not in relation to one disaster, but all disasters, distant and near, past and recent. Not only the disaster of which we are informed, but the plethora of 'normal hazardousness' that is the reality" (Lewis 2001).

Box 6.1 World Bank Portfolio Review of Projects in the Climate-Migration-Development Nexus

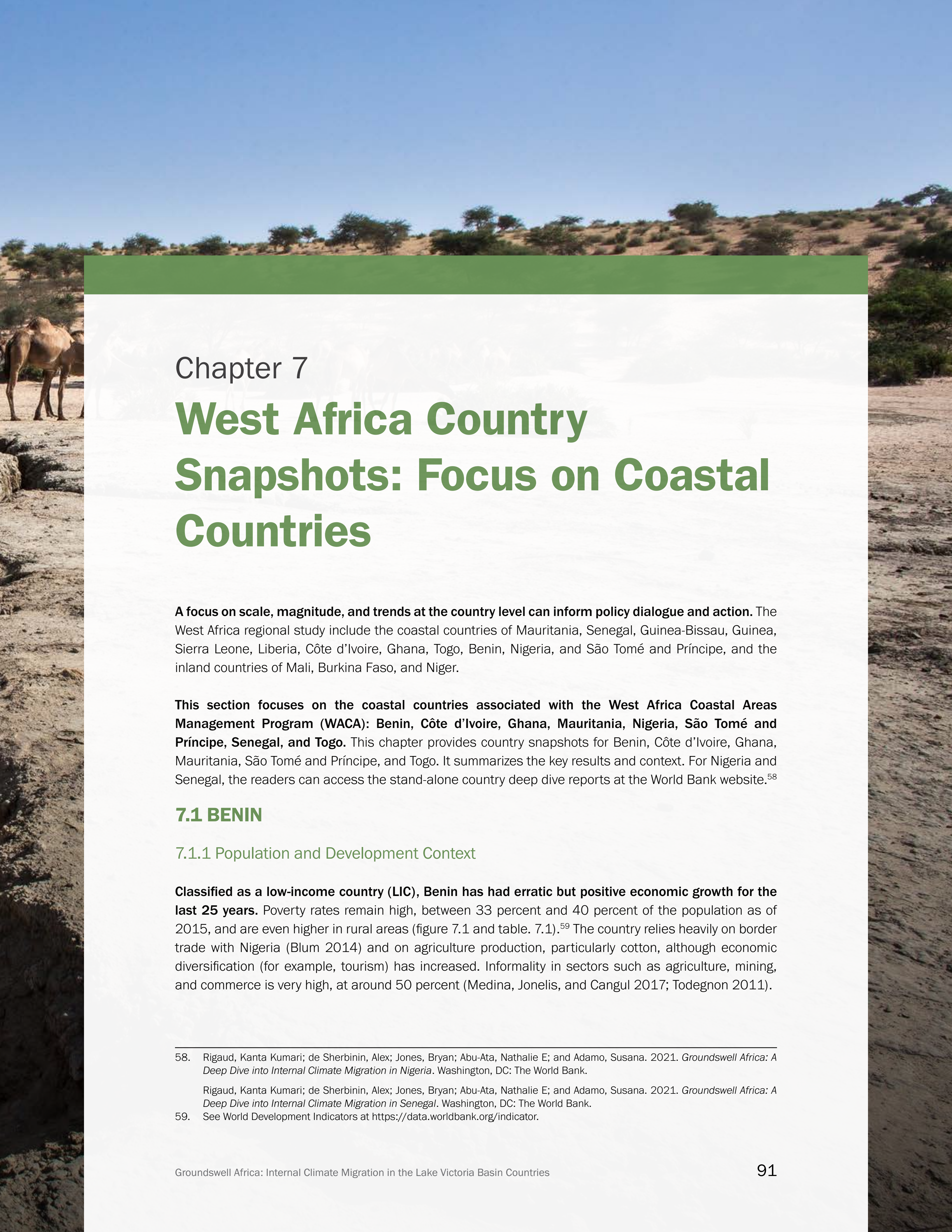
A portfolio review (Rigaud et al. 2021d) was carried out to examine and draw actionable insights from the design features of 165 World Bank projects operating at the climate-migration-development nexus; these had commitments amounting to US$197.5 billion between 2006 and 2019. The learnings from the portfolio prove instructive as we seek to address future challenges, complexities, and uncertainties that arise from slow- and rapid-onset climate impacts and influence mobility-immobility dynamics in the near and long term. The learnings show that a more systematic and anticipatory approach in designing projects geared toward addressing climate migration is possible. Increasingly, projects not only address migrants' direct needs but also provide for enabling interventions (early warning systems and social safety nets) and address root causes of mobility by investing in environmental restoration. We must step up on this with great vigor and urgency—acting in partnership and engagement of those directly affected.

By moving from a reactive to anticipatory approach through a focus on climate in-migration hotspots in secondary cities or peri-urban areas could lay the foundation for their development as growth poles in place of sprawling poverty. The emergence of climate in-migration hotspots projected in Cotonou in Benin and Accra, Cape Coast, and Takoradi in Ghana—areas of high poverty—could benefit from socially inclusive approaches. Policies should go beyond livelihood strategies to drive climate-smart urban transitions that combine with sustainable use and management of natural resources. Nurturing and building equity, skills, talent, and a workforce to harness the youth bulge through a focus on energy efficient, green, and resilient urban infrastructure and services would present win-win opportunities. Migration, seen through this lens, can be leveraged to consolidate human capital gains that run across core World Bank diagnostics (such as SCDs, CPFs, and the new CCDRs). Equally National Development Plan could be pivotal in this regard.

No country in West Africa is immune to a future projected increase in climate migration. Our collective efforts and actions can secure the foundations of a peaceful, stable, and secure region for the people of West Africa, and the global community. With conscious policy choices, migration can translate into an effective adaptation strategy that can be harnessed for jobs, equity, and economic transitions.

Climate migration is not uniform across countries and even within countries—some areas will be more adversely impacted than others. Absent concrete climate and development action, Nigeria and Senegal could have the highest numbers among West African coastal countries, with up to 9.4 and 1.0 million internal climate migrants by 2050, respectively.

Dominic Chavez / World Bank



Chapter 7

West Africa Country Snapshots: Focus on Coastal Countries

A focus on scale, magnitude, and trends at the country level can inform policy dialogue and action. The West Africa regional study include the coastal countries of Mauritania, Senegal, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, and São Tomé and Príncipe, and the inland countries of Mali, Burkina Faso, and Niger.

This section focuses on the coastal countries associated with the West Africa Coastal Areas Management Program (WACA): Benin, Côte d'Ivoire, Ghana, Mauritania, Nigeria, São Tomé and Príncipe, Senegal, and Togo. This chapter provides country snapshots for Benin, Côte d'Ivoire, Ghana, Mauritania, São Tomé and Príncipe, and Togo. It summarizes the key results and context. For Nigeria and Senegal, the readers can access the stand-alone country deep dive reports at the World Bank website.[58]

7.1 BENIN

7.1.1 Population and Development Context

Classified as a low-income country (LIC), Benin has had erratic but positive economic growth for the last 25 years. Poverty rates remain high, between 33 percent and 40 percent of the population as of 2015, and are even higher in rural areas (figure 7.1 and table. 7.1).[59] The country relies heavily on border trade with Nigeria (Blum 2014) and on agriculture production, particularly cotton, although economic diversification (for example, tourism) has increased. Informality in sectors such as agriculture, mining, and commerce is very high, at around 50 percent (Medina, Jonelis, and Cangul 2017; Todegnon 2011).

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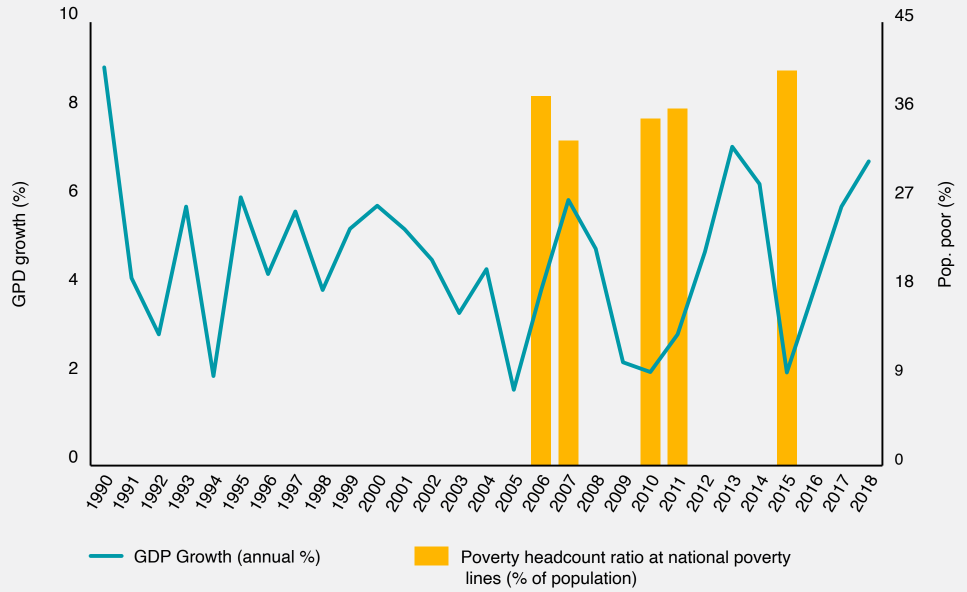
[58] Rigaud, Kanta Kumari; de Sherbinin, Alex; Jones, Bryan; Abu-Ata, Nathalie E; and Adamo, Susana. 2021. *Groundswell Africa: A Deep Dive into Internal Climate Migration in Nigeria*. Washington, DC: The World Bank.

Rigaud, Kanta Kumari; de Sherbinin, Alex; Jones, Bryan; Abu-Ata, Nathalie E; and Adamo, Susana. 2021. *Groundswell Africa: A Deep Dive into Internal Climate Migration in Senegal*. Washington, DC: The World Bank.

[59] See World Development Indicators at https://data.worldbank.org/indicator.

Figure 7.1 Socioeconomic Trends, Benin, 1990–2018



Source: WDI database[60]

Benin's population reached around 11 million in 2017, growing at an annual rate of 2.8 percent, down from 3.0 percent in 2000–05 on average (IADD 2019a). The declining trend is expected to continue, and the growth rate is projected to be below 1 percent by 2100, with a total population of about 47 million.[61] The projections under the Shared Socioeconomic Pathways (SSPs) show that Benin's population will approximately double by 2050, which will compound any impacts of climate change.

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[60] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

[61] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Population Prospects 2019 at https://population.un.org/wpp.

Andrea Borgarello / World Bank

Table 7.1 Development Indicators, Benin

Population	
Population (millions)	11.5
Annual population growth (%)	2.7
Population in 2050 under SSP2 (millions)	19.2
Population in 2050 under SSP4 (millions)	21
Urban share of population (%)	47.3
Employment in agriculture (% of total employment) (2019)	41
GDP	
GDP (current US$ billions)	10.4
Annual GDP growth (%)	6.9
GDP per capita (current US$)	901.5
Value added of agriculture (US% GDP)	22.6
Poverty	
Poverty headcount ratio at US$1.90 a day (2011 PPP) (% of population) (2015)	49.5
Climate and disaster risk indexes	
ND GAIN Index (2017)	
Rank	156
Score	35.7

Source: WDI database;[62] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better.

National population density figures mask large heterogeneities in population distribution, in particular the contrast between the more sparsely populated north and the densely populated south (Doevenspeck 2011) (figure 7.2, panels a and b). About one-fifth of the country's population concentrates in the coastal districts (Croitoru, Miranda, and Sarraf 2019) (where economic dynamism is higher [IADD 2019a]), in settlements that appear spatially clustered (Linard et al. 2012), and in the cities of Porto-Novo (the capital) and Cotonou (across Lake Nokoue, facing the ocean).

About 45 percent of Benin's population lived in urban areas in 2015 (4.8 million), and the average annual growth rate of the urban population was 3.96 percent for the 2010–15 period. The country is expected to complete the urban transition by 2025, when the urban population is estimated to reach 51.2 percent, and by 2050 about 65 percent of the population (15.6 million people) will be in urban areas.[63]

7.1.2 Historical and Current Migrtation Patterns

Internal migration.

Internal migration is extensive in Benin (Howard 2008) and has been a key factor in shaping population redistribution and urbanization (Todegnon 2011). It involves rural-urban flows, particularly to the coastal zone (Howard 2008; IADD 2019a) and to the central region (city of Parakou). There are also rural-rural flows, especially to central Benin, where some of the country's highest population growth rates are recorded (Doevenspeck 2011), and to the northwest. In both types of flows, looking for livelihood opportunities (labor, available land, trade opportunities) is a common reason to move, but family (especially marriage) is an important motive for women (Doevenspeck 2011; Howard 2008); see also Sow et al. (2014) for marriage-related international movements.

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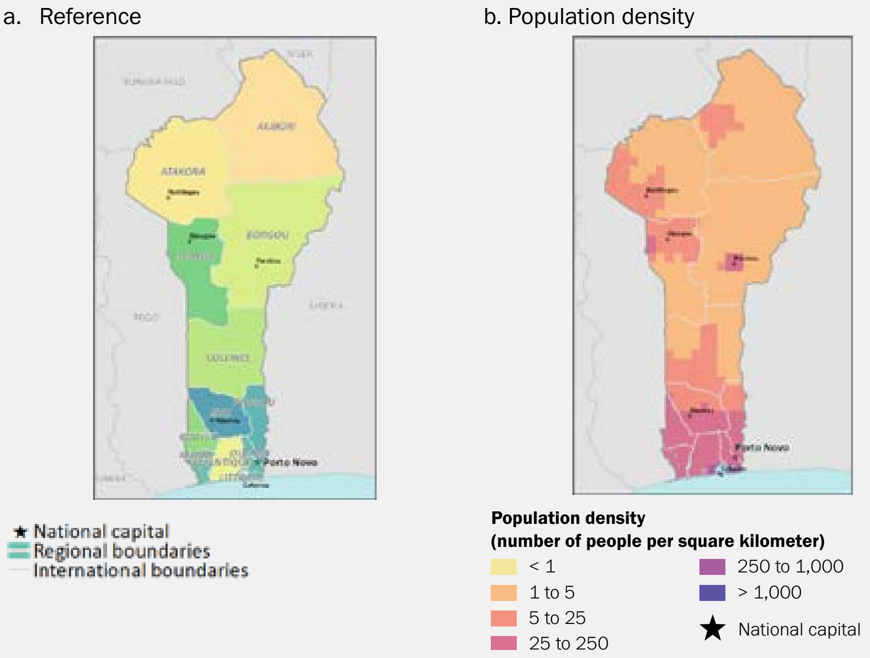
[62] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

[63] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Urbanization Prospects 2018 at https://population.un.org/wup.

Figure 7.2 Reference and Population Density Maps, Benin, 2010


a. Reference

b. Population density

International migration

These patterns are displayed in figure 7.3. Benin is a country of origin and destination, and international flows have included economic migrants as well as refugees (particularly Togolese) (IADD 2019a; Todegnon 2011). Although both emigration and immigration are trending upward, emigration has grown much more rapidly than immigration, resulting in a negative trend in net international migration. Nigeria has been Benin's main destination since at least 1990, followed by Côte d'Ivoire, Togo, Gabon, and France. Nigeria is also among the main sending countries, along with Niger, Togo, Ghana, and Côte d'Ivoire.

Formal and informal cross-border mobility and trade between Benin and Nigeria, part of the Abidjan-Lagos corridor, are an essential part of Benin's economy (about 75 percent of Benin's gross domestic product (GDP) is related to informal cross-border trade) but have raised human security concerns (Blum 2014). Remittances from international migrants represented 3.5 percent of Benin's 2018 GDP.[64]

Benin could see the number of internal climate migrants reduced by over 70 percent in a scenario with appropriate climate and development action.

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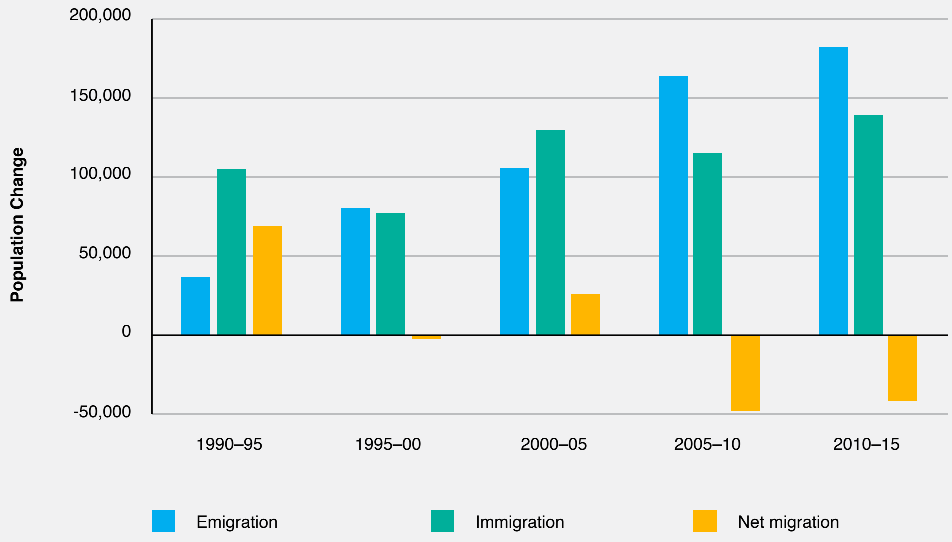
[64] See World Bank, Migrations and Remittances Data at https://www.worldbank.org/en/topic/migrationremittancesdiasporaissues/brief/migration-remittances-data.

Figure 7.3 International Migration Trends, Benin, 1990–2015



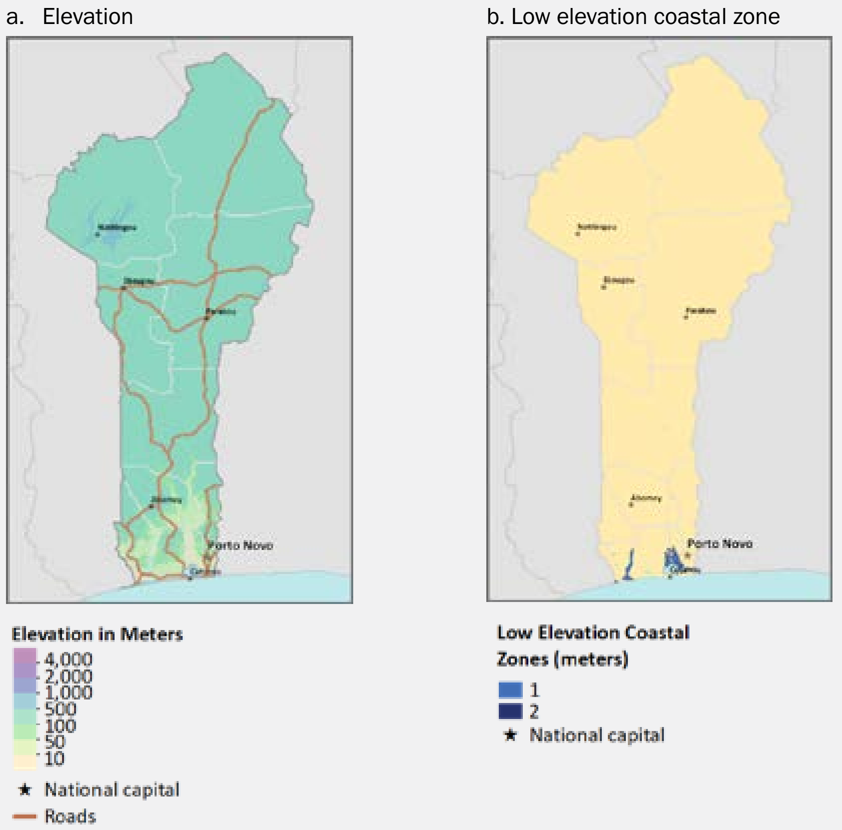
Source: Abel and Cohen 2019.

Environmental migration

In the semiarid northern districts, environmental migration factors for rural migration include climate variability, land degradation, and the resulting food insecurity; flooding also has significant impact on farmers' livelihoods though losses in agricultural income (Bonou et al. 2018). However, environmental processes are part of a complex mix of social, cultural, and institutional factors (Doevenspeck 2011), which may involve internal as well transborder movements (Sow, Adaawen, and Scheffran 2014). As in other parts of the region, diverse in situ responses have been documented, such as among maize farmers in northern Benin, where migration to other agroecological zones is one of several climate change adaptation strategies that include crop diversification, changes in agricultural practices, and calendar adjustments (Yegbemey et al. 2013).

Infrastructure as well as natural resources and linked activities (tourism, fishing, agriculture) in Benin's coastal zone—a main destination for internal migrants—are vulnerable to erosion, sea level rise, increasing temperatures, and flooding (IADD 2019a). About 65 percent of Benin's coast has been subjected to erosion between 1984 and 2016, with associated economic costs equivalent to 1.3 percent of 2017 GDP, while cost of flooding has been estimated at 0.3 percent of the same year's GDP (Croitoru, Miranda, and Sarraf 2019, 28–30). For example, the city of Cotonou is on a strip of land between the Gulf of Guinea and Lake Nokoue, and part of its area is built in lowlands just above or at sea level (Dossou and Gléhouenou-Dossou 2007, 67; Okou 1989). Because the city is a preferred destination of internal migrants, this level of exposure raises the probabilities of secondary migration and displacement. See figure 7.4, panels a and b.

Figure 7.4 Elevation and Low Elevation Coastal Zone Maps, Benin



a. Elevation

b. Low elevation coastal zone

7.1.3 Climate Trends and Projections

Benin is a climatically diverse country with a short coastal segment along the Gulf of Guinea. Its rainfall is affected by the movement of the Inter-Tropical Conversion Zone (ITCZ) and the West African monsoon. In the north, the wet season typically lasts from May to November. In the south, there are two wet seasons: March to July and September to November. Benin is largely made up of transitional tropical zones and therefore has less rainfall than many other countries at its latitude. The current average mean temperature is around 27°C, and the annual precipitation averages at 1,150 millimeters (MFAN 2018).

Benin's diverse environments face distinct climatic challenges, but the overall national trend has been toward higher temperatures, reduced annual rainfall, severe drought, and intensified precipitation and storms. In the north, desertification has accelerated and is projected to continue as droughts and extreme winds become more constant.[65] Trends suggest that mean annual temperature could rise from 1.0°C to 3.0°C by the 2060s. The south is prone to heavy rainfall and floods. Sea level rise threatens to exacerbate flooding and erosion, potentially damaging livelihoods and food security. Benin's coastal wetlands have been seriously degraded by human intervention; they are expected to diminish by around 40 percent by 2080 (MFAN 2018).

In this study, the population gravity model calibration found that the coefficients were highest for water availability, meaning that past shifts in water availability played a greater role than the other input variables in explaining shifts in population distribution. Panels in figures 7.5 to 7.7 show the average projected changes in water availability, crop production, and net primary productivity (NPP) for the 2010–50 time period, respectively. NPP gap-fills areas where there is no crop production. The coefficient for water availability in rural areas is around 2.75 times higher than that of either crops or NPP. It is the only climate factor other than

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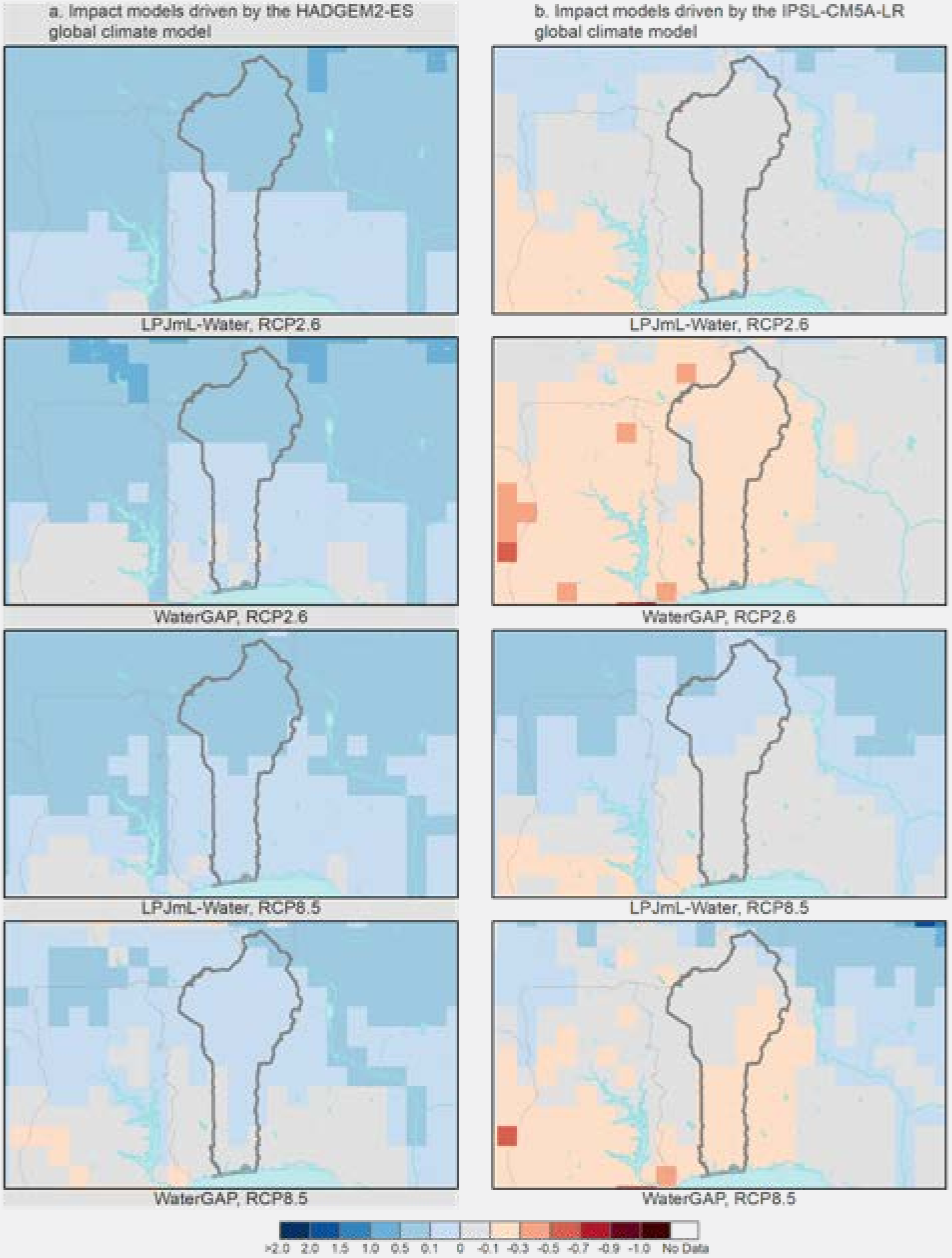
[65] See World Bank, Climate Change Knowledge Portal, Climate Data—Benin, at https://climateknowledgeportal.worldbank.org/country/benin.

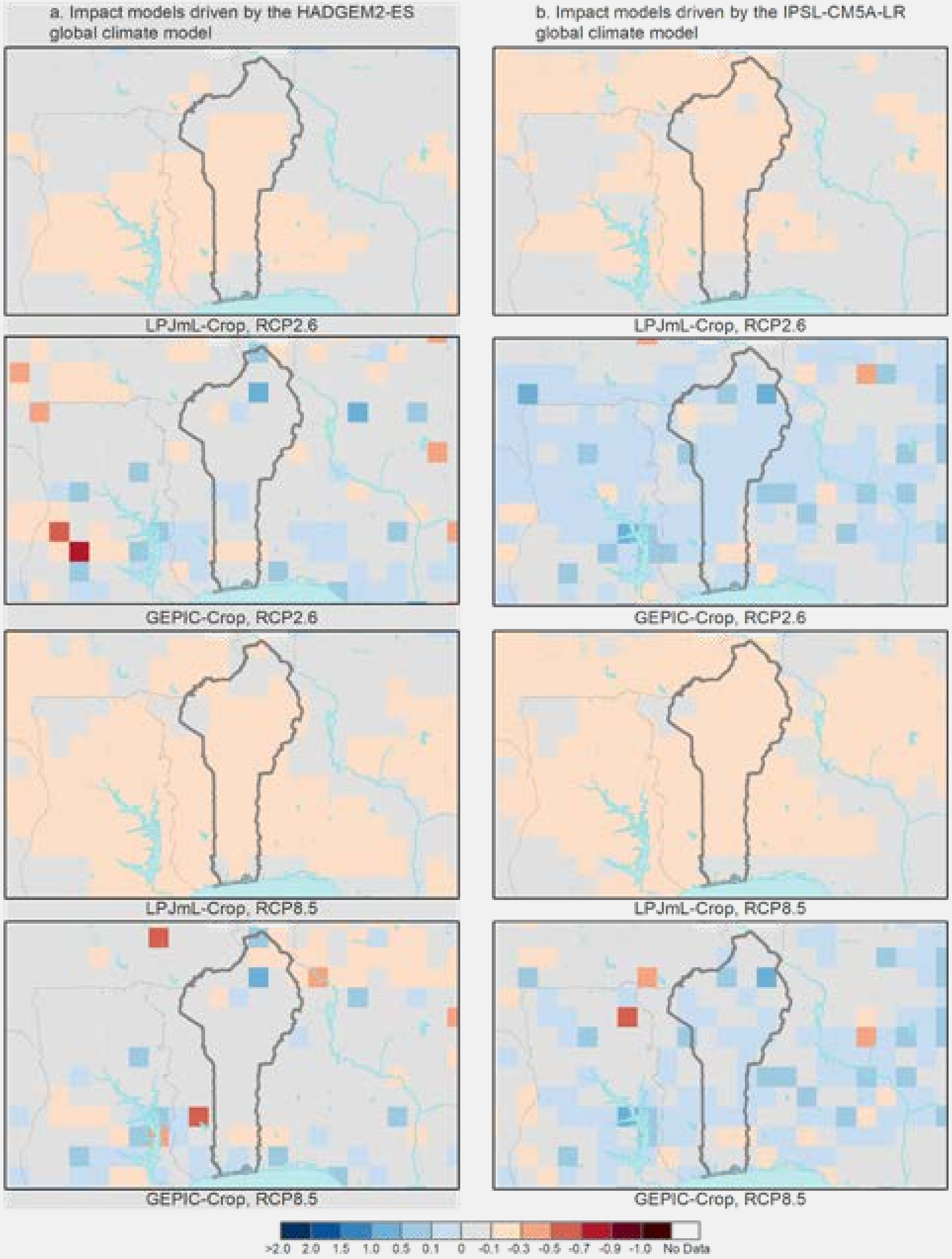
flood risk and sea level rise influencing future urban population distribution, which means it has a far greater influence on future population distribution than most other climate variables. Water modeling results suggest that Benin will not be as strongly affected by shifts in water availability as with some other countries in the study. Only under the IPSL-CM5A-LR global climate model coupled with WaterGAP (two out of eight model runs) are there 10 percent to 30 percent reductions in water availability compared to the historical baseline. Similar to neighboring countries (Ghana and Togo), crop models are more mixed, with the LPjML model showing 10 percent to 30 percent declines in the middle belt of the country, and GEPIC showing more mixed results but largely increases in crop production. The NPP model outputs are shown only for information purposes (there is no part of Benin without crop production), but the picture is one of largely increasing ecosystem productivity.

Figure 7.5 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Benin, 2010–50



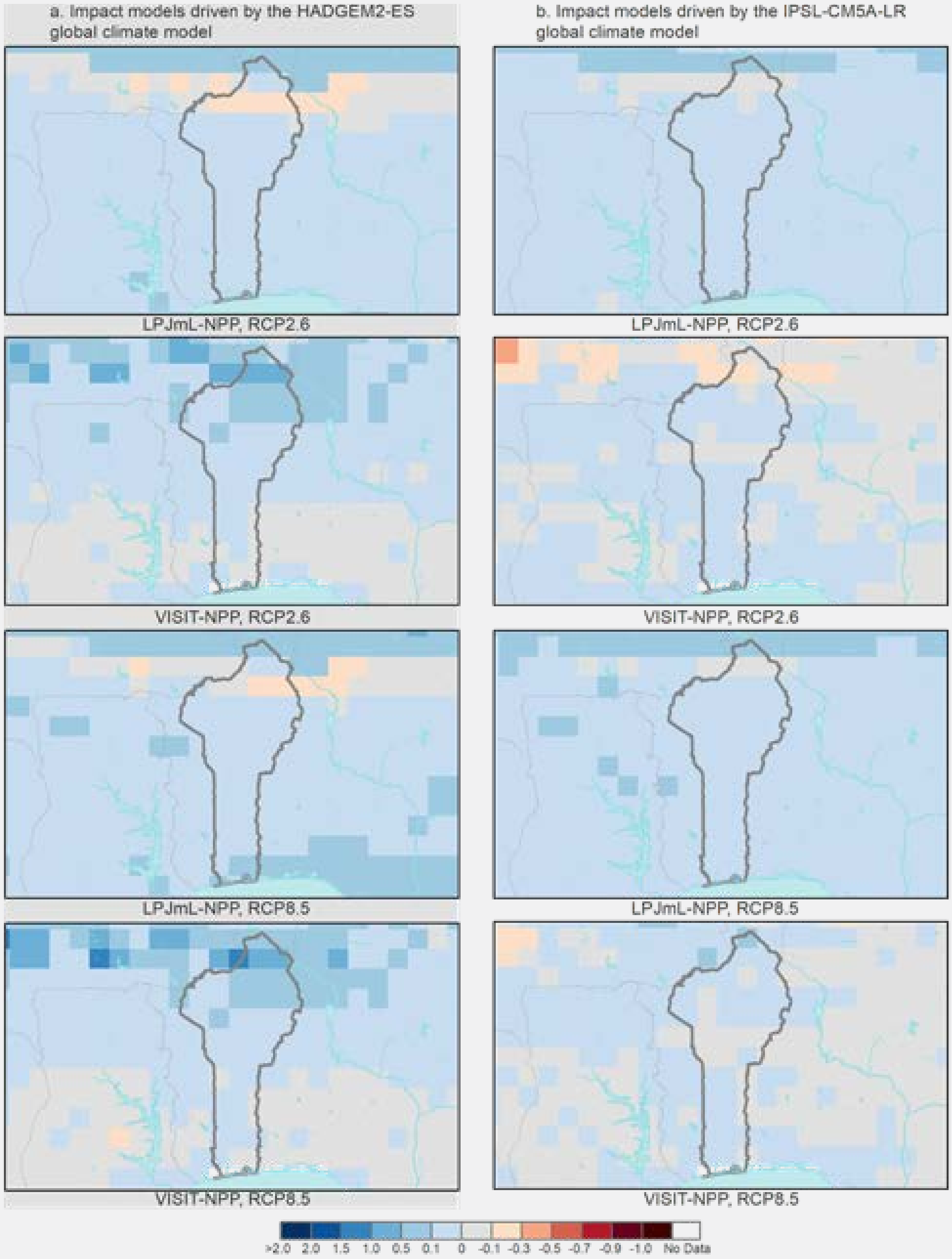
Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.6 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Benin, 2010–50



Note: Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production.

Figure 7.7 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Benin, 2010–50



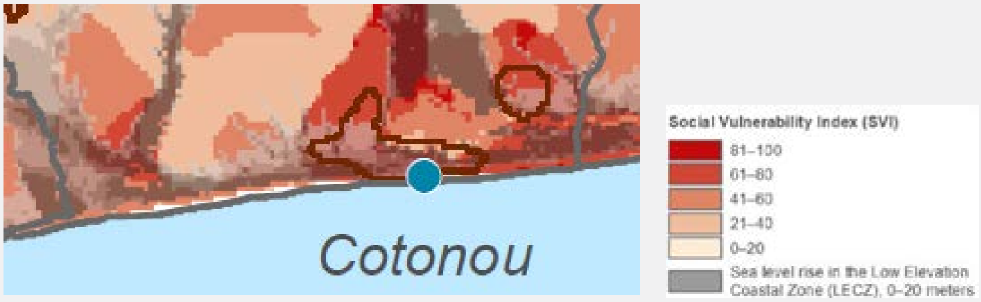
Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is used to gap-fill crop production, and therefore is not used to model future population distribution in Benin. NPP = net primary production.

7.1.4 Coastal Trends and Projections

The coastal areas at greatest risk of erosion in Benin are in eastern Cotonou, with an erosion rate of approximately 9 meters per year at Donatin, a district to the east of the outlet of Lake Nakoué (Degbe 2017). Similarly, Dossou and Glehouenou-Dossou (2007) find that the area of Cotonou to the east of the Lake Nakoué outlet are most vulnerable to coastal erosion. Further west, at Djondji, erosion rates are around 2 meters per year and, in the far west, between Hillacondji and Agoué, rates are around 5 meters per year (all sites plus or minus 0.03 meters) (Degbe 2017). In contrast, sites to the west of the Port of Cotonou are seeing coastal accretion at the rates of around 4 meters per year. Ndour et al. (2018) state that in the western reaches of Benin, damming of the Mono River at Nangbeto in Togo has led to the river's eastward migration on the coast at the rate of 700 meters per year. According to Croitoru, Miranda, and Sarraf (2019), the costs of coastal erosion amount to US$117 million or 1.3 percent of GDP in 2017 based on the value of assets and annual production per hectare as well as the value of the land.

De Sherbinin et al. (2014) measured social vulnerability levels as a function of population density, population growth, subnational poverty, maternal education levels, market accessibility (travel time to markets), and political violence (figure 7.8). Results suggest that areas north of Cotonou exhibit the highest levels of social vulnerability.

Figure 7.8 Social Vulnerability Index for the Coastline of Benin



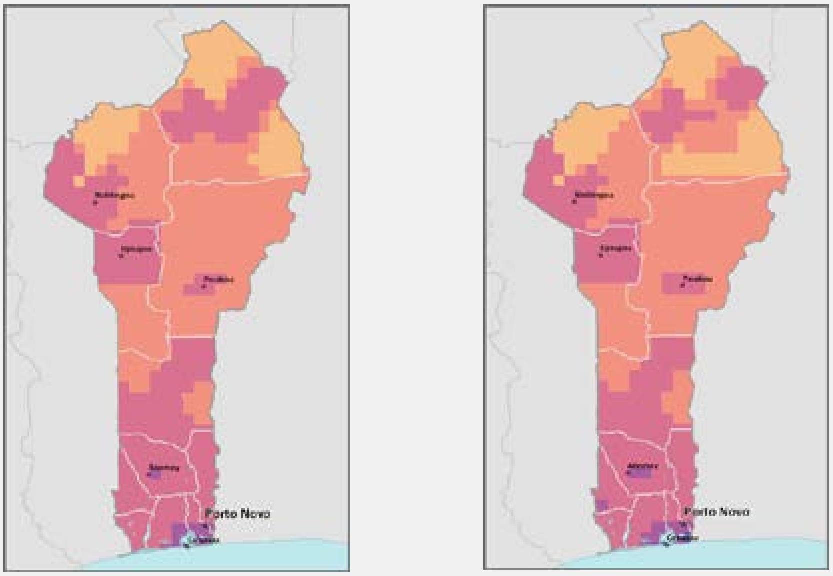
Source: de Sherbinin et al. 2014.

Hinkel et al. (2012) applied the Dynamic Interactive Vulnerability Assessment (DIVA) model to the West African coast, finding that Benin is ranked among the top 15 most vulnerable countries in Africa in terms of sea level rise projections.

7.1.5 Projected Changes in Population

Projections of future population size to 2050 depend on the SSP scenario (figure 7.9). Total population would reach 23.7 million under the SSP4 scenario, and 21.5 million under the SSP2 scenario. Higher 2010 population densities are predicted in the southern provinces followed by the northwest regions, while lower densities are observed on the east and northern areas. Projections to 2050 under the four scenarios reveal a continuation, intensification, and expansion of these 2010 patterns, with very few differences among them (figure 7.9, panels a–d).

Figure 7.9 Projected Population under the Four Scenarios, Benin, by 2050

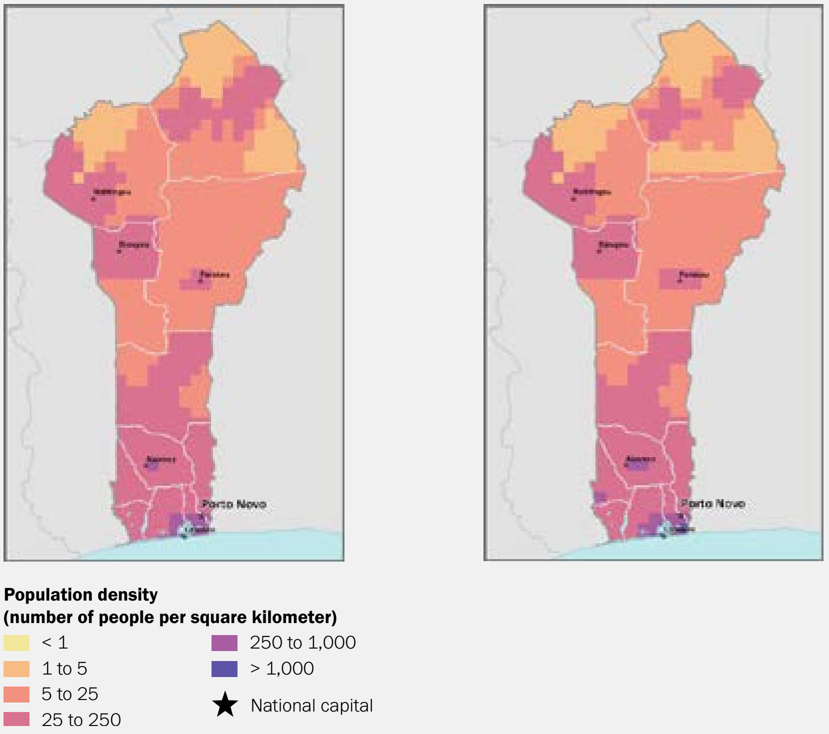


a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6)

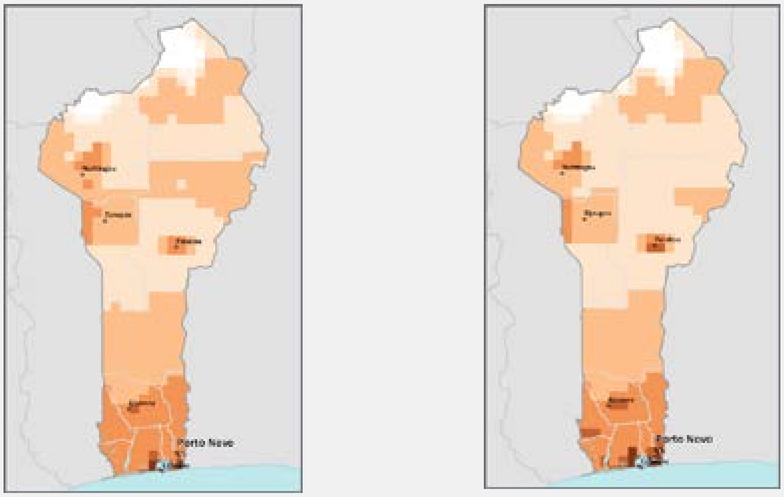
d. Climate-friendly (SSP4 and RCP2.6)



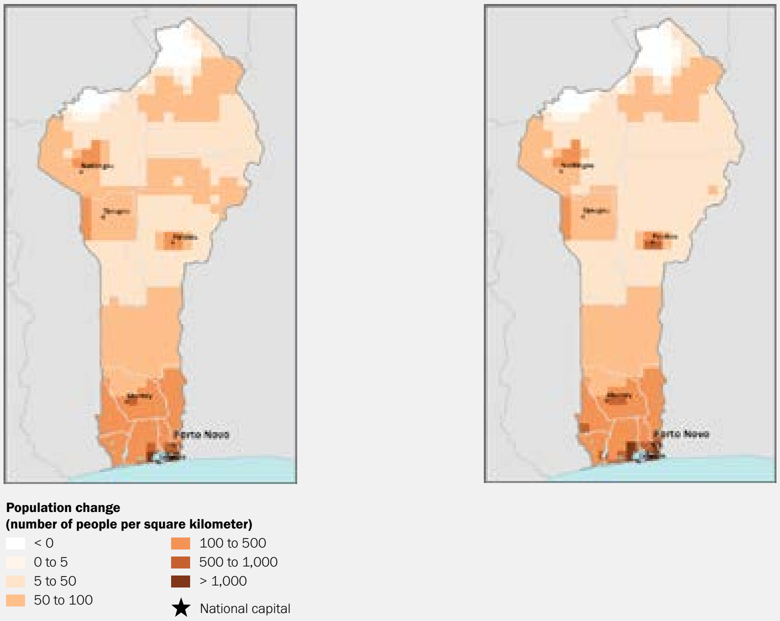
Changes in population density (figure 7.10, panels a–d) appear more pronounced in the large urban areas such as Porto-Novo, the southern coastal zone around Cotonou, and the city of Parakou in central Benin. The northern areas on the country, on the border with Burkina Faso and Niger, show almost no change in population density between 2010 and 2050.

Figure 7.10 Projected Population Density under the Four Scenarios, Benin, 2010–50

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

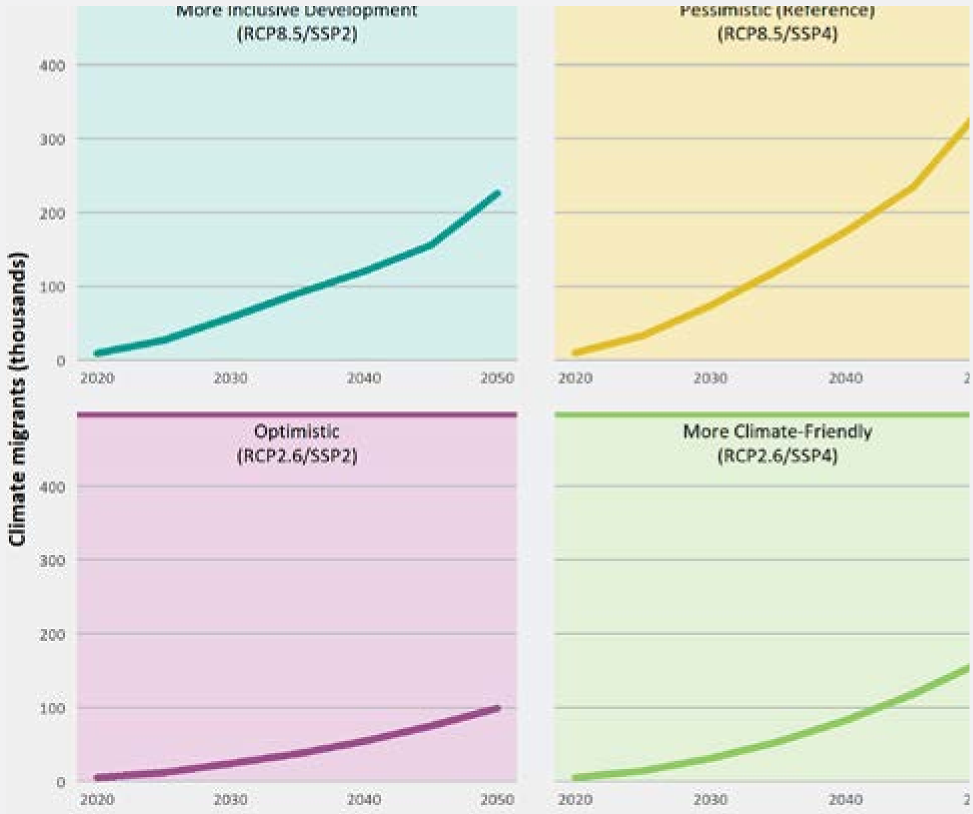


7.1.6 Internal Climate Migration Futures and Trends

Scale and Trajectory of Internal Climate Migration

Figure 7.11, panels a–d, presents the projected number of climate migrants by scenario and decade, from 2015 to 2050, and table 7.2 provides the numbers and percentages at the low and high ends of the confidence intervals for 2050. All the scenarios display an upward trend, but they differ in the magnitude of climate migration and its pace. Benin has a remarkable degree of consistency across the model runs for each scenario, leading to very small confidence intervals around the projections. The optimistic scenario has the lowest number of climate migrants in 2050, around 100,000 (about 0.5 percent of 2050 total population under SSP2). This number grows considerably under the more climate-friendly scenario to reach about 162,000. This growth seems to accelerate in the more inclusive development (226,000 by 2050) and especially for the pessimistic scenario, projected to reach 340,000 climate migrants by midcentury (about 1.4 percent of the 2050 total population under SSP4).

Figure 7.11 Projected Total Climate Migrants, Benin, 2020–50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.09	0.41	0.72	1.18	0.09	0.51	0.97	1.62

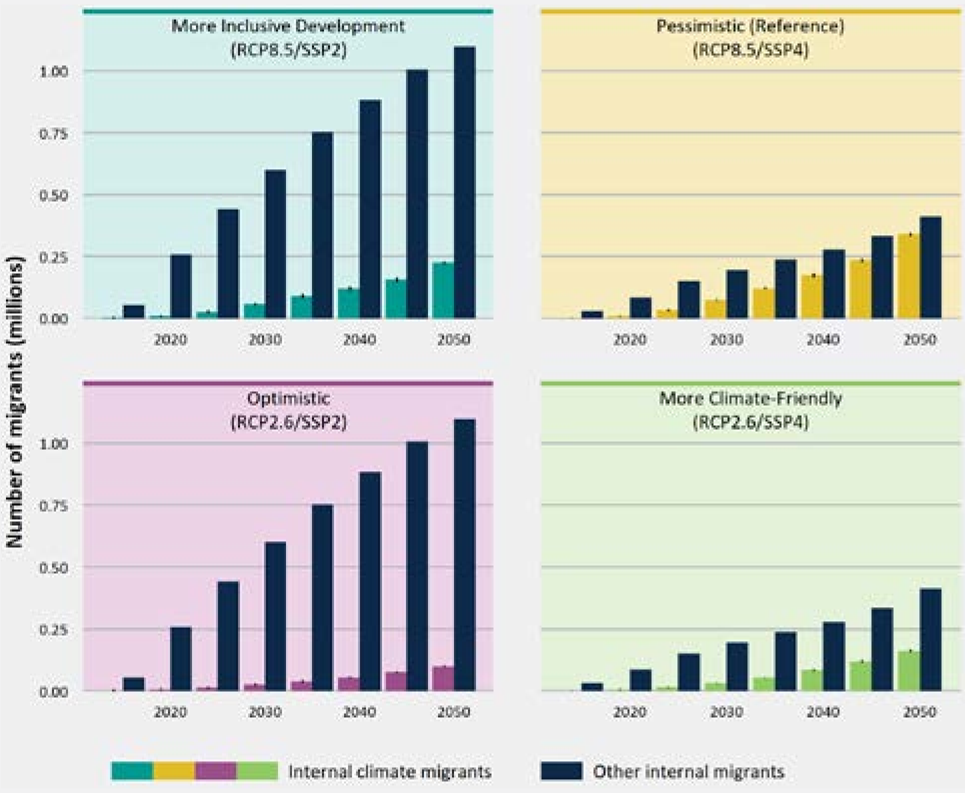
Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.05	0.17	0.32	0.52	0.05	0.21	0.46	0.77

Table 7.2 Projected Total Internal Climate Migrants in Four Scenarios for Benin by 2050

	Scenario							
	Pessimistic (reference)		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	0.340		0.226		0.161		0.099	
Min. (left) and max. (right) (millions)	0.337	0.342	0.223	0.229	0.160	0.164	0.097	0.101
Internal climate migrants as a % of pop.	1.62		1.18		0.77		0.52	
Min. (left) and max. (right) (%)	1.6	1.63	1.16	1.19	0.76	0.78	0.5	0.53

The number of climate migrations compared to other (development) migrants is quite high under the pessimistic scenario, and very low under the optimistic scenario (figure 7.12, panels a–d). The changes in population distribution because of other (or economic) migration under SSP2 are consistently higher than under SSP4.

Figure 7.12 Projected Climate Migrants Compared to Other Migrants, Benin, 2010–50

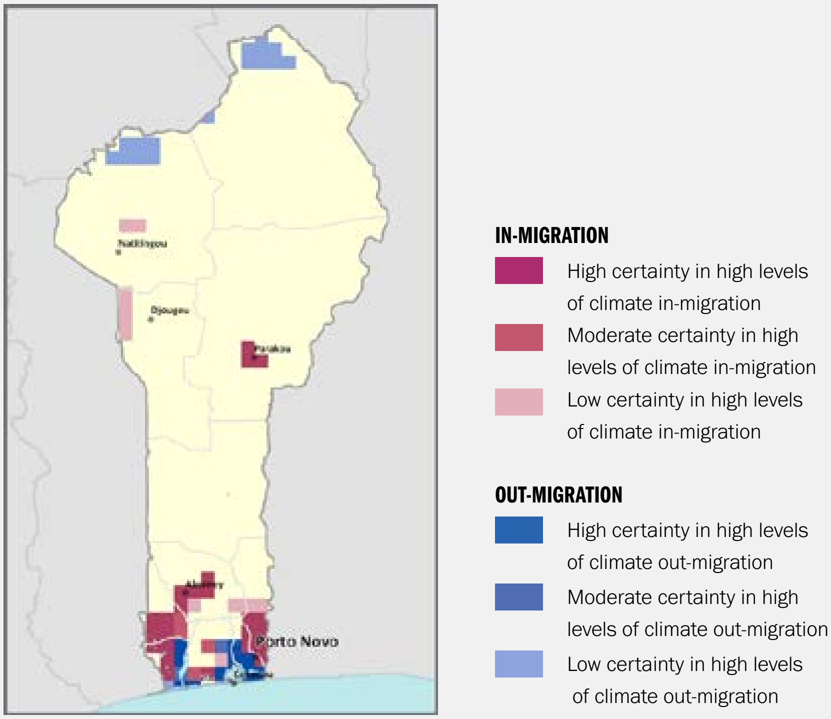


Internal Climate Migration Hotspots

To interpret the climate migration hotspots, one must understand that more highly populated areas are more likely to have high in- or out-migration, since thinly settled areas typically do not see a lot of difference in absolute numbers of population between the climate and no climate impacts model runs.

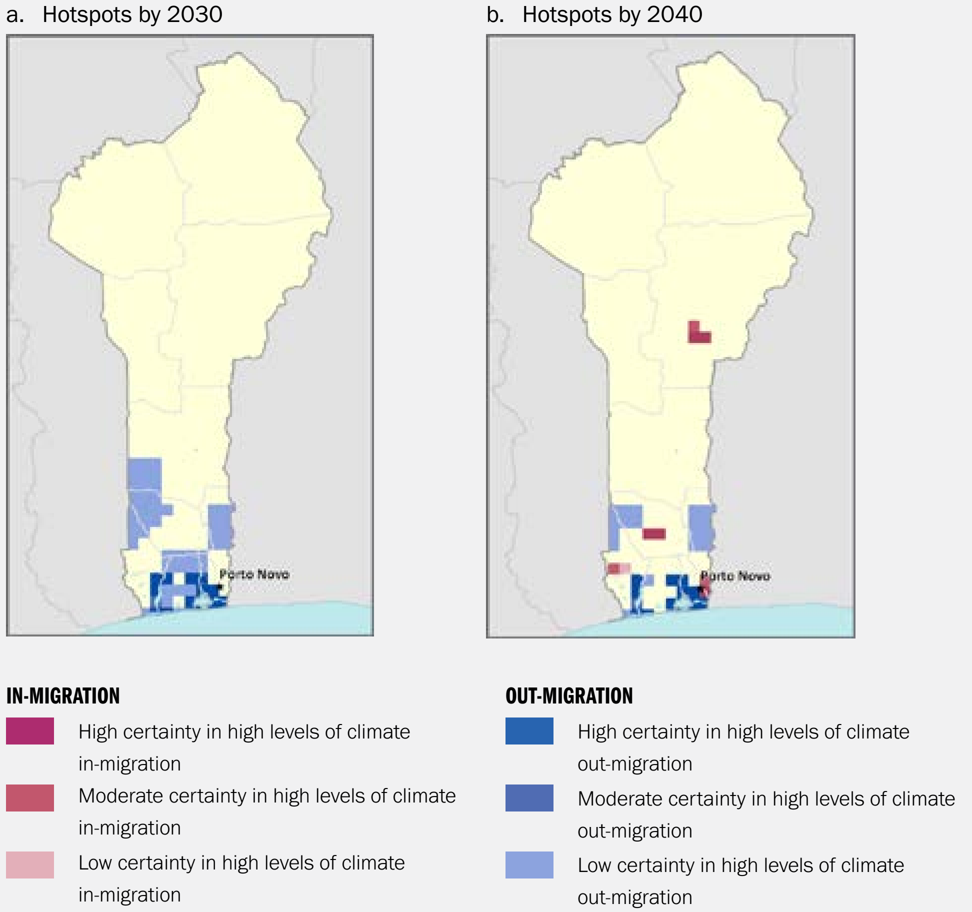
Figure 7.13 displays the results for 2050. Areas with high certainty of climate in-migration concentrate in the south, outside the lower elevation areas. Areas of high certainty of climate out-migration also concentrate in the south, but in the low-lying areas prone to flooding and coastal erosion. Climate in-migration spots and some low-certainty climate out-migration ones appear in 2040 (figure 7.14, panel b), which might suggest an acceleration of the process, in agreement with the slope change between 2040 and 2050 for the more inclusive and pessimistic scenarios.

Figure 7.13 Projected Hotspots of Climate In- and Out-Migration, Benin, 2050



Note: Data results reflect top and bottom 5 percent highest differences between the climate and no climate impact scenarios for the region as a whole.

Figure 7.14 Projected Hotspots of Climate In- and Out-Migration, Benin, 2030 and 2040

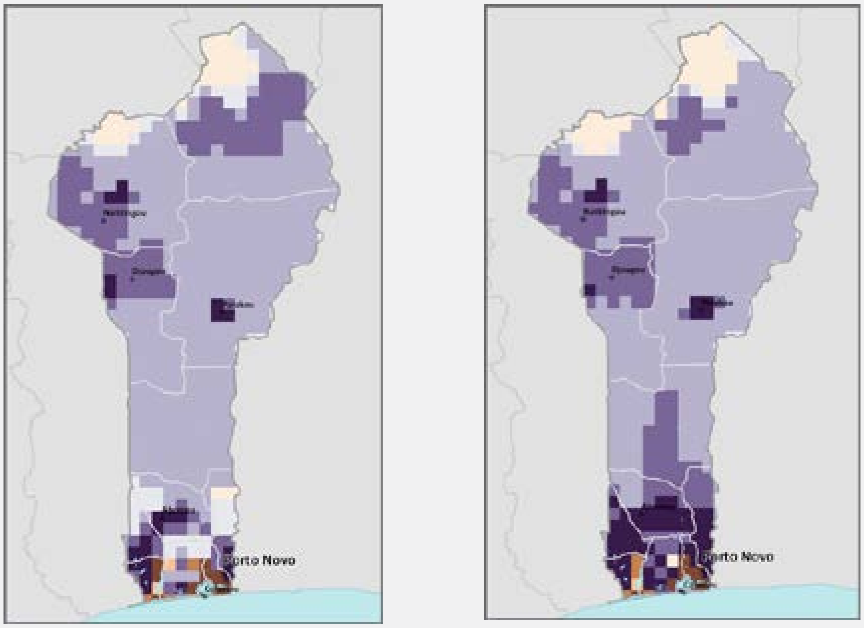


a. Hotspots by 2030

b. Hotspots by 2040

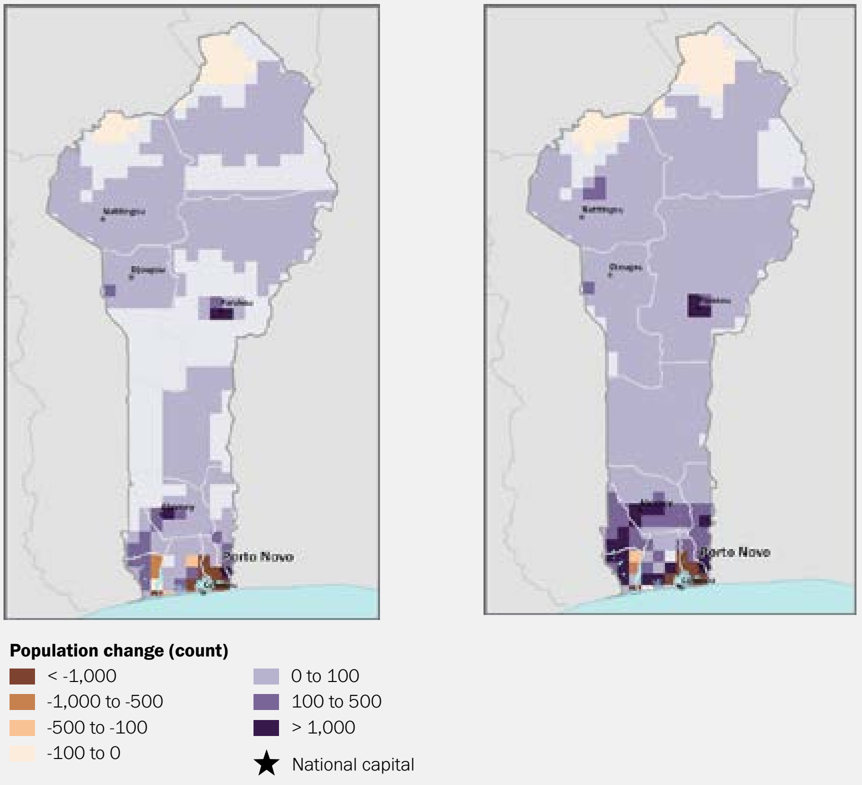
To contribute to the interpretation of figure 7.13, figure 7.15, panels a–d, displays the absolute differences between climate and no climate scenarios. Negative differences are concentrated in the south, intertwined with positive ones in an almost checked pattern common to the four scenarios. Large differences appear in the center and west of the country, home to some urban centers (Parakou, Djougou, Natitingou). While the magnitude and location of the negative differences are similar across scenarios, positive differences are higher and cover larger areas in the pessimistic one, followed by more inclusive development, more climate-friendly, and the optimistic scenarios.

Figure 7.15 Projected Population Change Due to Climate Migration, Benin, 2050



a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

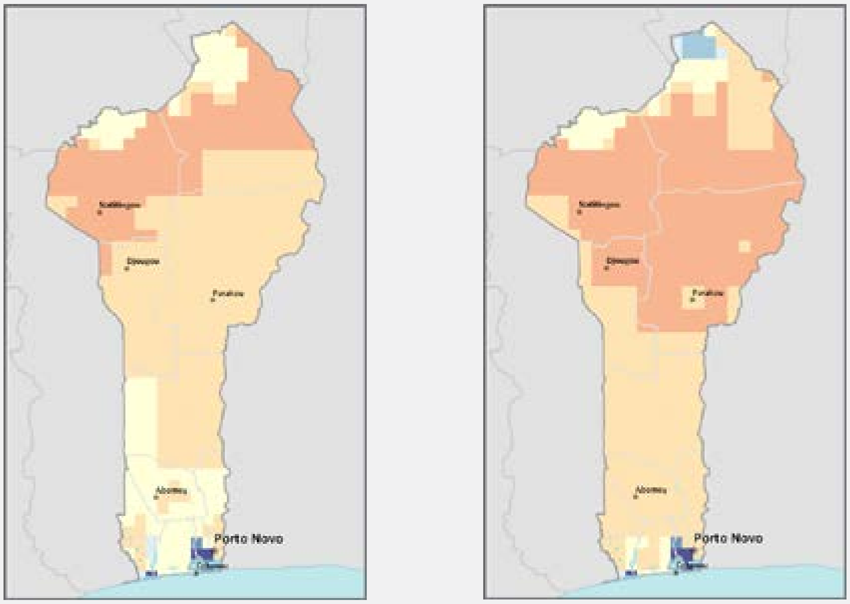
d. Climate-friendly (SSP4 and RCP2.6)

Note: Changes shown per square kilometer.

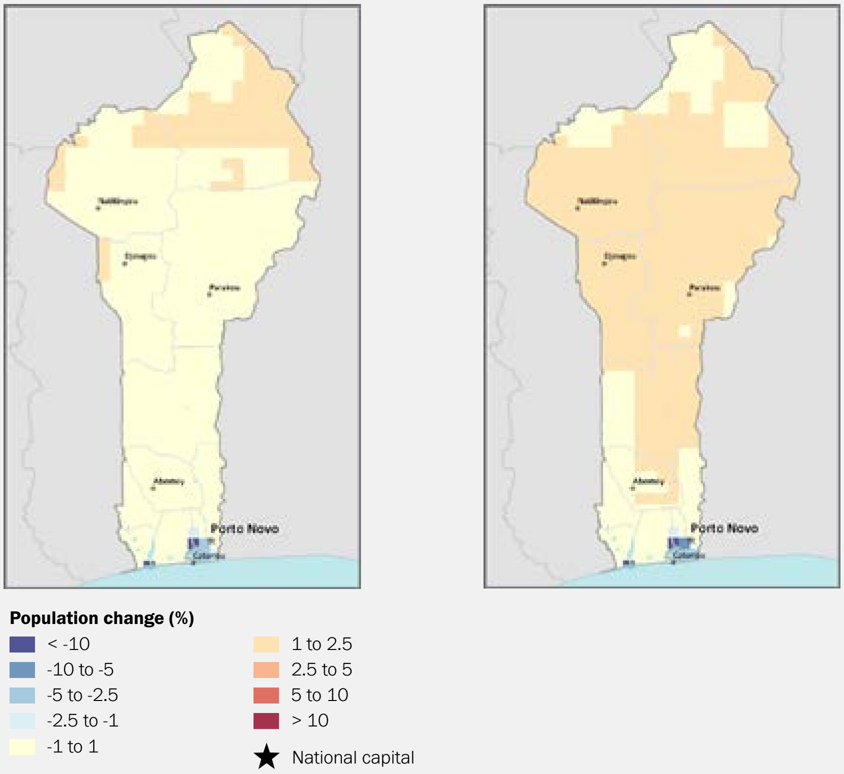
Figure 7.16, panels a–d, displays the difference between climate and no climate impact scenarios as percentages. In all the scenarios, the largest proportional differences correspond to the southeast, close to the capital city of Porto-Novo. This is currently a densely populated region and an important destination for internal migrants. It is also exposed to coastal erosion and flooding, and likely to be further affected by sea level rise impacts.

Figure 7.16 Projected Percentage of Differences between Climate Impact Scenarios and the Respective No Climate Impact (SSP-Only) Scenario, Benin, 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)



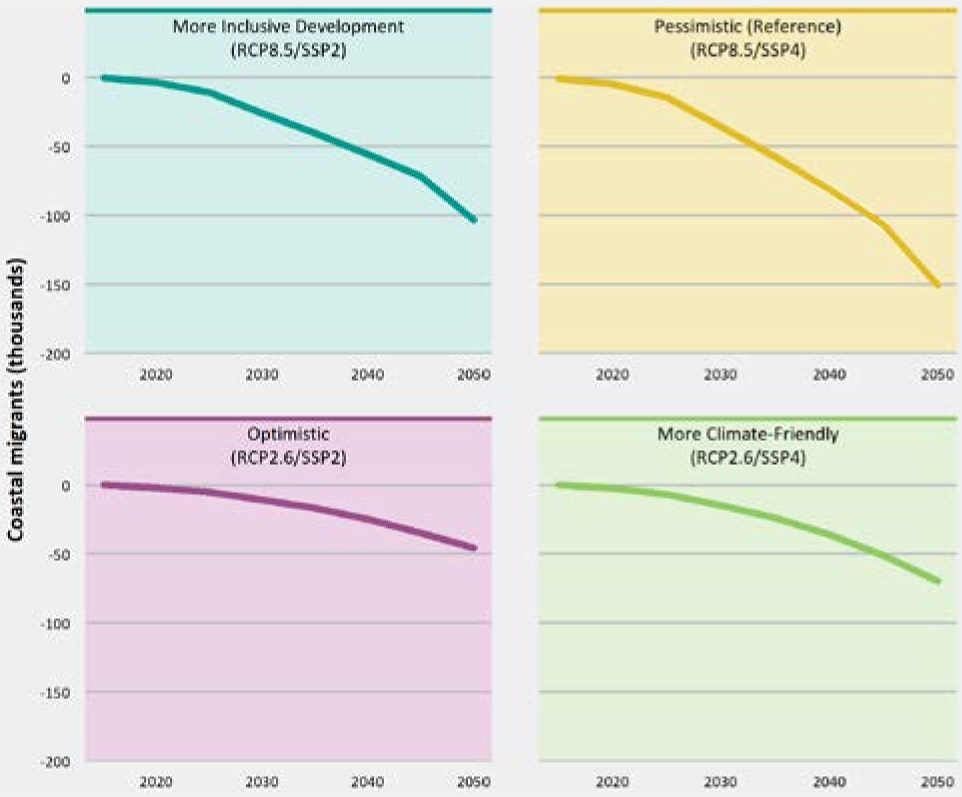
Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, processing the coastal climate migration uses the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level.

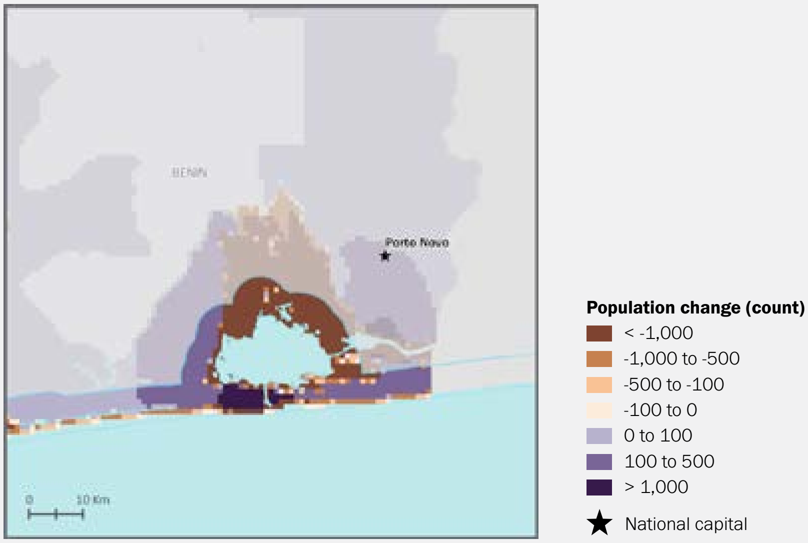
The four scenarios project that population would leave coastal areas in Benin due to the projected impacts of climate change, but they differ in the magnitude and the pace of the process (figure 7.17, panels a–d). The pessimistic scenario displays the largest number of climate emigrants, about 150,000 in 2050, while the optimistic scenario shows a much smaller number (around 50,000).

Figure 7.17 Projected Coastal Climate Migrants, Benin, 2015–50



Coastal zone has both climate in- and out-migration because of different push and pull factors (figure 7.18). The attraction of Cotonou and to a lesser extent of nearby coastal areas contrast with the negative balances of the lagoon areas (particularly the ones farther away from Cotojou) and a thin coastal line immediately by the sea, where the impact of sea level rise is likely to be the dominating factor.

Figure 7.18 Projected Population Change 2050 Because of Climate Migration, Coastal Zone, Benin, 2050



Note: Data based on per square kilometer using the pessimistic scenario.

Climate Migration by Livelihood Zone

Rainfed croplands is the most extensive of Benin's biomes (figure 7.19), covering large sections on the west, east, and south-central regions. The seminatural/wildlands biome is second, found along the border with Burkina Faso and Niger in the north and in central areas of the country. Country results for these two biomes indicate that net climate migration is positive in each decade and scenario (table 7.3). Instead, the balance is negative for dense settlements, probably due to the location of major cities in the coastal area.

Figure 7.19 Livelihood Zones, Benin

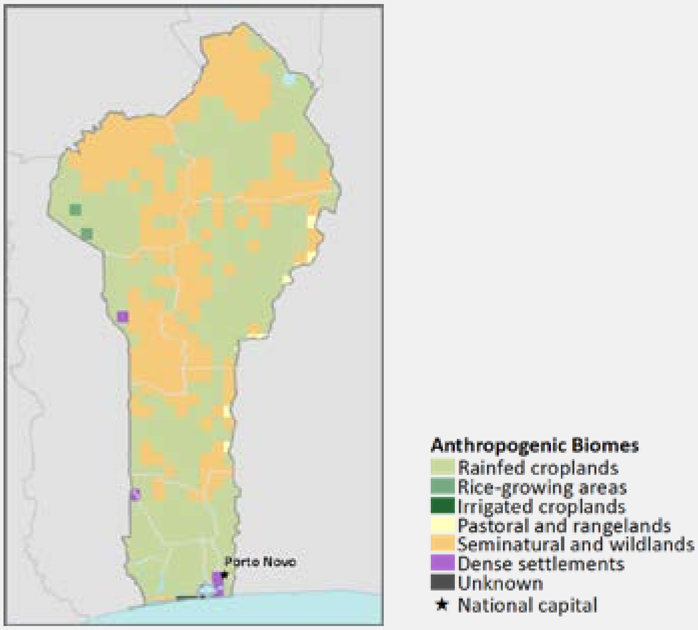


Table 7.3 Projected Net Climate Migration by Scenario, Livelihood Zone, and Decade, Benin, 2030, 2040, and 2050 (number of people)

Year and livelihood zone	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
2030				
Dense settlements	−10,267	−16,597	−6,995	−24,100
Irrigated croplands	103	90	121	113
Pastoral and rangelands	159	337	108	416
Rainfed croplands	4,825	6,701	2,715	12,433
Rice-growing areas	177	370	151	375
Seminatural and wildlands	5,345	11,306	4,371	12,884
Unknown	−341	−2,208	-471	−2,120
2040				
Dense settlements	−27,659	−37,263	−17,632	−57,885
Irrigated croplands	183	375	202	297
Pastoral and rangelands	388	570	235	945
Rainfed croplands	13,789	15,704	8,371	29,270
Rice-growing areas	385	822	309	806
Seminatural and wildlands	11,323	22,299	8,419	27,706
Unknown	1,590	−2,507	95	−1,139
2050				
Dense settlements	−53,187	−77,914	−32,130	−118,196
Irrigated croplands	283	646	318	481
Pastoral and rangelands	730	1,086	475	1,770
Rainfed croplands	28,811	32,639	16,794	60,275
Rice-growing areas	667	1,380	516	1,323
Seminatural and wildlands	19,618	41,640	14,521	48,510
Unknown	3,079	523	-493	5,838

Climate Migration by Province

Figure 7.20 and table 7.4 display net climate migration by province, which further confirms the spatial heterogeneity of climate migration patterns shown in figure 7.13 and highlight the 2050 distribution of climate migration stocks. Three coastal provinces—Atlantique, Oueme and Mono—consistently show the largest negative balance for climate migration in all the scenarios. This is due to sea level rise impacts and declining water availability in several model runs. In contrast, results for the small coastal province of Littoral (with its capital, Cotonou) vary across scenarios: negative for those based on SSP2 (optimistic and climate-friendly), and positive for those based on SSP4 (more development friendly and pessimistic).

In contrast, the northern provinces of Atacora and Alibori and the central province of Borgou (home to Parakou, an important destination of internal migration) show a positive net climate migration balance. As with neighboring Togo, projected increases in water availability largely explain the increases in these regions. High climate in-migration in Borgou is partly due to high median age in the capital of that region, Parakou.

Figure 7.20 Projected Net Climate Migration by Province and Scenario for Benin, 2050

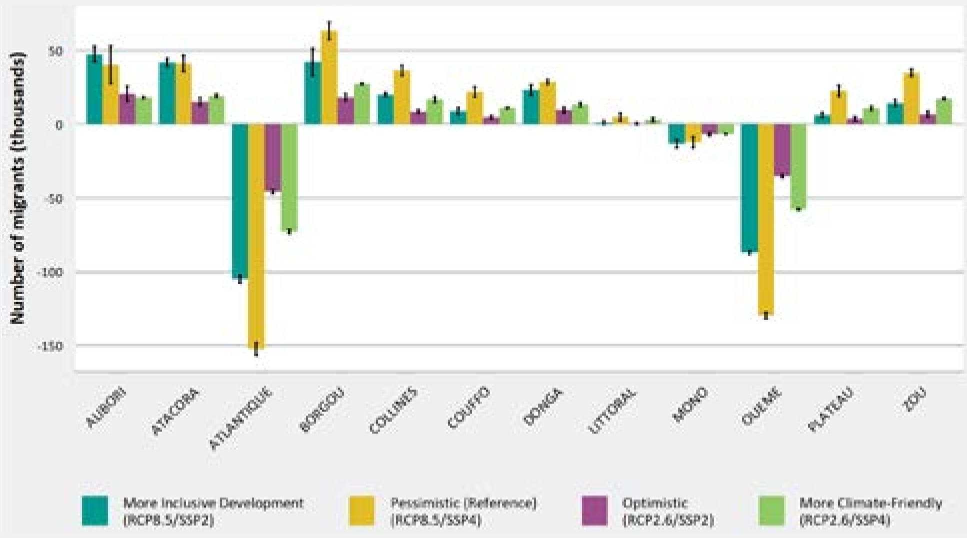


Table 7.4 Projected Net Migration by Scenario and Province, Benin, 2050 (number of people)

Admin 1	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Atlantique	–214,811	–311,553	–140,873	–454,327
Oueme	–167,949	–249,013	–107,611	–368,851
Mono	–20,495	–49,687	–21,381	–44,849
Littoral	6,151	–3,537	–40	3,521
Plateau	25,946	7,975	6,008	54,496
Couffo	29,050	17,414	11,551	54,716
Donga	40,272	69,607	30,374	90,354
Zou	44,760	30,362	15,377	91,605
Collines	45,156	49,805	21,562	104,163
Atacora	62,649	137,562	51,984	134,533
Alibori	66,004	163,123	76,151	139,220
Borgou	83,267	137,941	56,897	195,418

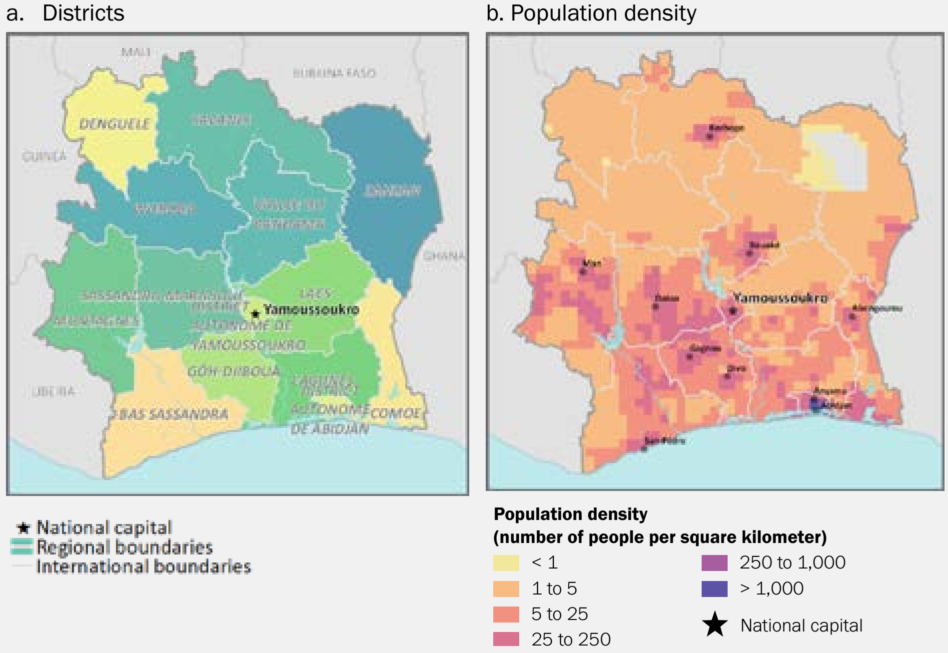
Note: “Admin. level” refers to governmental level. 1 = state or province.

7.2 CÔTE D'IVOIRE

7.2.1 Population and Development Context

Classified as a lower-middle-income country (LMIC),[66] Côte d'Ivoire, once an engine of economic growth in francophone West Africa, experienced civil war in the first decade of the 21st century that resulted in negative growth rates and increasing debts. Since the end of the civil war in 2011, annual economic growth rates have varied from 4.8 percent to 8 percent. Despite the apparent prosperity of Abidjan, the nation's largest city, the country still ranks low in the Human Development Index (HDI) (170 out of 189 countries) (UNDP 2018). National figures mask within-country heterogeneities in development achievements: northwestern Côte d'Ivoire, on the borders with Mali, Guinea, and Liberia, has among the highest infant mortality rates in West Africa (CIESIN 2019). Additional development statistics are in table 7.5. Figure 7.21, panels a and b, shows regions and population density, respectively.

Figure 7.21 Districts and Population Density Maps, Côte d'Ivoire, 2010


a. Districts

b. Population density

Côte d'Ivoire's population was 25.1 million in 2018, with an annual growth rate of 2.6 percent. This rate is quite high when compared with the annual world rate of 1.09 percent for 2015–20. The SSPs project between 32.4 million and 39.3 million people by 2050, although the UN median variant projections suggest the number could be as high as 51.3 million.[67] Abidjan is the primary city, with a population of 4.5 million, followed by Bouake, with a population of just over 500,000,[68] while the capital of Yamoussoukro has just over 200,000. Despite the concentration of population in these cities, around 49 percent of the population reside in rural areas, many of whom rely on commercial cocoa plantations, subsistence agriculture, or artisanal fisheries.

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[66] See World Development Indicators, Côte d'Ivoire Profile, at https://data.worldbank.org/country/cote-divoire.

[67] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Population Prospects 2019 at https://population.un.org/wpp.

[68] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Urbanization Prospects 2018 at https://population.un.org/wup.

Table 7.5 Development Statistics, Côte d'Ivoire

Population	
Population (millions)	25.1
Annual population growth (%)	2.6
Population in 2050 under SSP2 (millions)	30.6
Population in 2050 under SSP4 (millions)	37.3
Urban share of population (%)	50.8
Employment in agriculture (% of total employment) (2019)	47.6
GDP	
GDP (current US$ billions)	43.0
Annual GDP growth (%)	7.4
GDP per capita (current US$)	1,715.50
Value added of agriculture (% GDP)	19.8
Poverty	
Poverty headcount ratio at US$1.90 a day (PPP, 2011) (% of population) (2015)	28.2
Climate and disaster risk indexes	
ND GAIN Index (2017)	
Rank	145
Score	37.9

Source: WDI database;[69] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better

7.2.2 Historical and Current Migration Patterns

Internal migration

Like many countries in West Africa, Côte d'Ivoire experienced a long period of rural-to-urban migration during the colonial and postindependence periods because of industrialization, education opportunities, and the attraction of urban amenities. However, in the 1990s and into the early 2000s, there was a reversal, with migration from urban to rural (origin) areas mostly because of the impact of structural adjustment programs on urban areas. According to Beauchemin (2011): "Structural adjustment programs aimed to reduce the gap between urban and rural areas in order to counter the 'urban bias,' perceived as an obstacle to economic development." These programs affected spending in education, job opportunities, and salaries because of trade liberalization at the expense of industrial domestic growth, making urban areas less attractive and rural areas relatively more attractive. It is unclear if this pattern has reverted to the normal pattern of rural-to-urban migration more recently. There was also a progressive movement of cocoa production (and farmers) from the central portions of Côte d'Ivoire toward the west and southwest, where land was converted from native forest cover to plantations (Ruf et al. 2015).

In the 1990s and 2000s, tensions rose over the large immigrant community in the country, most of whom worked as laborers on Ivorian cocoa plantations (Mitchell 2011). By the late 1990s, 26 percent of the nation's population were foreign nationals, the majority of whom were from Burkina Faso (Adjami 2016). Nationalist sentiment rose, abetted by then-President Laurent Gbagbo's nationalist policies. Throughout much of the 2000s, Côte d'Ivoire was divided into a southern portion controlled by forces loyal to Gbagbo,

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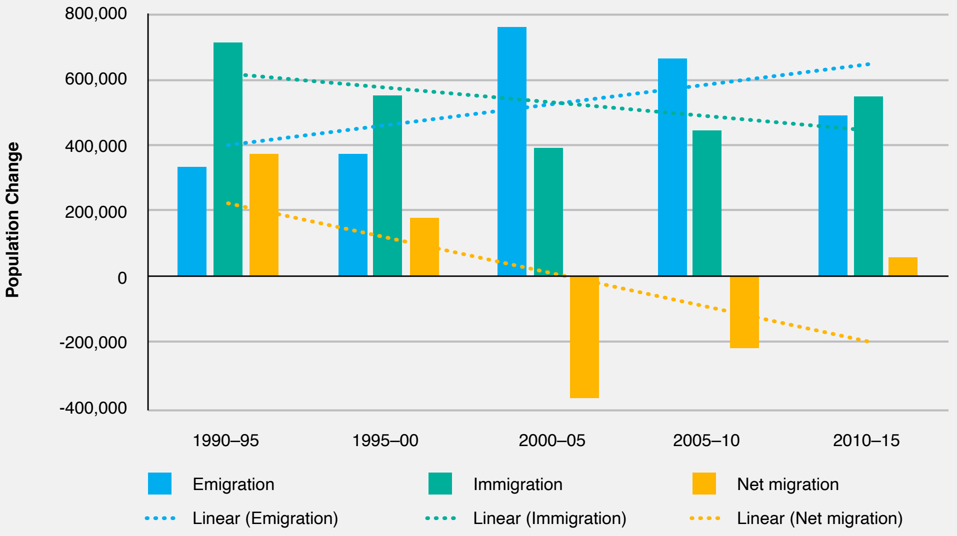
[69] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

and a northern portion controlled by Forces Nouvelles, which held 60 percent of the country. In 2010 elections were held, and Alassane Ouattara won the election. Gbagbo refused to concede defeat, and the election violence of 2011 resulted in up to 1 million internally displaced people (IDPs) before a UN-brokered agreement saw Ouattara assume power. As of 2018 there were still 300,000 conflict-displaced people.[70]

International migration.

Côte d'Ivoire has been a migrant destination and transit country for the West African region, particularly toward rural regions, including Sud-Comoé, Bas-Sassandra, Moyen-Cavally, Moyen-Comoé, and Haut-Sassandra. In 2015, immigrants originate mostly in Burkina Faso (59.5 percent), Mali (16.4 percent), Guinea (4.37 percent), and Liberia (3.79 percent), with economic reasons accounting for about half of migrant motivations, and family reunification between one-third and one-quarter of migrant motivations (IOM 2009; MGSoG 2017). From 2000–10, emigration overtook immigration, and Côte d'Ivoire became a net sending country (figure 7.22).

Figure 7.22 International Migration Trends, Côte d'Ivoire, 1990–2015



Source: Abel and Cohen 2019.

Environmental migration

Compared with other countries in West Africa, there is comparatively little research on environmental migration in Côte d'Ivoire. Mitchell (2011) explores the ways in which migration may have contributed to the conflict that the country experienced in the first decade of this century. Resource conflicts going back to the French appropriation of local lands for cocoa production and the large-scale importation of migrant labor from the rest of French West Africa, especially the Sahel zone, contributed to that conflict. This appropriation overrode the landholding customs of the local indigenous population of Côte d'Ivoire, and since labor was scarce, the French encouraged migration from the northern areas of its then colony.

According to a study by Läderach et al. (2013), which investigated the impact of climate change on cocoa production, some current cocoa producing areas will become unsuitable, including Lagunes and Sud-Comoe in southeastern Côte d'Ivoire, requiring crop change, while other areas will require adaptations in agronomic management. Climatic suitability for growing cocoa will increase in

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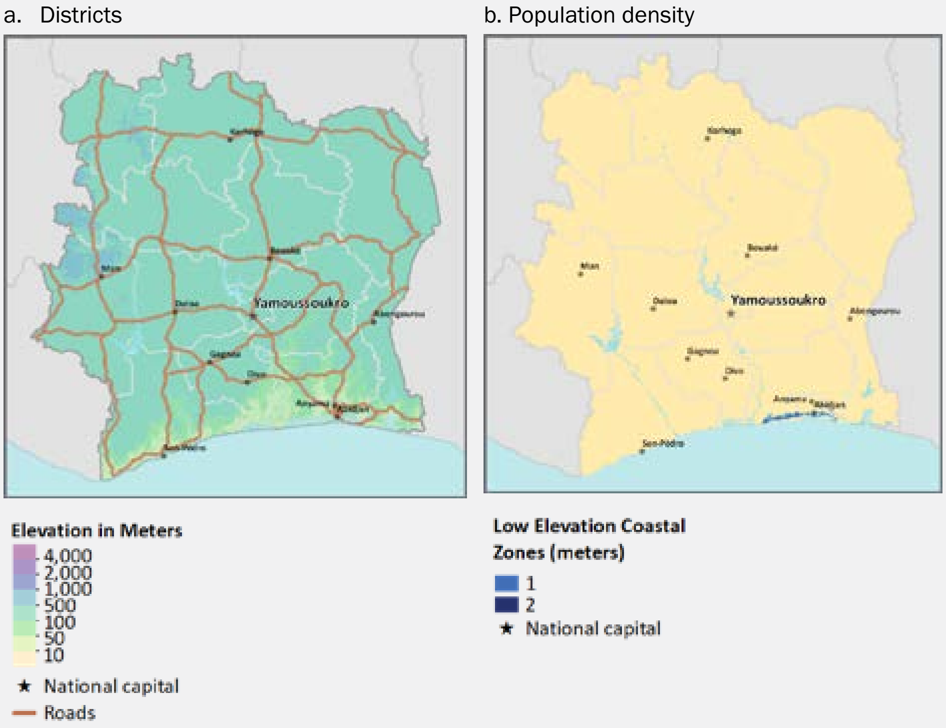
[70] See International Displacement Monitoring Centre (IDMC), Displacement Data at http://www.internal-displacement.org/database/displacement-data.

southwestern areas, which could result in further deforestation in this region, including potential positive feedbacks on the microclimate that would result in drying (Ruf et al. 2015). Continued migration out of existing cocoa producing regions and into southwestern areas may occur if adaptation is unsuccessful. This illustrates how climate change impacts differ by agroecological zones, which could make an area more or less attractive to migrants.

Research in the coastal zone suggests that, to date, migration has not been used systematically as an adaptation strategy when facing the impacts of sea level rise and storm surge (including erosion and salinization of aquifers), and that the government has constructed coastal defenses to prevent displacement (Traore 2016). That said, the city of Grand-Lahou had to be relocated in 1973 to higher ground, and where migration has been less organized there are very little data on the impacts of coastal erosion on population change. As can be seen from figure 7.23 (panel b), the lowest elevation coastal areas are concentrated in the country's southeast, which are also among the most heavily populated areas.

Figure 7.23 Elevation and Low Elevation Coastal Zone Maps, Côte d'Ivoire



a. Districts

b. Population density

Given the relatively moderate climate impacts on water availability and crop productivity in Côte d'Ivoire, the significant driver of out-migration will be coastal impacts, including sea level rise impacts on erosion and flooding, particularly on densely settled Abidjan and San Pedro.

7.2.3 Climate Trends and Projections

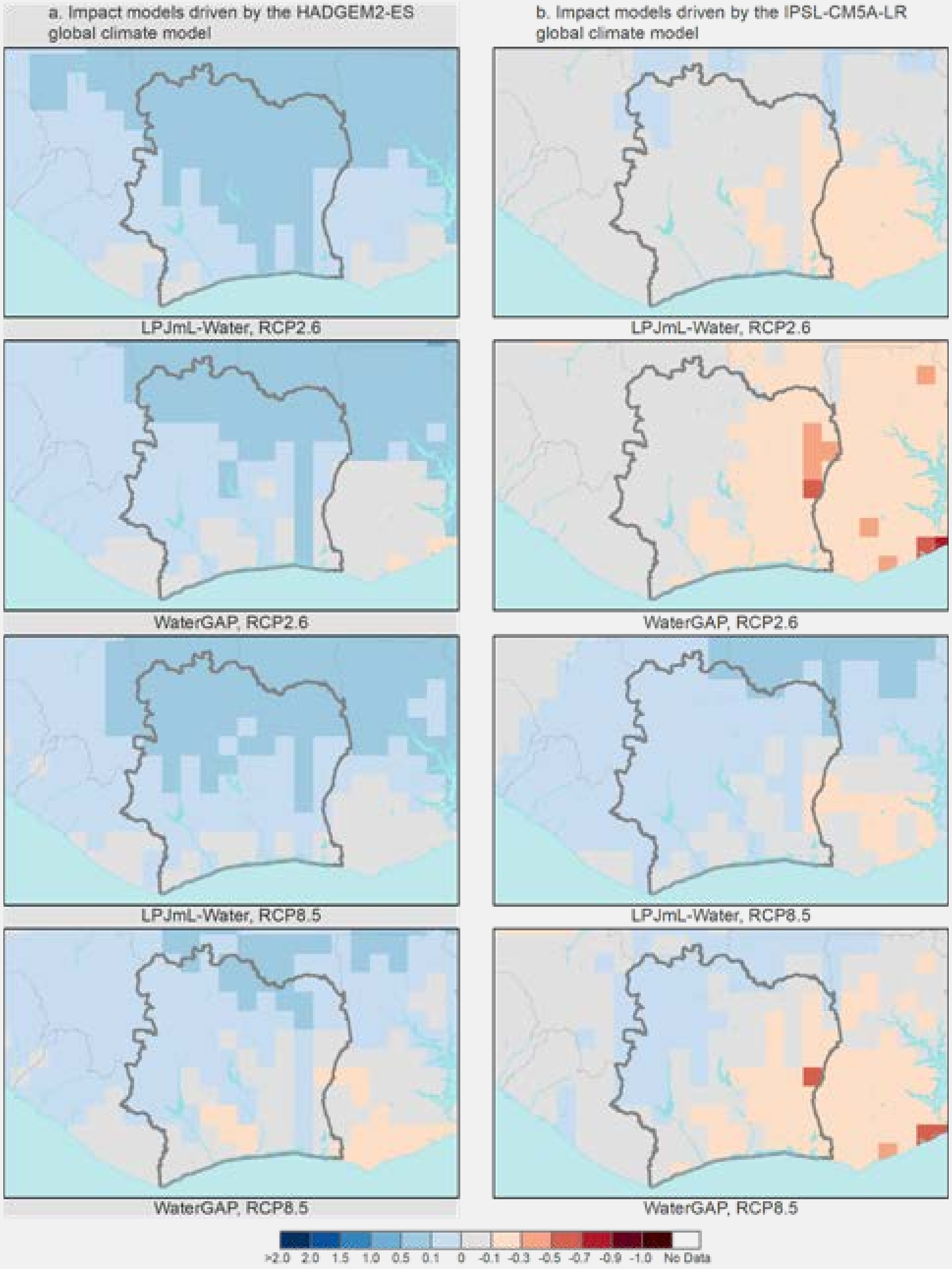
Côte d'Ivoire is a coastal country with a tropical shoreline and semiarid northern region. Across its distinct climatic zones, seasons are characterized by precipitation and wind direction. The north sees heavy rainfall of about 1,100 millimeters per year, with the bulk between June and October. Along the coast, the average annual rainfall is 2,000 millimeters, and there are four distinct seasons (CIMA 2018). Côte d'Ivoire has a large forested area, which made up approximately 37 percent of national land in 1960, but as of 2010 has diminished to under 14 percent of the country (World Bank 2018a).

In the past several decades, Côte d'Ivoire has been challenged with increasingly high temperatures, rising sea levels resulting in coastal erosion, salinization and loss of agricultural land, and degradation of its diverse natural resources (USAID 2018). Estimates put the temperature increase between 1970 and 2015 at a little over 1°C (1.8°F) (USAID 2018). Changes in rates of rainfall are harder to assess given the diverse ecosystems that make up the country. The frequency and intensity of heavy rainfall events is projected to increase between 1 and 12 percent by 2050 (USAID 2018).

In a pessimistic climate change scenario in which GHG emissions continue at current levels, Côte d'Ivoire could see a temperature rise between 1.5°C and 4°C (2.7°F to 7.2°F) by 2050 to 2074, with more erratic rainfall anywhere from 15 percent more or less than present rates (CIMA 2018). A World Bank report (2018b) indicates that by 2050, the country will likely be confronted with the combined effect of the increase in temperatures (more than 2°C), variation in rainfall, and rising sea levels (30 centimeters). The projected changes significantly threaten existing land, ecosystems, and settlements.

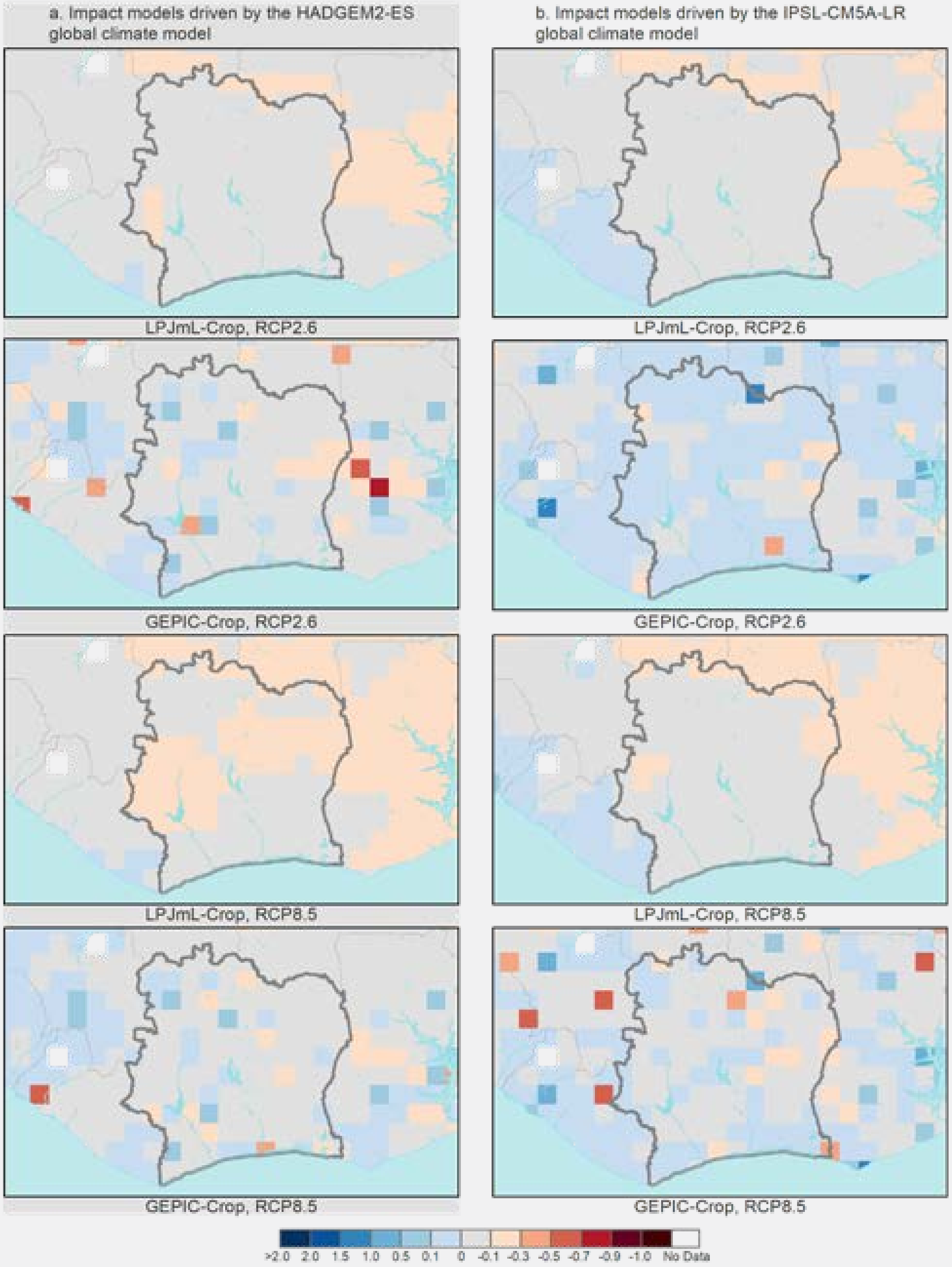
The population gravity model calibration in this work finds that the coefficients are highest for water availability, meaning that past shifts in water availability played a greater role than the other input variables in explaining shifts in population distribution (see appendix B). Panels in figures 7.24 to 7.26 show the average projected changes in water availability, crop production, and NPP for the 2010–50 time period, respectively. NPP is used to gap-fill areas where is no crop production. The coefficient for water availability in rural areas is around 2.75 times higher than that of either crops or NPP, and it is the only climate factor other than flood risk and sea level rise influencing future urban population distribution. This means it has a far greater influence on future population distribution than most other climate variables. Intersectoral Impacts Model Intercomparison Project (ISIMIP) results suggest that Côte d'Ivoire will see an increase in water availability between now and 2050 under most model runs. Only under the IPSL-CM5A-LR global climate model is there some drying in the eastern portion of the country. Most models project modest wetting, particularly in the northwest. Agriculture will largely see stable or increasing yields for staple crops, with patches of declines. The NPP model outputs are shown only for information purposes (there is no part of Côte d'Ivoire without crop production), but the picture shows largely increasing ecosystem productivity, with some slight declines in the southwest of the country under the VISIT model.

Figure 7.24 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Côte d'Ivoire, 2010–50



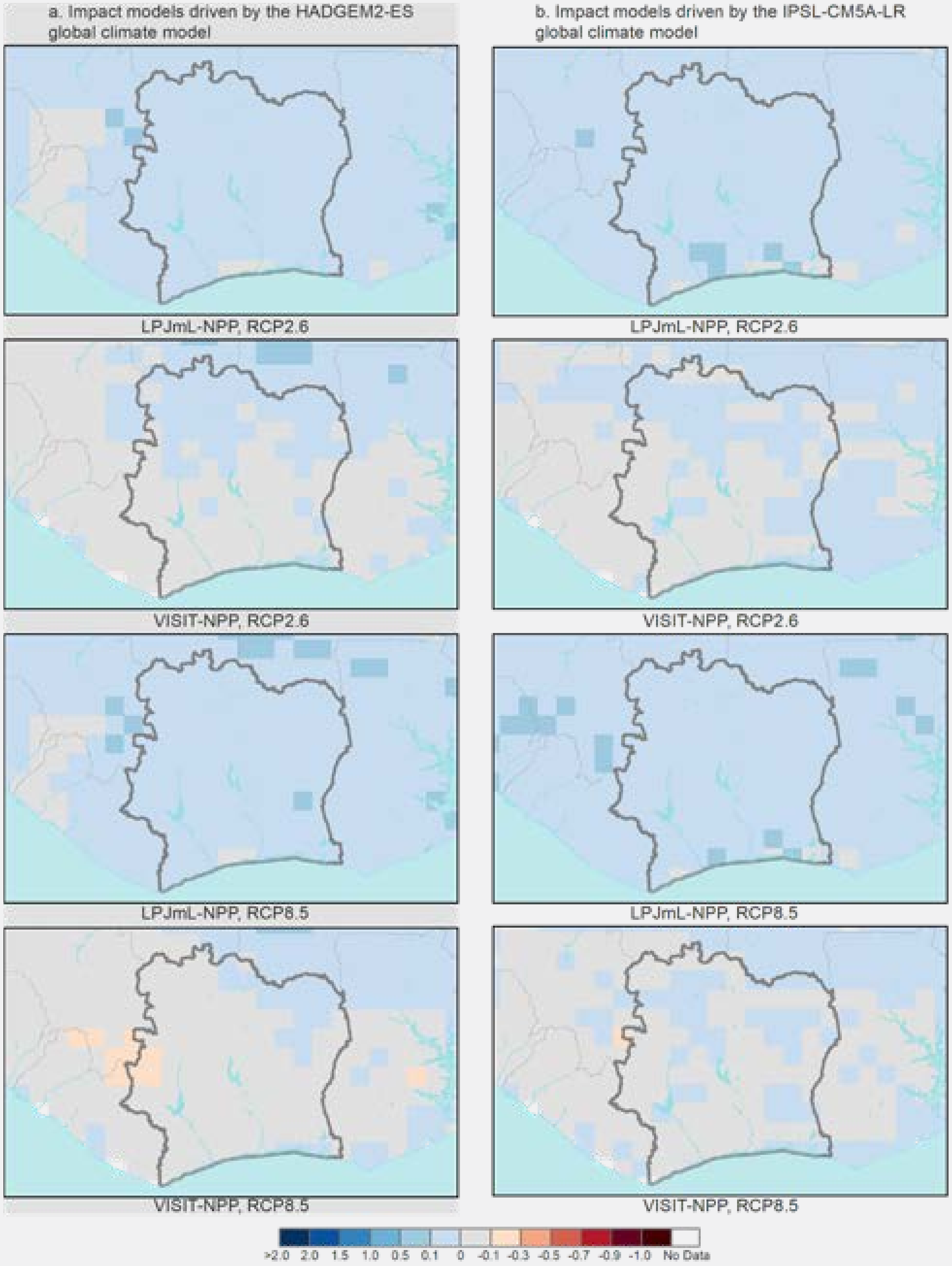
Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.25 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Côte d'Ivoire, 2010–50



Note: Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production.

Figure 7.26 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Côte d’Ivoire, 2010–50


a. Impact models driven by the HADGEM2-ES global climate model

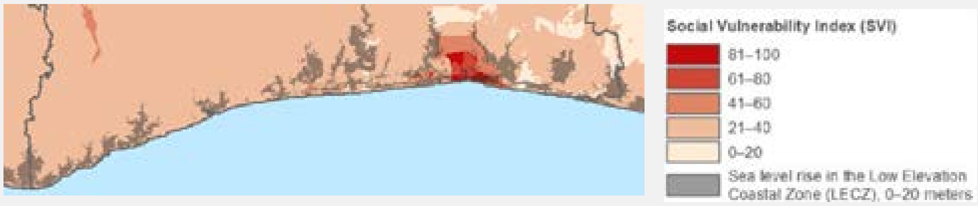
b. Impact models driven by the IPSL-CM5A-LR global climate model

Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is used to gap-fill crop production, and therefore is not used to model future population distribution in Benin. NPP = net primary production.

7.2.4 Coastal Trends and Projections

Côte d'Ivoire has a 590-kilometer coastline, and coastal districts are home to 36 percent of the country's population (Croitoru, Miranda, and Sarraf 2019). Figure 7.27 depicts how the main areas of inundation from sea level rise will be concentrated around Abidjan. The coast has witnessed significant erosion around Abidjan, Port Bouet, Grand Bassam, Sassandra, and San Pedro (USAID 2018). The World Bank estimates that half the coastline experiences average rates of erosion of 1.8 meters per year (Croitoru et el. 2019). A meta-analysis of vulnerability studies sponsored by the USAID-funded West Africa Biodiversity and Climate Change project finds that San Pedro and the and Port Bouet have the highest Coastal Vulnerability Index (CVI) scores (USAID 2020). The CVI is based on geomorphology, slope of the coastline, sedimentation and erosion, coastal climate extremes, and bathymetry. It is largely a measure of physical climate risk in the coastal zone, and does not include measures related to social vulnerability. De Sherbinin et al. (2014) measured social vulnerability levels as a function of population density, population growth, subnational poverty and extreme poverty, maternal education levels, market accessibility (travel time to markets), and political violence. Results suggest that Abidjan has the highest levels of social vulnerability.

Figure 7.27 Social Vulnerability Index for the Coastline of Côte d'Ivoire



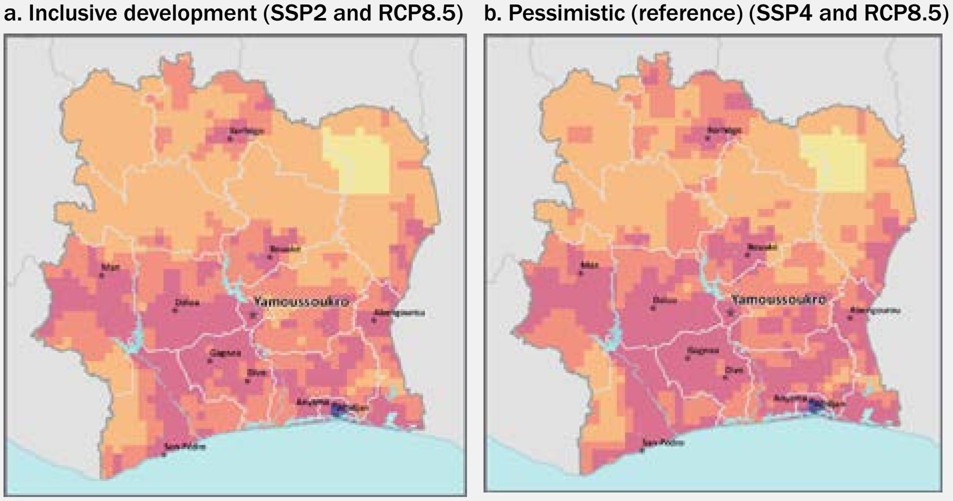
Source: de Sherbinin et al. 2014.

Floods are extremely damaging in Côte d'Ivoire, costing the country US$1.2 billion per year, mainly due to large areas affected by pluvial floods (Croitoru, Miranda, and Sarraf 2019). Floods are prevalent in the coastal cities. The costs of coastal erosion amount to US$117 million, or 1.3 percent of GDP, in 2017 based on the value of assets and annual production per hectare as well as the value of the land (Croitoru, Miranda, and Sarraf 2019). Hinkel et al. (2012) applied the DIVA model to the West African coast. They find that Côte d'Ivoire is ranked among the top 15 most vulnerable countries in Africa.

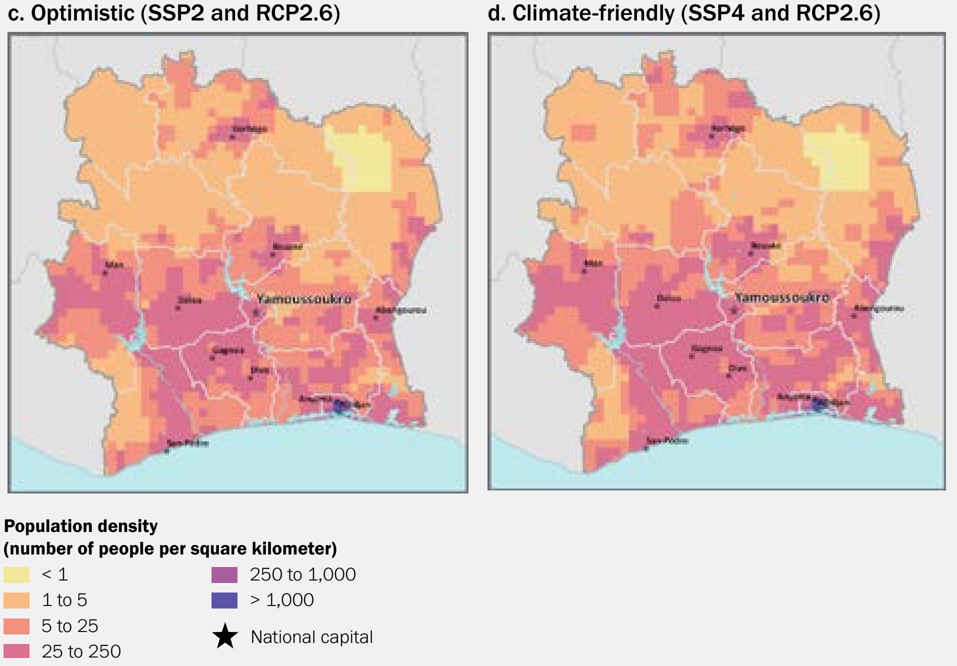
7.2.5 Projected Changes in Population

The total projected population to 2050 is higher under the SSP4 scenario (39.3 million) compared with the SSP2 scenario (32.4 million) (table 4.8). There are relatively modest variations in population distribution among the future scenarios, with SSP4 showing a bit more expansion of Abidjan and Bouake, the two largest cities (figure 7.28, panels a–d). The large unpopulated area in the northeast is the Parque Nationale de la Comoe, a protected area.

Figure 7.28 Projected Population under the Four Scenarios, Côte d'Ivoire, 2010–50


a. Inclusive development (SSP2 and RCP8.5)

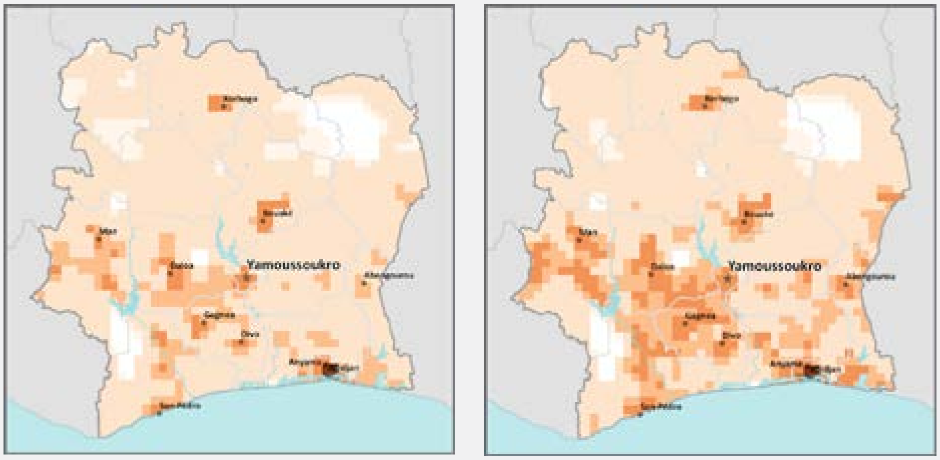
b. Pessimistic (reference) (SSP4 and RCP8.5)


c. Optimistic (SSP2 and RCP2.6)

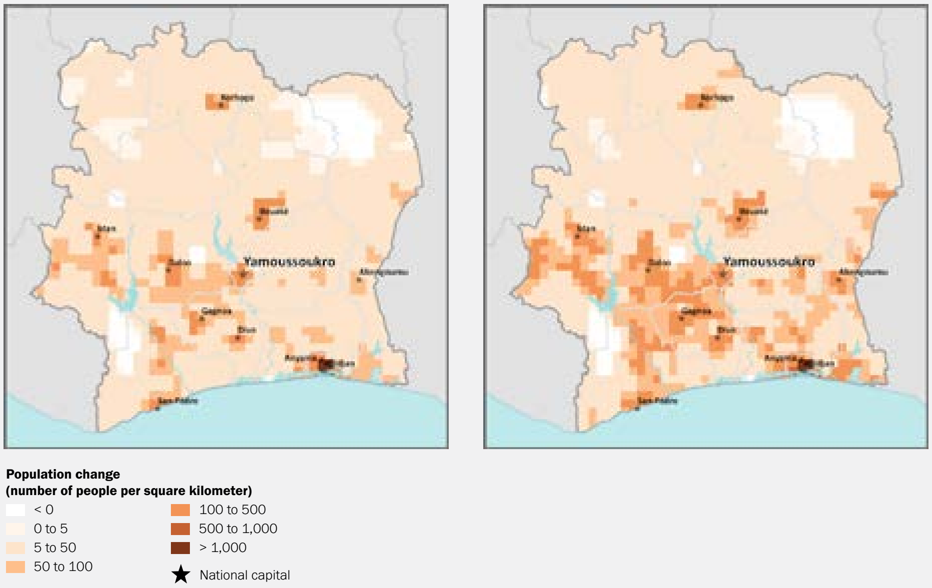
d. Climate-friendly (SSP4 and RCP2.6)

Figure 7.29, panels a–d, shows that the more densely populated southwestern region and the areas around the capital, Yamoussoukro, and the economic capital, Abidjan, will grow the most between 2010 and 2050. The scenarios incorporating SSP4, with higher population totals, shows larger increases in population in these regions.

Figure 7.29 Projected Change in Population Density under the Four Scenarios, Côte d'Ivoire, 2010–50



a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



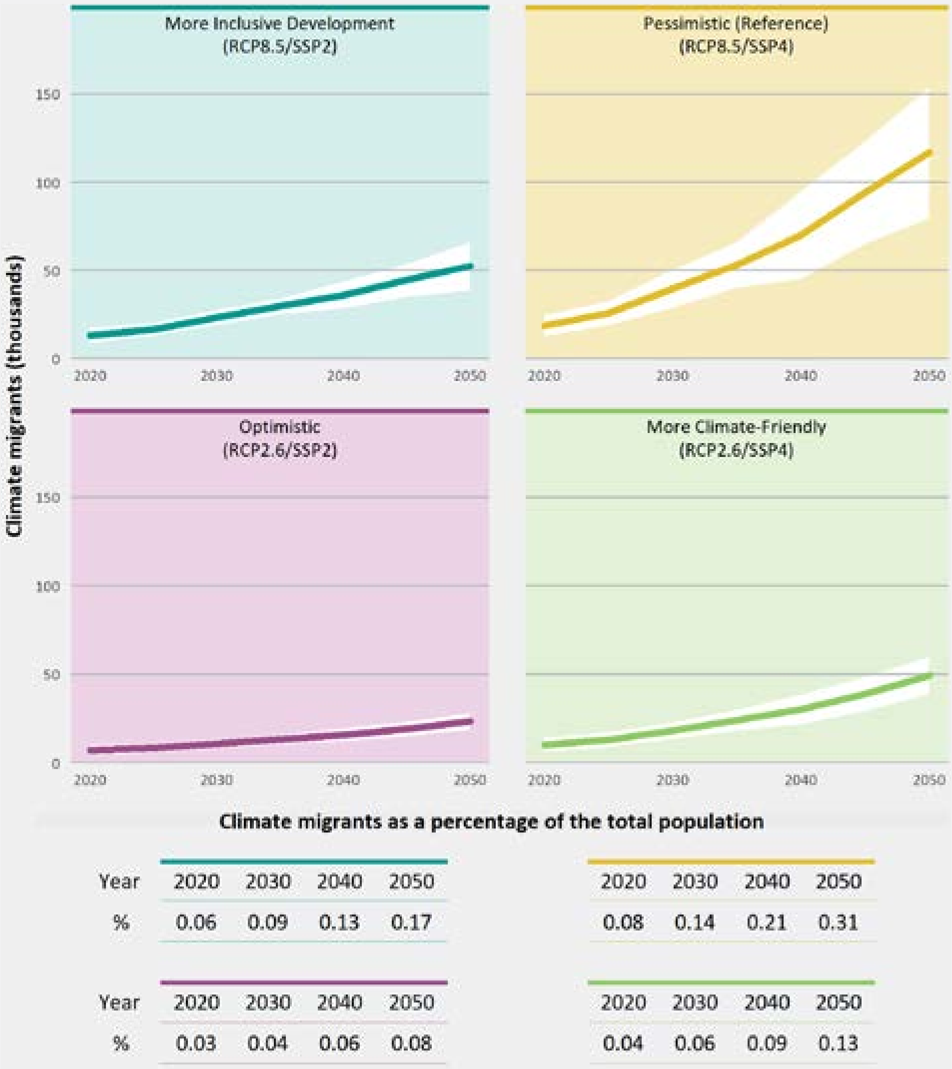
c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

7.2.6 Climate Migration Scale and Trends

Scale and Trajectory of Internal Climate Migration

Figure 7.30, panels a–d, presents the projected number of climate migrants by scenario and five-year interval, from 2020 to 2050. All the scenarios display an upward trend, but with important differences. The optimistic scenario and pessimistic scenarios provide the lower and upper bounds for number of climate migrants by 2050: 23,000 thousand and 116,800, respectively. At the high end of the confidence interval of the pessimistic scenario, there are 153,900 climate migrants (0.4 percent of the population). Given the relatively moderate climate impacts on water availability and crop productivity, a significant driver of out-migration will be coastal impacts, including sea level rise impacts on erosion and flooding, particularly on densely settled Abidjan and San Pedro.

Figure 7.30 Projected Total Climate Migrants by Scenario, Côte d'Ivoire, 2020–50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050
%	0.06	0.09	0.13	0.17

2020	2030	2040	2050
0.08	0.14	0.21	0.31

Year	2020	2030	2040	2050
%	0.03	0.04	0.06	0.08

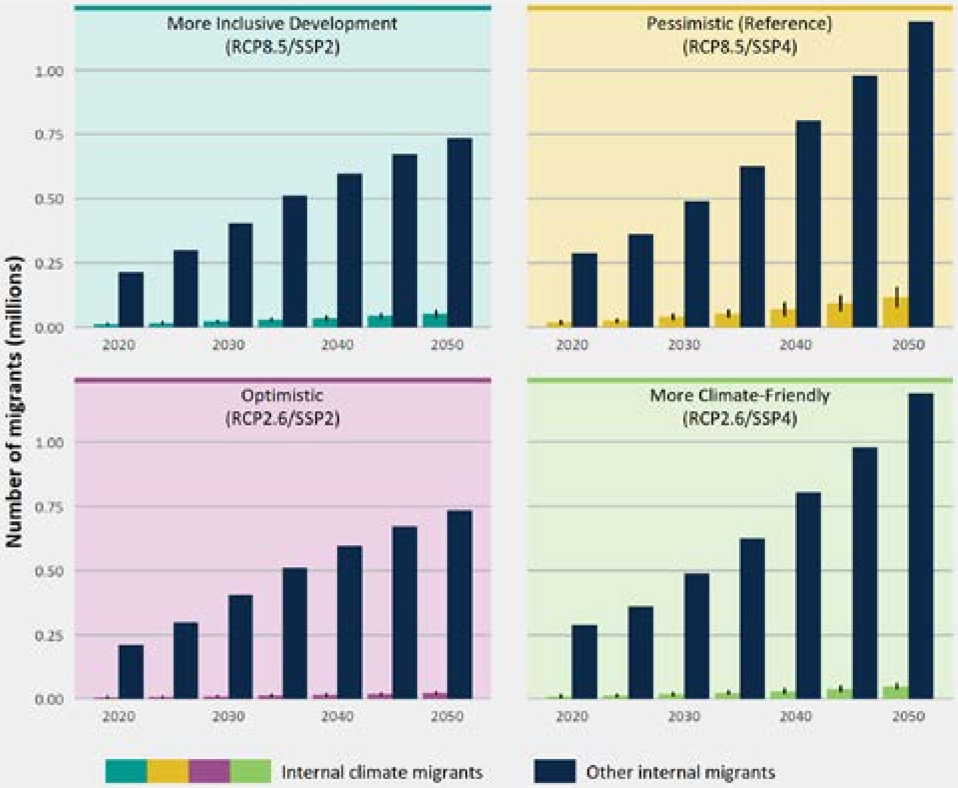
2020	2030	2040	2050
0.04	0.06	0.09	0.13

Table 7.6 Projected Total Climate Migrants in Four Scenarios for Côte d'Ivoire by 2050

	Scenario							
	Pessimistic (reference)		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	0.117		0.053		0.049		0.023	
Min. (left) and max. (right) (millions)	0.080	0.154	0.039	0.066	0.039	0.060	0.019	0.028
Internal climate migrants as % of pop.	0.31		0.17		0.13		0.08	
Min. (left) and max. (right) (%)	0.21	0.41	0.13	0.22	0.1	0.16	0.06	0.09

Figure 7.31, panels a–d, shows that climate migrants are a tiny fraction of the projected levels of other internal migration. This is a function of the relatively modest climate impacts in Côte d'Ivoire for water supply and the crops included in the ISIMIP model runs. If models were available climate impacts on cocoa production, there might be higher levels of migration.

Figure 7.31 Projected Climate Migrants Compared to Other Migrants, Côte d'Ivoire, 2020–50



Internal Climate Migration Hotspots

The climate migration hotspots results to 2050 (figure 7.32) indicate high levels (and high certainty) climate in-migration around Yamoussoukro and Bouake in the central part of the country, as well as near Korhogo in the north and several towns in the west. There is high climate out-migration from the Abidjan and the area around Lagune Aby in the southeast and San Pedro in the southwest because of sea level rise. Some model runs also show the southeastern portion of the country drying out more than other parts. There is an out-migration hotspot southwest of Yamoussoukro near Gagnoa in Gôh-Djiboua Province. The cause is likely to be drying and decreased crop production, based on multiple models run.

Water availability is a primary driver of migration, with more than double the effect of changes in crop production (appendix B). Given the relatively modest changes to water availability in Côte d'Ivoire, at least between 2020 and 2050, climate migration levels are small compared to those of Ghana (a country with a similar population size but a high-end projection of 450,000 climate migrants under the pessimistic scenario). A primary driver of the numbers of climate migrants is sea level rise, which drives climate migration out of Abidjan, Port Bouet, Adiake, and San Pedro (figure 7.23).

A noteworthy hotspot of in-migration is in the densely settled area on the eastern side of Côte d'Ivoire, on the border with Ghana. In two model runs (the IPSL GCM paired with WaterGAP) this area shows decreases in water availability. We cannot conclude that this will lead to transboundary migration, but it may be potentially attractive to new migrants under climate change scenarios. The hotspots in 2030 and 2040 (figure 7.33, panels a–d) generally represent a graduate increase in the levels of in- and out-migration.

Figure 7.32 Projected Hotspots of Climate In- and Out-Migration, Côte d'Ivoire, 2050

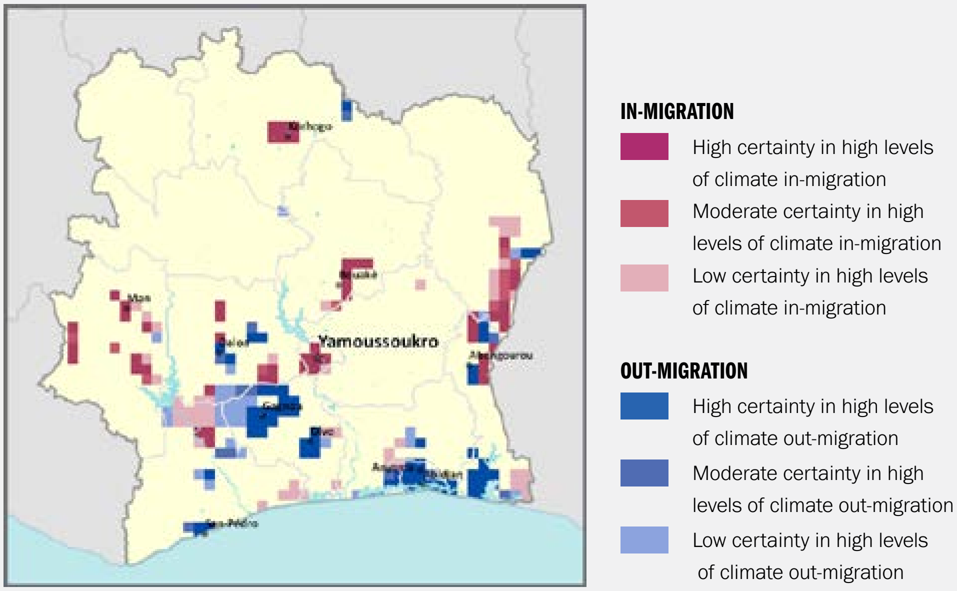
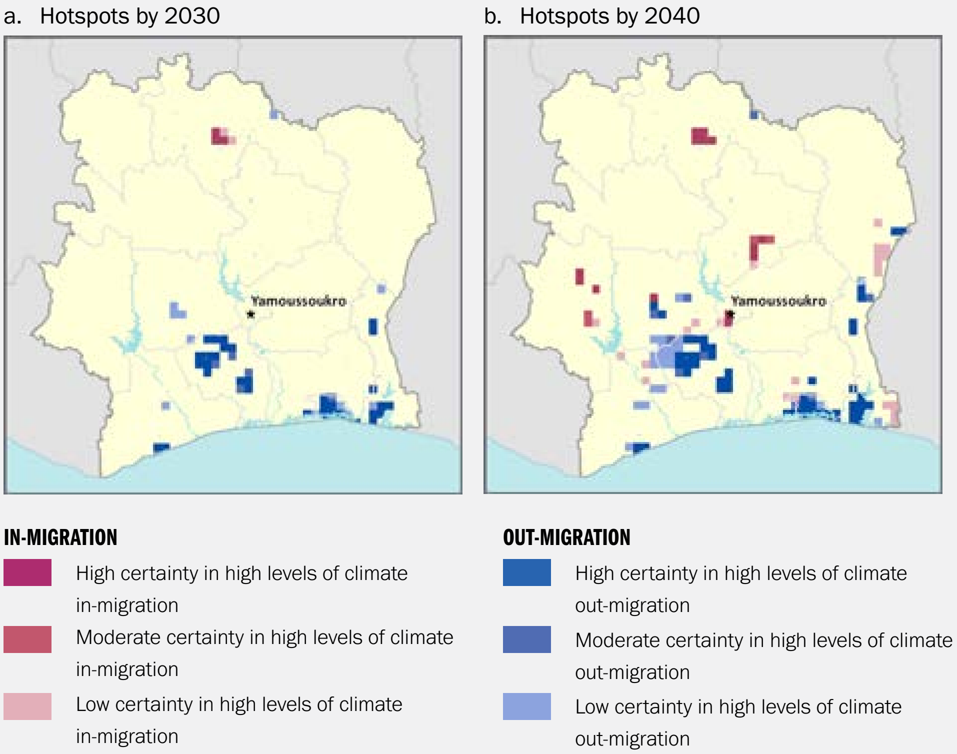


Figure 7.33 Projected Hotspots of Climate In- and Out-Migration, Côte d'Ivoire, 2030 and 2040

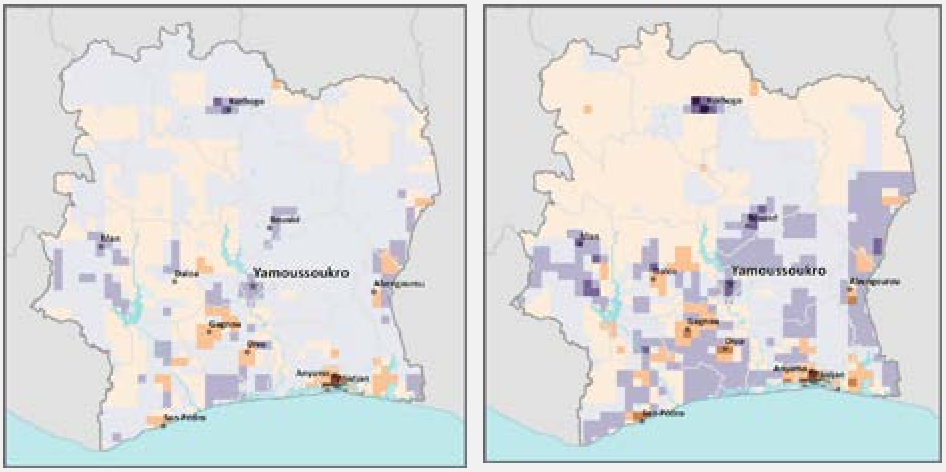

a. Hotspots by 2030

b. Hotspots by 2040

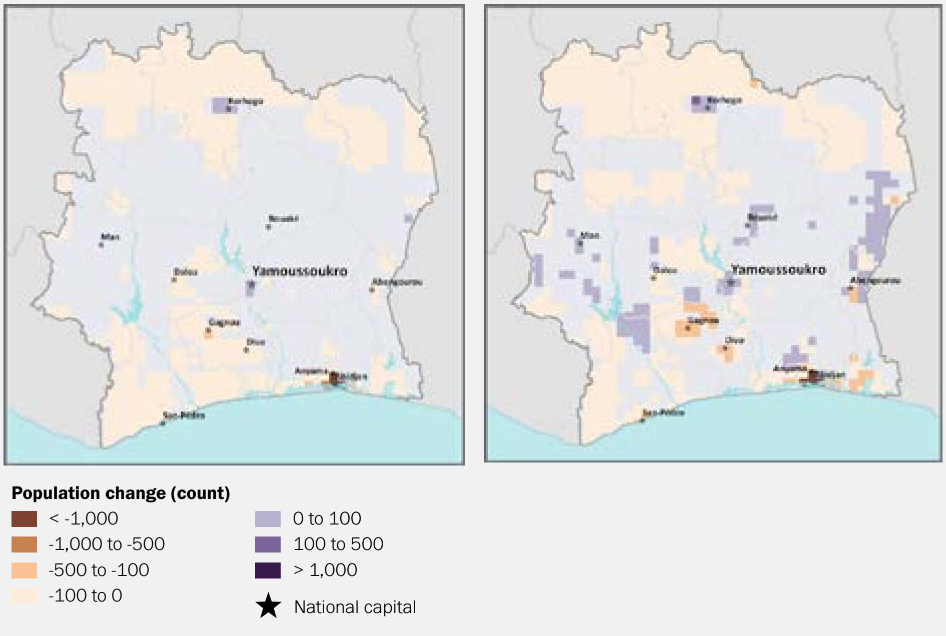
Figure 7.34, panels a–d, displays the absolute difference between population distributions in the climate and no climate scenarios for 2050 in absolute terms. Figure 7.35, panels a–d, presents the same data in percentage terms. Climate scenarios reflect the potential push impact of sea level rise in selected areas along the coast, and declining crop productivity in the southern and southwestern parts of the country (per the ISIMIP results). They also reflect the pull of inland urban areas.

Figure 7.34 Projected Population Change Due to Climate Migration, Côte d'Ivoire, 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

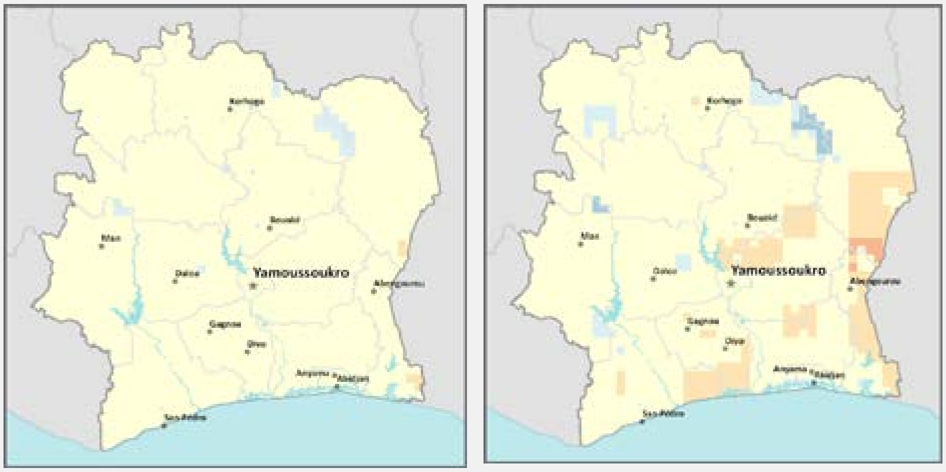


Note: Changes shown per square kilometer.

As shown in 7.35, panels a–d, there are very few percentage shifts that go beyond 2.5 percent of the population in an area. Under SSP2, all shifts are under plus or minus 1 percentage point of the population.

Figure 7.35 Projected Percentage of Difference in Population Change Due to Climate Migration, in No Climate Scenario, Côte d'Ivoire, 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

d. Climate-friendly (SSP4 and RCP2.6)

Population change (%)

- 🟦 < -10
- 🟦 -10 to -5
- 🟦 -5 to -2.5
- 🟦 -2.5 to -1
- 🟨 -1 to 1
- 🟧 1 to 2.5
- 🟧 2.5 to 5
- 🟥 5 to 10
- 🟥 > 10
- ★ National capital

Note: Changes shown per square kilometer.

Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, processing of the coastal climate migration uses the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level.

Climate migration out of the area within 5 kilometers of the coast is negative across all scenarios (figure 7.36, panels a–e), with negative balances in 2050 ranging from about 5,000 (optimistic scenario) to around 20,000 (pessimistic scenario) because of the increased frequency of inundation. Projected inundation in and around Abidjan is a major driver of this coastal out-migration (figure 7.37).

Figure 7.36 Projected Coastal Climate Migrants with Uncertainty Bands; with Scenarios Combined, Côte d'Ivoire, 2020–50

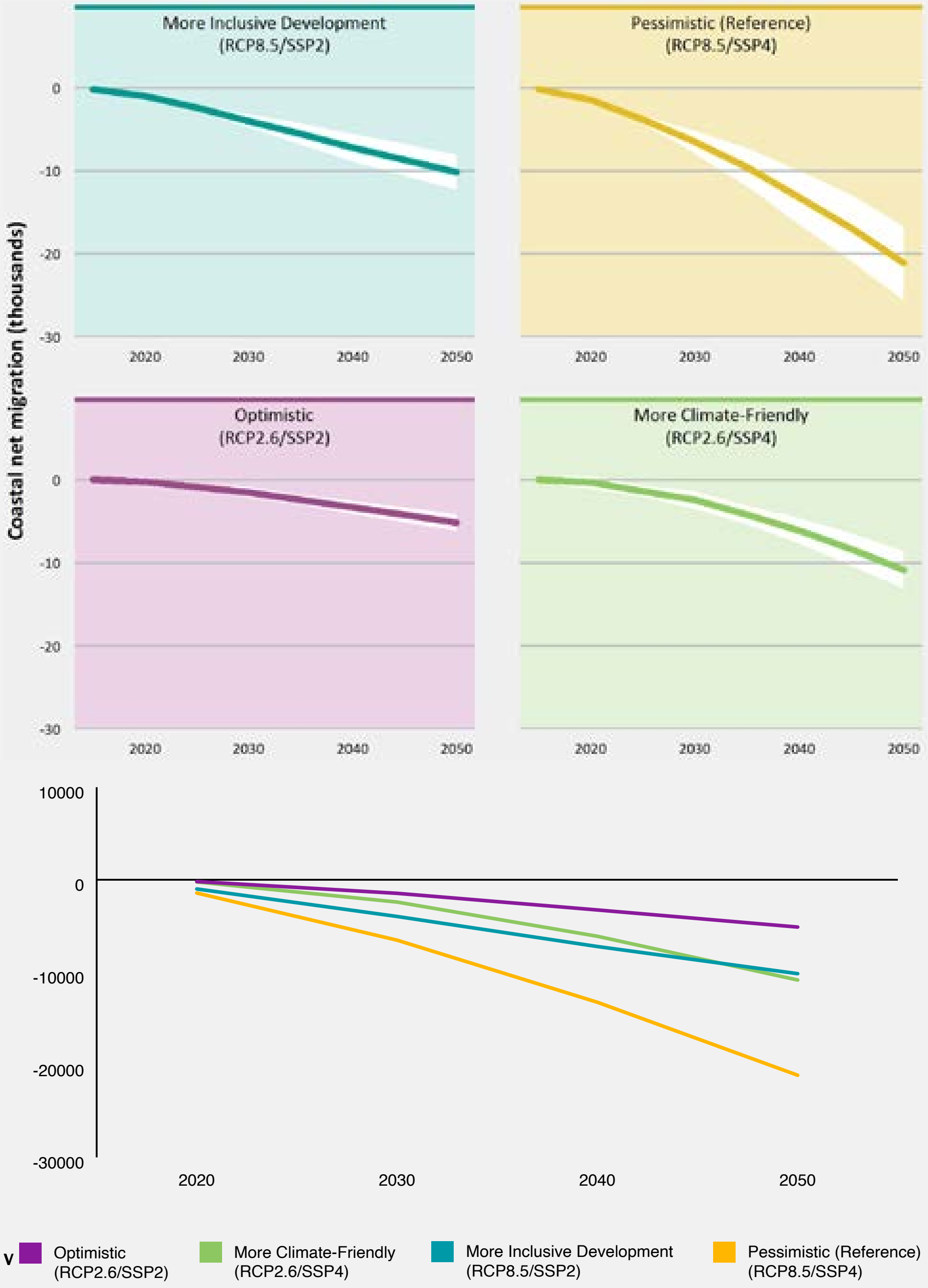
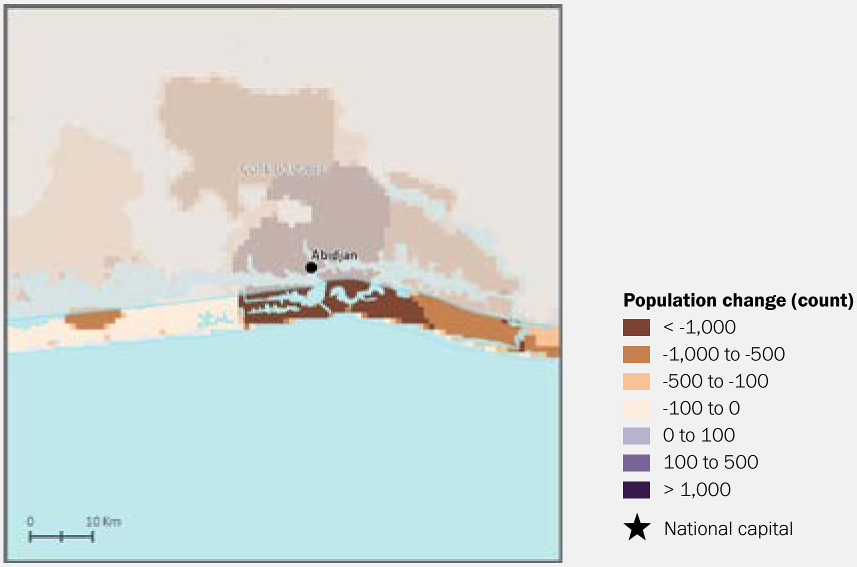


Figure 7.37 Projected Population Change Because of Climate Migration for Coastal Zone of Abidjan and Port Bouet Area, Côte d'Ivoire, by 2050



Note: Calculations based on per square kilometer under the pessimistic scenario.

Climate Migration by Livelihood Zone

Figure 7.38 displays the distribution of livelihood zones in Côte d'Ivoire. Rainfed croplands, with pastoral lands and rangelands, make up most of the country's zones, followed by seminatural and wildlands in the protected area to the north and forest areas in the southwest. The cocoa growing areas are part of the rainfed cropland areas in the south. See box 7.1.

Figure 7.38 Livelihood Zones, Côte d'Ivoire

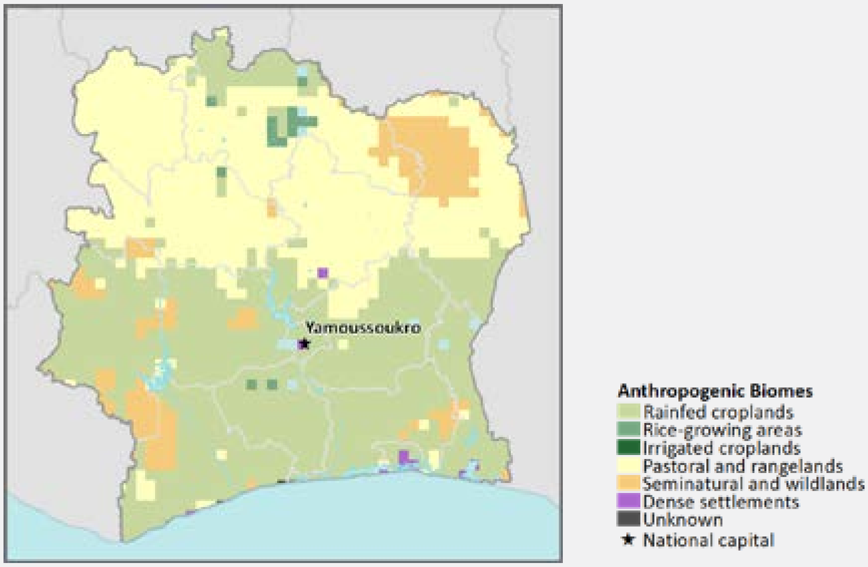
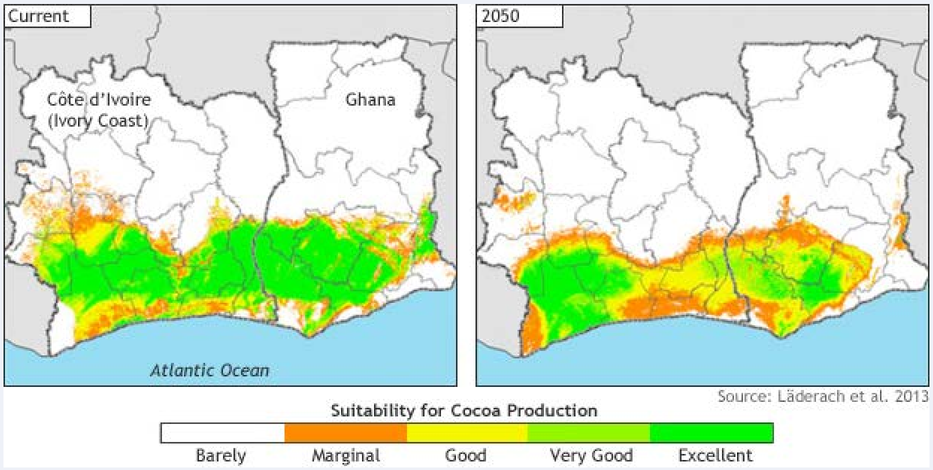


Table 7.7 provides projections of net climate migration in each livelihood zone, by decade. Under the pessimistic scenario, there is net out-migration from urban areas of around 52,000 people by 2050, and a net in-migration into cropped areas of around 47,000 people.

Box 7.1 Cacao Production in Côte d'Ivoire and Ghana, 2010 and 2050

Figure B7.1.1 Projected Changes in Cacao Production, Côte d'Ivoire and Ghana, 2010 and 2050



Source: Läderach et al. 2013

By 2050, rising temperatures will push the suitable cacao cultivation areas uphill (figure B7.1.1, panels a and b). The Intergovernmental Panel on Climate Change (IPCC 2004) reports that Côte d'Ivoire and Ghana's optimal altitude for cacao cultivation is expected to rise from 350–800 feet (100–250 meters) to 1,500–1,600 feet (450–500 meters) above sea level.

Table 7.7 Projected Net Climate Migration by Scenario, Livelihood Zone, and Decade, Côte d'Ivoire, 2030, 2040, 2050 (number of people)

Year and livelihood zone	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/ SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
By 2030				
Dense settlements	−6,032	−10,309	−3,385	−17,585
Irrigated croplands	53	152	47	192
Pastoral and rangelands	1,631	3,879	1,694	2,744
Rainfed croplands	4,684	5,792	1,857	14,295
Rice-growing areas	138	592	119	695
Seminatural and wildlands	−455	−134	−311	−409
Unknown	−19	27	−22	67
By 2040				
Dense settlements	−12,518	−16,804	−6,432	−31,975
Irrigated croplands	138	231	85	310
Pastoral and rangelands	3,777	6,547	2,917	4,906
Rainfed croplands	9,163	9,652	3,703	27,022
Rice-growing areas	353	911	231	1,127
Seminatural and wildlands	−864	−551	−461	−1,455
Unknown	−49	12	−44	64
By 2050				
Dense settlements	−21,480	−23,858	−9,812	−51,706
Irrigated croplands	217	261	109	430
Pastoral and rangelands	5,449	6,067	3,447	5,198
Rainfed croplands	16,682	17,892	6,708	47,459
Rice-growing areas	540	1,057	271	1,664
Seminatural and wildlands	−1,326	−1,460	−662	−3,176
Unknown	−83	40	−62	128

Climate Migration by Province

Figure 7.39 and table 7.8 display net climate migration for 2050, by province. Abidjan sees the highest levels of net out-migration, mostly due to coastal impacts, but also due to conflict hotspots. In contrast, the regions of Lacs, Montagnes, and Zanzan generally see increases. Lacs and Zanzan are in the northeastern part of Côte d'Ivoire, which under most scenarios are projected to see increases in water availability, which is also true of Montagnes in the west. The median age data do not have an impact in Côte d'Ivoire, because of a lack of subnational data. The sex ratios tend to be highest in the southwestern portion of the country where cacao growing and extractive industries are prevalent (ratios of up to 130 males to 100 females are common there). This may exercise a modest attractive pull in regions such as Bas-Sassandra.

Figure 7.39 Projected Net Climate Migration by Province and Scenario for Côte d'Ivoire, 2050

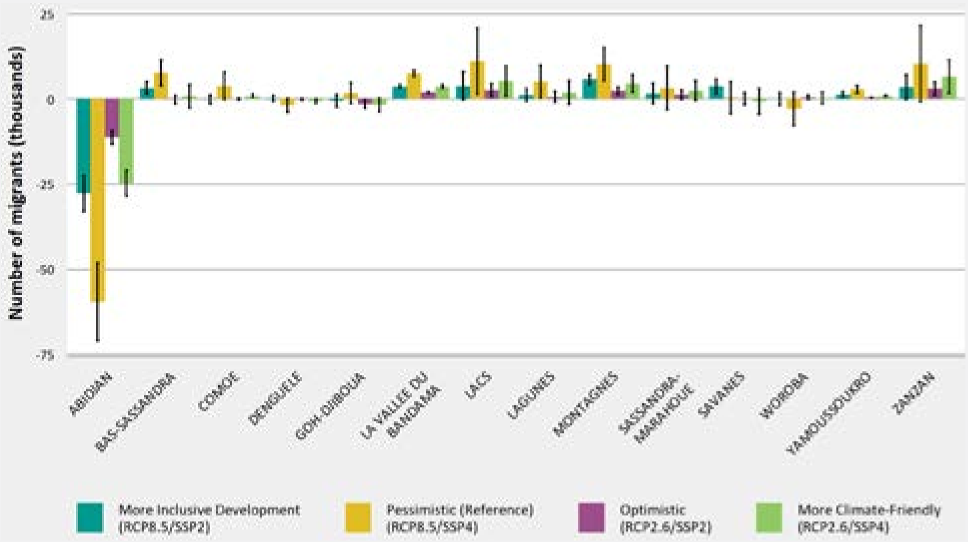


Table 7.8 Projected Net Climate Migration by Scenario and Province, Côte d'Ivoire, 2050

Scenario averages

Admin 1	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Abidjan	−24,674	−27,697	−11,307	−59,569
Bas-Sassandra	836	3,280	−162	7,689
Comoé	915	−80	80	3,828
Denguélé	−596	191	−90	−1,841
Gôh-Djiboua	−1,659	−536	−1,526	1,748
Vallée du Bandama	3,732	3,701	1,935	7,546
Lacs	5,288	3,888	2,595	11,143
Lagunes	1,925	1,204	671	5,140
Montagnes	4,544	5,750	2,416	10,287
Sassandra-Marahoué	2,469	1,629	1,236	3,274
Savanes	−624	3,762	101	435
Woroba	279	33	503	−2,922
Yamoussoukro	931	1,363	449	2,805
Zanzan	6,634	3,511	3,099	10,435

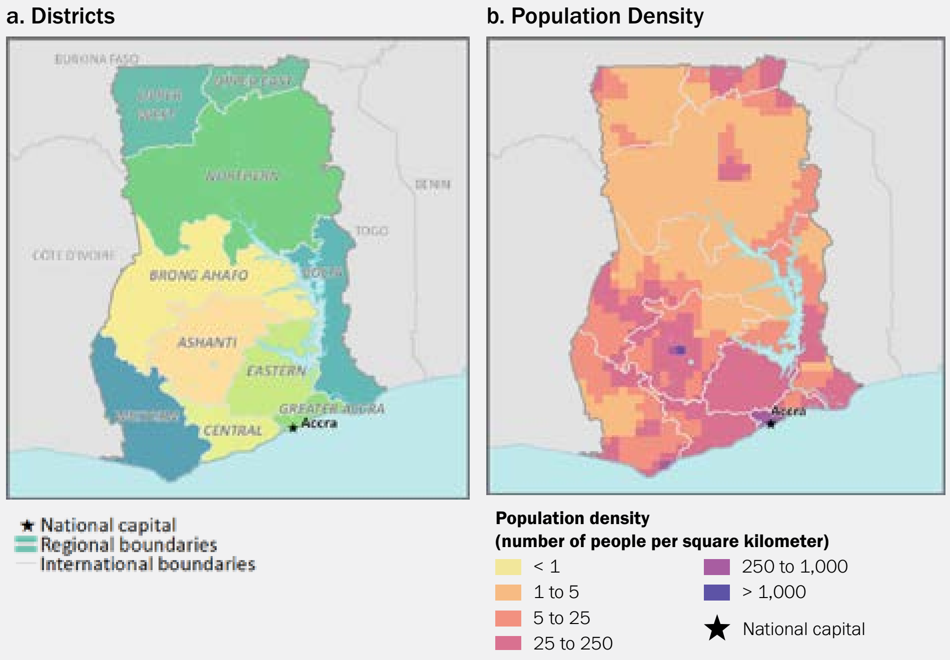
Note: "Admin. level" refers to governmental level. 1 = state or province.

7.3 GHANA

7.3.1 Population and Development Context

Ghana is classified as an LMIC.[71] It has experienced steady economic growth and poverty reduction over the past three decades as it moved from an economy primarily dependent on agricultural sector exports (especially cacao) to one that is more diversified, with a strong boost in recent years from minerals and oil exports (Darko 2015). However, the country shows high and increasing levels of inequality (Gini index was 42.6 in 2012, up from 36 in 1988),[72] and national figures mask in-country heterogeneities in development achievements. For example, poverty levels are higher in the Upper West and Ashanti regions. Additional development statistics are in table 7.9. See figure 7.40, panels a and b, for regions and population density.

Figure 7.40 Regions and Population Density Maps, Ghana, 2010



a. Districts

b. Population Density

Ghana's population was 29.5 million in 2018, with an annual growth rate of 2.2 percent (PRB 2018). This rate is quite high when compared with the average world rate of 1.09 percent for 2015–20.[73] Current projections indicate that the population would reach 37.8 million by 2030, 52.0 million by 2050, and 79.0 million by 2100. Accra is the capital and largest city of Ghana, with a population of around 4.7 million in the greater Accra region, or roughly 16 percent of the country's population. Despite the concentration of population in the national capital, 45 percent of the population is still classified as rural in 2017, many of whom rely on subsistence agriculture or artisanal fisheries.

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[71] See World Development Indicators, Ghana Profile, at https://data.worldbank.org/country/ghana.

[72] See World Bank data, Gini index, Ghana, at https://data.worldbank.org/indicator/SI.POV.GINI?locations=GH.

[73] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Population Prospects 2019 at https://population.un.org/wpp.

Table 7.9 Development Statistics, Ghana

Population	
Population (millions)	29.8
Annual population growth (%)	2.2
Population in 2050 under SSP2 (millions)	46.4
Population in 2050 under SSP4 (millions)	54.1
Urban share of population (%)	56.1
Employment in agriculture (% of total employment) (2019)	33.5
GDP	
GDP (current US$ billions)	65.6
Annual GDP growth (%)	6.3
GDP per capita (current US$)	2202.3
Value added of agriculture (% GDP)	18.3
Poverty	
Poverty headcount ratio at US$1.90 a day (2011 PPP) (% of population) (2016)	13.3
Climate and disaster risk indexes	
ND GAIN Index	
Rank (2017)	107
Score (2017)	45.1

Source: WDI database;[74] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better

7.3.2 Historical and Current Migration Patterns

Internal migration

In Ghana, rural people with skills and adequate levels of education tend to move to urban areas, and the less educated tend to move to mining and cocoa growing areas (IADD 2019b). As in other countries, flows are driven by a mix of factors, including migrants' desires to improve living conditions, deteriorating livelihoods in source areas, food insecurity and the need for external sources of income in rural areas (through remittances), and job opportunities in both rural and urban areas of the central and southern areas. The bimodal rainfall distribution in the south enables an additional cropping season from April to June, which coincides with the dry season in the north. Thus, when labor opportunities are scant in the north, there is a labor demand on the cacao plantations and farms in the south. In addition, artisanal mining, the oil industry, and service sectors are all concentrated in the south.

Molini et al. (2016) find that migration increases household consumption significantly, and the effect is driven by households migrating from inland regions to the coastal areas of the country. While on average there are benefits, migrant households headed by males and highly educated individuals fare significantly better than migrant households headed by females and low-educated individuals.

International migration

Ghana has been both a source and destination for international migration over the past 30 years (figure 7.41). As its economy grew during the 2000s, Ghana became increasingly attractive, and its net international migration was positive. Emigration rose significantly from 2010 to 2015, resulting in the country becoming a net sender. Primary destinations included the United States, Nigeria, the

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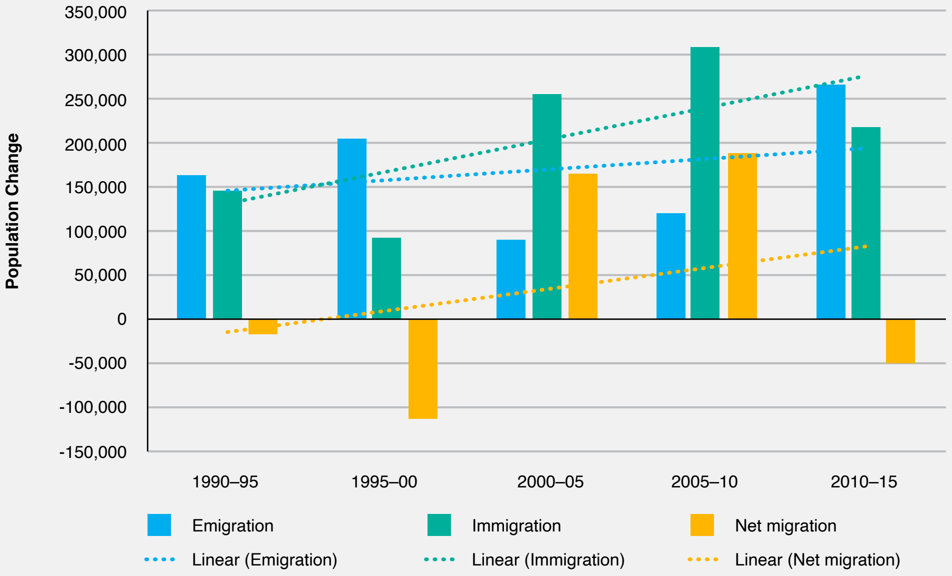
[74] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

United Kingdom, Togo, Italy, and Germany (Abel and Cohen 2019). Remittances from international migrants represented 7.3 percent of Ghana's GDP in 2018 (World Bank 2019a). Immigration to Ghana is predominantly from Nigeria, Togo, Côte d'Ivoire, Liberia, and Burkina Faso, as well as some return migration from the United States and the United Kingdom.

Figure 7.41 International Migration Trends, Ghana, 1990–2015



Source: Abel and Cohen 2019.

Environmental migration

As for other West African farmers and pastoralists, migration is one strategy for coping with the adverse effects of climate variability and change (van der Geest 2011). There is a strong north-to-south movement in Ghana related to rainfall levels and variability and land degradation in the north, and the continued availability of land in more humid regions to the south (van der Geest 2011). Van der Geest (2011) states that, according to the 2000 census statistics, one in five residents in the south were born in the north. In the northwest corner of Ghana (Nadowli District), increasing temperatures, delays in rainfall onset, and longer gaps in rainfall during the rainy season contribute to food insecurity and increase the propensity to migrate; migrants typically go to the central area of Ghana as farm laborers in the winter rainy season or try gold mining (Rademacher-Schulz and Mahama 2012).

In the Central Gonja District of the central area, some household members migrate to towns and cities to seek employment opportunities during the rainy seasons because of flood damage to crops (Kwadwo and Ganle 2017). Abu et al. (2013) find that rainfall variability in the forest-savannah transition region tops stressors that households experience (followed by unemployment, poverty, lack of education, bush fire, poor soil fertility, and poor health services). In a rural area further south, Carr (2005) paints a more nuanced picture of environmental factors in contributing to migration, pointing to power relations within household and communities and other aspects of political economy that shape migration.

Research in the coastal zone finds mixed patterns. Accra is an economic engine for the country and attracts many migrants, leading to rapid population growth in that segment of the coast; to the west there has been similarly rapid population growth (White et al. 2009). The population of the Volta Delta region, a low-lying area to the east of Accra that has experienced significant erosion and storm flooding, grew at 2 percent from 2000 to 2010, slightly below the national average of 2.5 percent (Appeaning et al. 2018). Government of Ghana (GoG) statistics suggest that during 2000 to 2010, Accra had the second highest out-migration in the country, just after the Upper West region (Hillman and Ziegelmayer 2016). Ayamga, Das, and Banerjee (2019) and Codjoe et al. (2017) find that most migration out of the delta is for economic reasons and not because of climate or sea level rise risks. Yet Ayamga, Das, and Banerjee (2019) state that risks are growing in severity: apart from seaward hazards, there is a strong positive association between perceived impact of droughts on economic security of livelihood and migration. Hillman and Ziegelmayer (2016) find that 20 percent of migrant households interviewed in Keta, located on a spit of land that encloses the Keta Lagoon in the eastern delta, had lost a home to the sea. Resettlement is occurring from the southern (seaward) side of the spit to the lagoon side. However, as in the research by Ayamga, Das, and Banerjee (2019), people's awareness of flood risks, lack of economic opportunity appears to be driving most migration out of the town.

7.3.3 Climate Trends and Projections

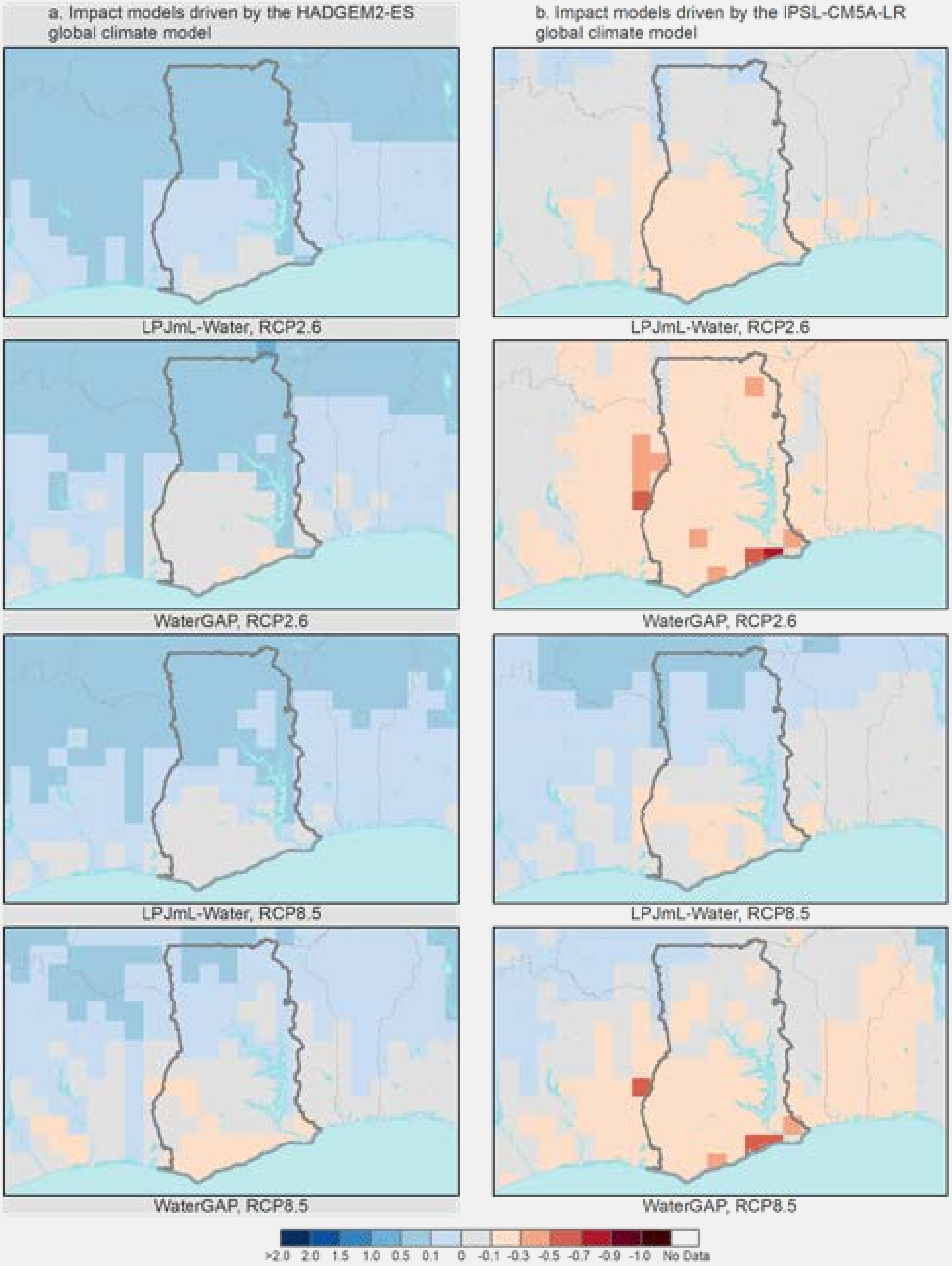
Ghana's coastal location and diverse hydrological features shape three distinct climatic zones across the country's 238,500 square kilometers (World Bank 2011a). The average annual temperature is around 26°C, although temperatures range on the higher end in the north during the dry season (USAID 2017). The southwestern region is the most humid and sees an average of 1,500–2,000 millimeters of rainfall per year (World Bank 2011a). The Volta River Basin in the north has the same average annual rainfall in its forested area, and an average of 1,000 mm per year in its savanna area. The driest region is the coastal area, which sees about 900 millimeters of rain annually. Ghana's rainfall varies according to the movement of the ITCZ. The West African monsoon heavily influences the wet and dry seasons in the country's northern, southeastern, and southern regions.

Due to ITCZ variation, seasonal rainfall is highly variable. It is most reliably affected by the El Niño–Southern Oscillation (ENSO), which tends to create warmer and drier conditions in the south between December and March, and wetter conditions in the north between November and May. Northern Ghana experiences the most variation in temperature throughout the year, with a hot, dry season reaching up to 27°C to 30°C (80.6°F to 86°F) (World Bank 2011a).

Average annual temperatures have been steadily increasing by around 1°C per decade since 1960 (USAID 2017). Sea levels have risen by 63 millimeters in the past few decades, resulting in significant coastal erosion. While the country's diverse climate produces considerable regional variation in projected impacts of climate change on precipitation, weather, and propensity to natural disasters, temperatures are expected to continue to rise, with a projected increase of 1°C to 3°C (1.8°F to 5.4°F) by the 2060s, and lower rainfall, with a projected decline in annual rainfall of 20.5 percent by 2080 (World Bank 2011a). Wet seasons are expected to see heavier rainfall, and dry seasons to see more arid, hot conditions. These changes would exacerbate existing environmental threats such as floods, landslides, coastal erosion, and droughts.

In this work, the population gravity model calibration found that the coefficients were highest for water availability, meaning that past shifts in water availability played a greater role than the other input variables in explaining past shifts in population distribution. Panels in figures 7.42 to 7.44 show the average projected changes in water availability, crop production, and NPP for the 2010–50 time period, respectively. NPP is used to gap-fill areas where there is no crop production. Note that the coefficient for water availability in rural areas is around 2.75 times higher than that of either crops or NPP, and it is the only climate factor other than flood risk and sea level rise influencing future urban population distribution. This means that it has a far greater influence on future population distribution than most other climate variables. Results suggest that Ghana will see modest wetting in the north and drying across several models in the south. Drying may be as high as 50 percent to 70 percent reductions in water availability in the Accra metropolitan area under the IPSL-CM5A-LR global climate model coupled with WaterGAP. For crop production, the LPJmL model projects modestly slight to moderate declines in crop production (from east to west), whereas the GEPIC model is spottier. The NPP model outputs are shown only for information purposes (there is no part of Ghana without crop production), but they show increasing ecosystem productivity, with some slight declines in the southwest of the country under the VISIT model.

Figure 7.42 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Ghana, 2010–50

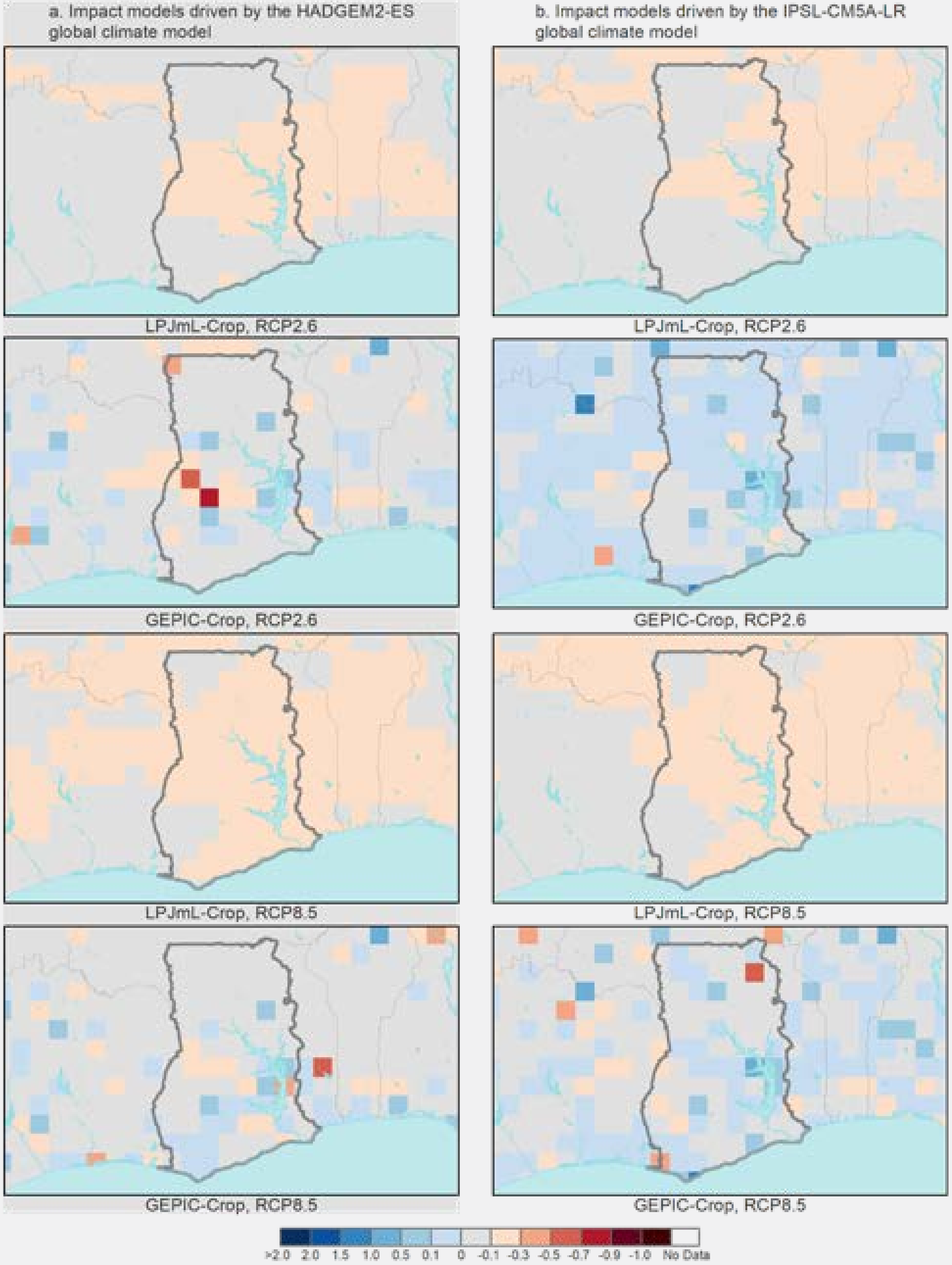


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A-LR global climate model

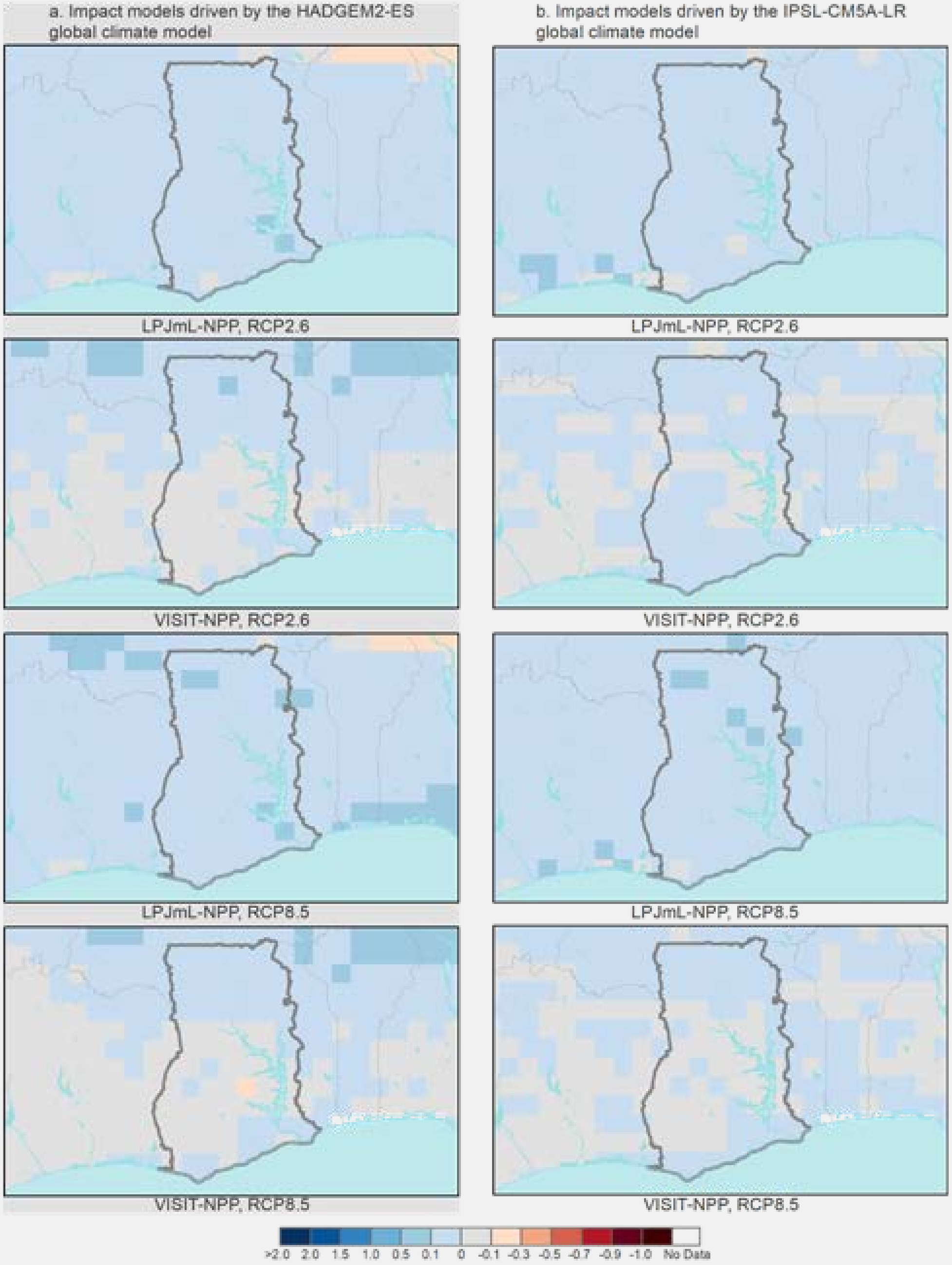
Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.43 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Ghana, 2010–50



Note: Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production.

Figure 7.44 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Ghana, 2010–50



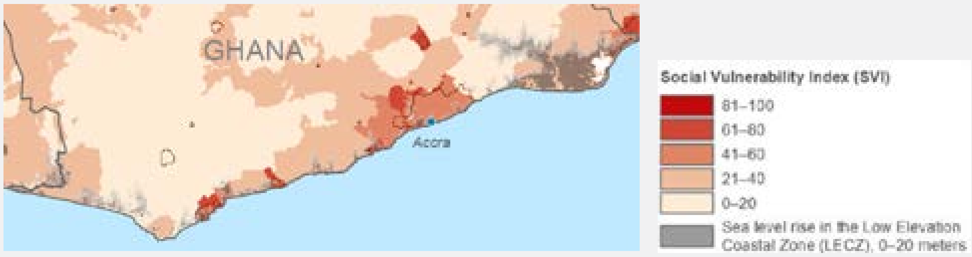
Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is used to gap-fill crop production, and therefore is not used to model future population distribution in Ghana. NPP = net primary production.

7.3.4 Coastal Trends

Ghana has a 528-kilometer shoreline (USAID 2011). Coastal erosion is progressing rapidly in Ghana, as it is along much of the Gulf of Guinea given the strong, predominantly eastward currents. Appeaning et al. (2008) find that the mean historic rate of erosion in the Accra region was 1.13 meters per year (plus or minus 0.17 meters per year), which was less than previously reported rates of 2–8 meters per year but still very high. The erosion rates depend on local geomorphology (for example, how quickly the land rises from the coast) and the underlying sediment and rock layers. Much of the Accra region rises fairly steeply, while the delta areas (for example, Volta and Densu) as well as lagoons at Cape Coast and on the border with Côte d'Ivoire tend to be low lying. Boateng (2012) reports significant losses of settlements in the eastern coast (Keta and Ada) and the central coast (Accra, Shama, and Sekondi-Takoradi), but losses are mitigated somewhat by the traditional buffer of undeveloped land between the coastline and developed areas—a buffer that is being reduced by tourism development.

De Sherbinin et al. (2014) measured social vulnerability levels as a function of population density, population growth, subnational poverty, maternal education levels, market accessibility (travel time to markets), and political violence (figure 7.45). Results suggest that areas north of Accra and surrounding Cape Coast and Takoradi have the highest levels of social vulnerability.

Figure 7.45 Social Vulnerability Index for the Coastline of Ghana



Source: de Sherbinin et al. 2014.

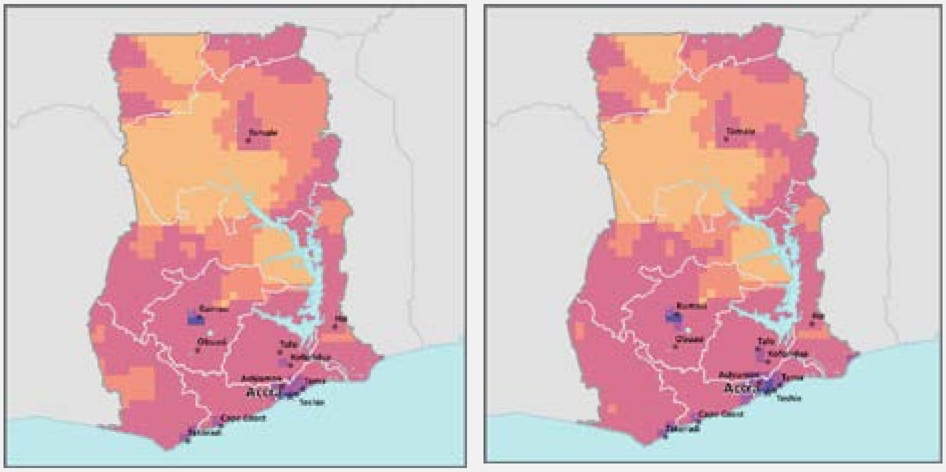
Projections indicate sea surface temperatures will increase with potential negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity (USAID 2011). Because coastal residents depend primarily on the marine fisheries for their livelihoods, vulnerabilities are tied to threats confronting this resource. Hinkel et al. (2012) applied the DIVA model to the West African coast, finding that Ghana is ranked among the top 15 most vulnerable countries in Africa for sea level rise projections.

7.3.5 Projected Changes in Population

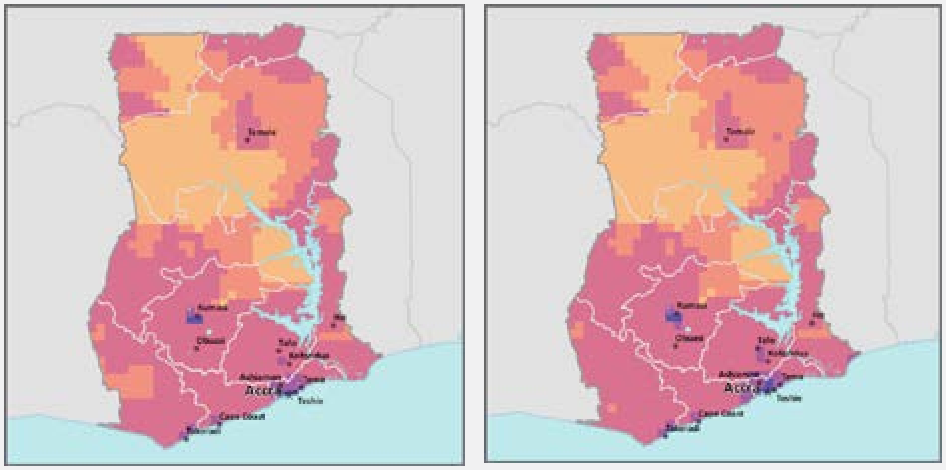
Indicators in figure 7.41 show that the future population size is dependent on the scenario under consideration. The total projected population to 2050 is higher under the SSP4 scenario (57.8 million) compared with the SSP2 scenario (49.7 million). Regarding population distribution, there are relatively modest variations among the future scenarios, with SSP4 showing a bit more expansion of Accra and Kumasi, the two largest cities (figure 7.46, panels a–d).

Figure 7.46 Projected Population under the Four Scenarios, Ghana, by 2050

a. Inclusive development (SSP2 and RCP8.5)   b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)   d. Climate-friendly (SSP4 and RCP2.6)

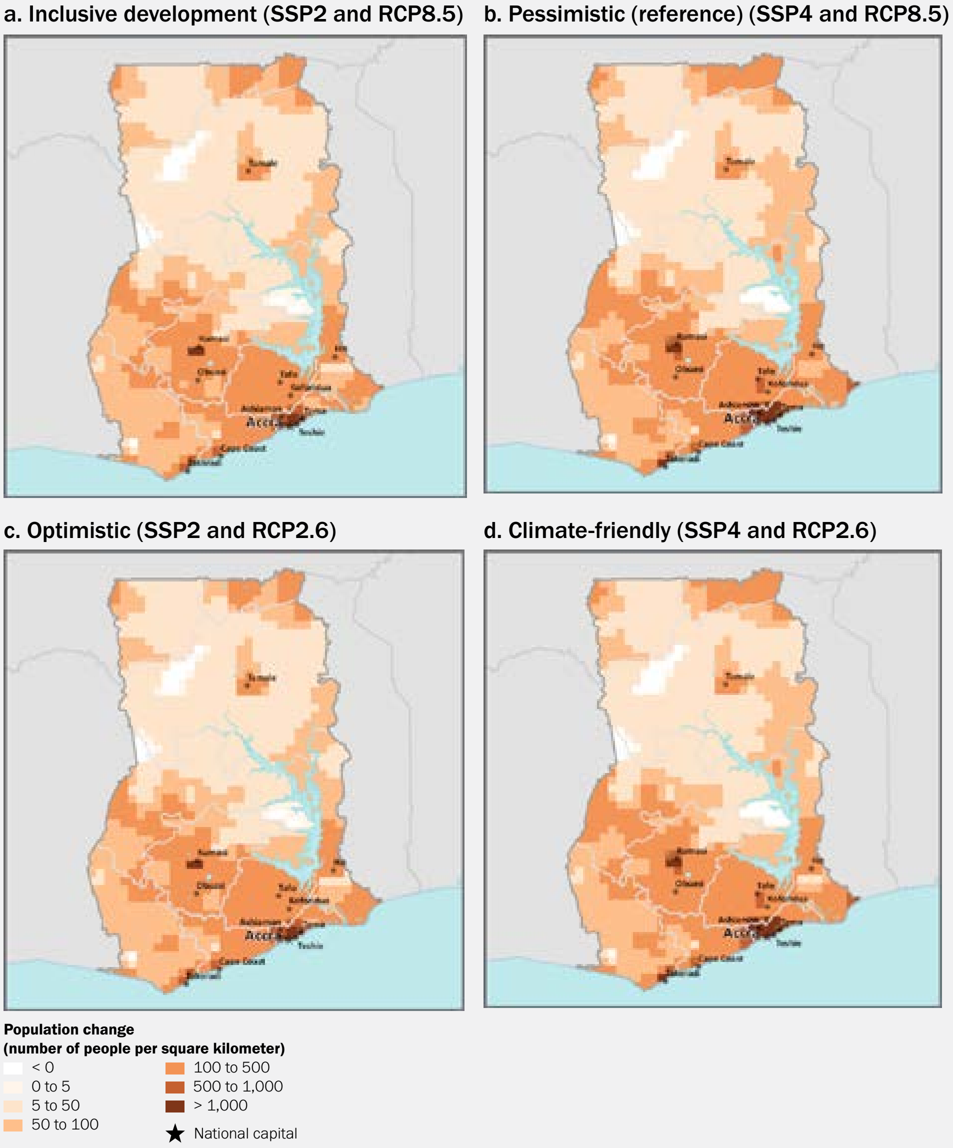


Population density
(number of people per square kilometer)

🟨 < 1	🟪 250 to 1,000
🟧 1 to 5	🟦 > 1,000
🟥 5 to 25	★ National capital
🟥 25 to 250	

Changes in population density between 2010 and 2050 (figure 7.47, panels a–d) show that the more densely populated south and areas along the border with Togo will grow the most, with fairly consistent patterns across scenarios. Accra expands the most under the pessimistic scenario.

Figure 7.47 Projected Change in Population Density under the Four Scenarios, Ghana, 2010–50



a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6)

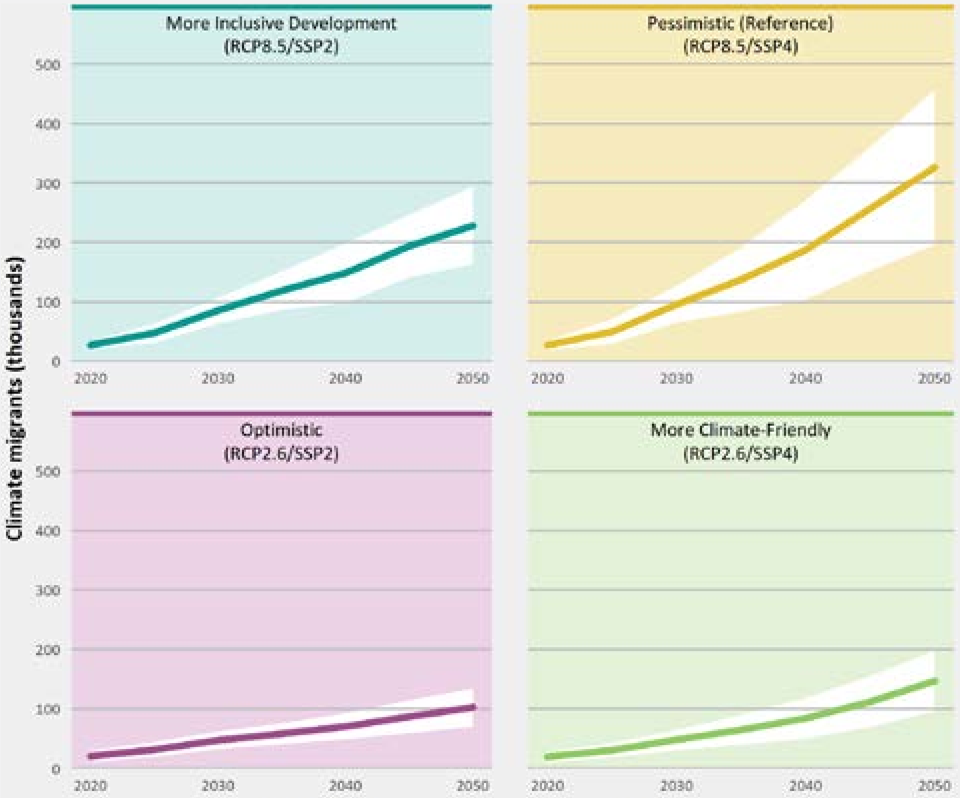
d. Climate-friendly (SSP4 and RCP2.6)

7.3.6 Internal Climate Migration Futures and Trends

Scale and Trajectory of Internal Climate Migration

Figure 7.48, panels a–d, presents the projected number of climate migrants by scenario and decade, from 2020 to 2050. All the scenarios display an upward trend, but with important differences. The optimistic scenario and pessimistic scenarios provide the lower and upper bounds for number of climate migrants: 102,000 and 327,000, respectively. The confidence intervals also are low and high, respectively, suggesting less certainty with the numbers in the pessimistic scenario. Even under the highest estimate (model run) of 457,000 migrants under the pessimistic scenario, climate migrants still make up under 1 percent of the population. Climate migrants are generally a small fraction of other migrants, though the percentage is higher under the pessimistic scenario (figure 7.48).

Figure 7.48 Projected Total Climate Migrants, Ghana, 2020–50



Climate migrants as a percentage of the total population

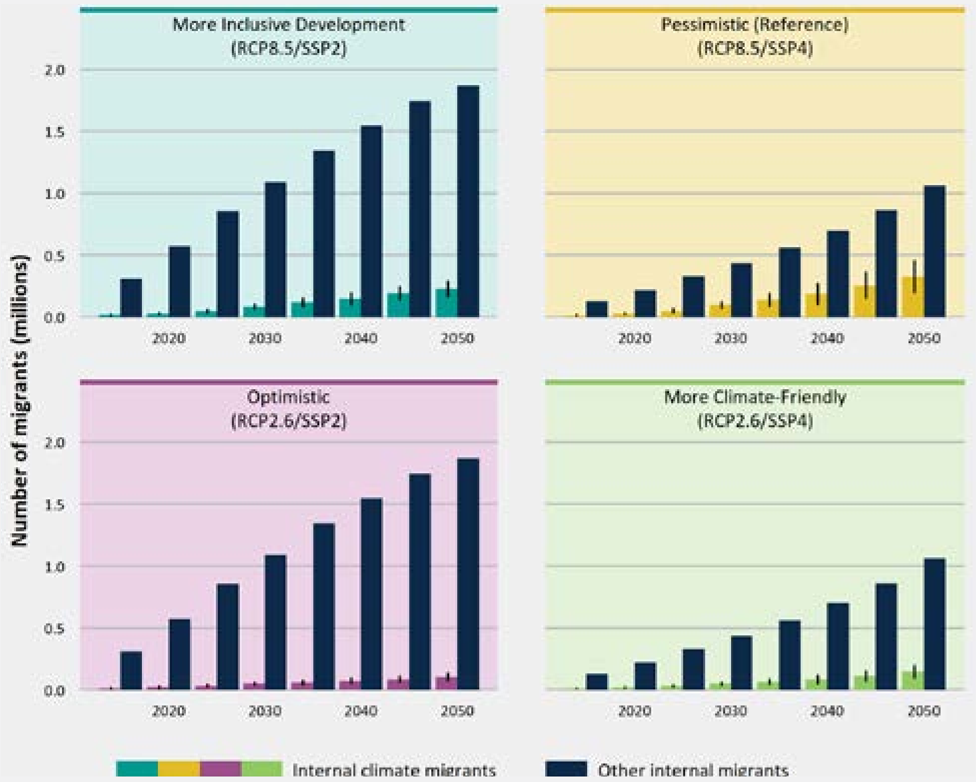
Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.09	0.24	0.36	0.49	0.09	0.25	0.41	0.61

Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.07	0.13	0.17	0.22	0.06	0.13	0.18	0.27

Table 7.10 Projected Total Climate Migrants for Ghana by 2050

	Scenario							
	Pessimistic reference		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	0.327		0.228		0.147		0.103	
Min. (left) and max. (right) (millions)	0.197	0.458	0.164	0.293	0.096	0.198	0.071	0.134
Internal climate migrants as % of pop.	0.61		0.49		0.27		0.22	
Min. (left) and max. (right) (%)	0.36	0.85	0.35	0.63	0.18	0.37	0.15	0.29

Figure 7.49 Projected Climate Migrants Compared to Other Migrants, Ghana, 2020–50



Internal Climate Migration Hotspots

The results to 2050 (figure 7.50) show high levels of climate out-migration from the coastal zone, a function of sea level rise impacts and declining water availability (figure 7.42). They also indicate high levels of climate in-migration around Kumasi (south-central Ghana), on the eastern banks of the Volta reservoir, and in the northeastern and northwestern corners of the country. The latter is in response to projected wetting in northern areas in the ISIMIP climate impacts data, with some models showing projected drying in the south. The hotspots in 2030 (figure 7.51, panels a and b) generally represent a graduate increase in the levels. However, up to 2030, the area around Kumasi tends to repel climate migrants, but from 2040 to 2050 it attracts them.

In Ghana, vibrant coastal areas are projected to see a dampening of population growth due to climate out-migration in response to sea-level rise and declining levels of water availability in the south. At the same time, the poorer areas in the north are projected to see climate-in migration, in response to increased water availability trends.

Figure 7.50 Projected Hotspots of Climate In- and Out-Migration, Ghana, 2050

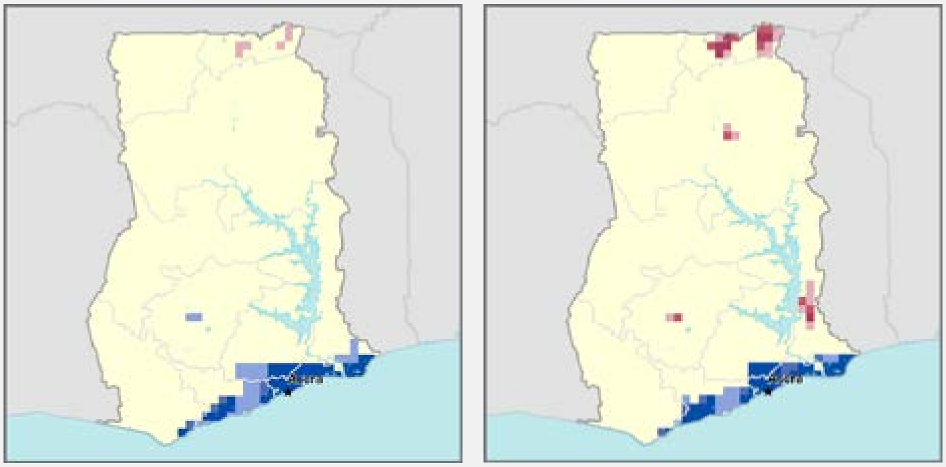
IN-MIGRATION

- 🟥 High certainty in high levels of climate in-migration
- 🟥 Moderate certainty in high levels of climate in-migration
- 🟥 Low certainty in high levels of climate in-migration

OUT-MIGRATION

- 🟦 High certainty in high levels of climate out-migration
- 🟦 Moderate certainty in high levels of climate out-migration
- 🟦 Low certainty in high levels of climate out-migration

Figure 7.51 Projected Hotspots of Climate In- and Out-Migration, Ghana, 2030 and 2040



a. Hotspots by 2030

b. Hotspots by 2040

IN-MIGRATION

- 🟥 High certainty in high levels of climate in-migration
- 🟥 Moderate certainty in high levels of climate in-migration
- 🟥 Low certainty in high levels of climate in-migration

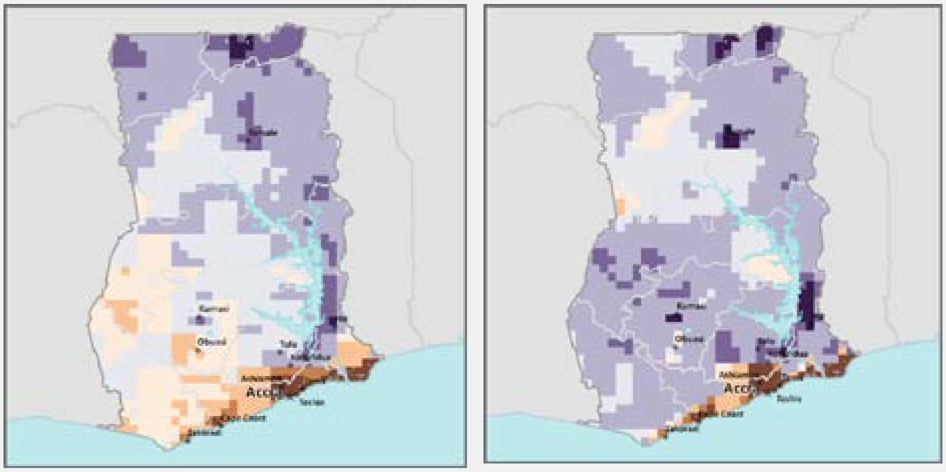
OUT-MIGRATION

- 🟦 High certainty in high levels of climate out-migration
- 🟦 Moderate certainty in high levels of climate out-migration
- 🟦 Low certainty in high levels of climate out-migration

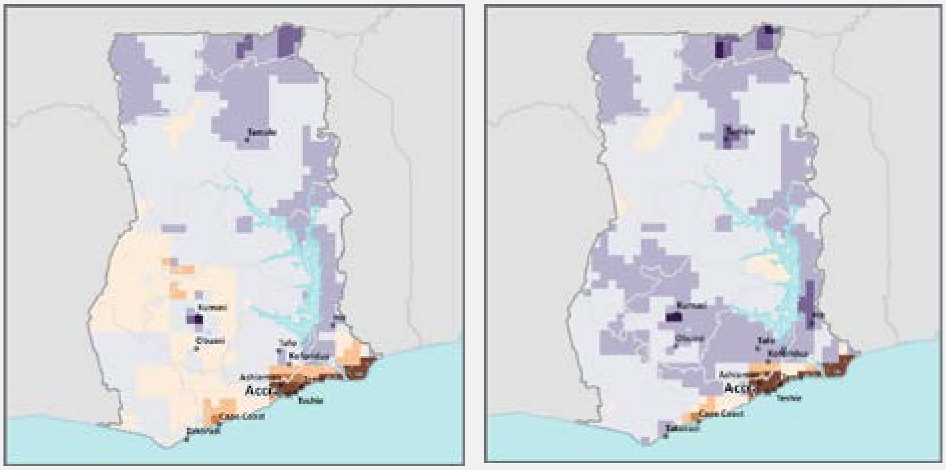
Figure 7.52, panels a–d, displays the absolute difference between population distributions in the climate and no climate scenarios for 2050 in absolute terms. Climate scenarios reflect the potential push impact of sea level rise in selected areas along the coast, and of declining water availability in the southern and southwestern parts of the country (per the ISIMIP results).

Figure 7.52 Projected Population Change Due to Climate Migration, Ghana, 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)



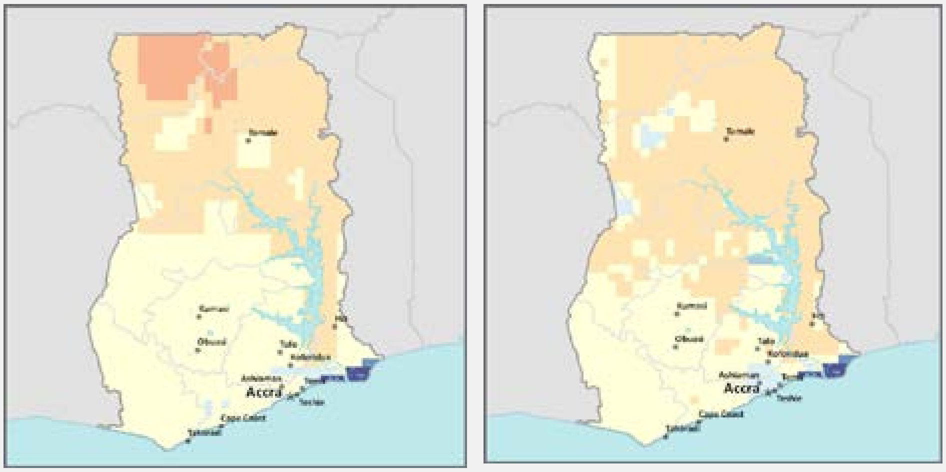
Population change (count)

■ < -1,000	■ 0 to 100
■ -1,000 to -500	■ 100 to 500
■ -500 to -100	■ > 1,000
■ -100 to 0	★ National capital

Note: Changes shown per square kilometer.

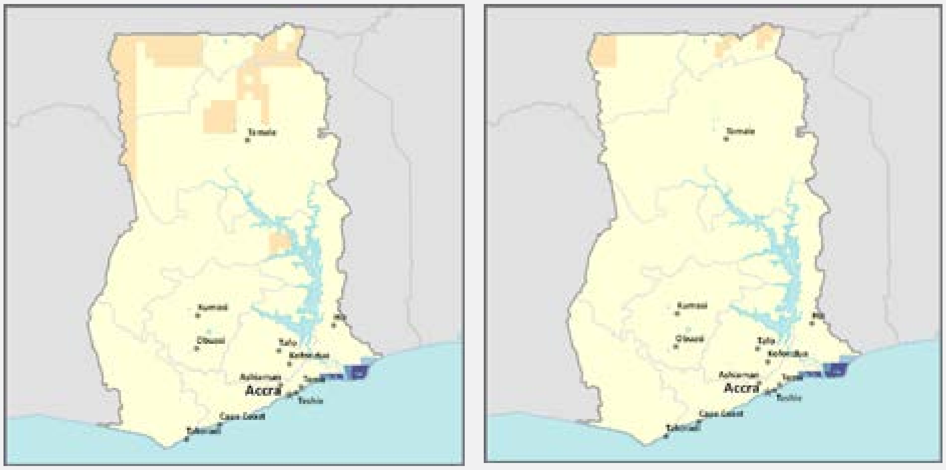
Figure 7.53, panels a–d, displays the information in figure 7.52, panels a–d, as percentages. The clear signal is declines of more than 10 percent in the Volta Delta region across all scenarios, smaller percentage declines around Accra, and relative growth of up to 5 percent in the northwestern region, if projected increases in water availability materialize.

Figure 7.53 Projected Percentage of Difference between Climate Impact Scenarios and Respective No Climate Impact (SSP-Only) Scenario, Ghana, 2050



a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

d. Climate-friendly (SSP4 and RCP2.6)

Population change (%)

- 🟦 < -10
- 🟦 -10 to -5
- 🟦 -5 to -2.5
- 🟦 -2.5 to -1
- 🟨 -1 to 1
- 🟨 1 to 2.5
- 🟧 2.5 to 5
- 🟥 5 to 10
- 🟥 > 10
- ★ National capital

Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, we processed the coastal climate migration with the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level.

Climate out-migration within 5 kilometers of the coast is negative across all scenarios, but particularly high for the pessimistic scenario (figure 7.54, panels a–d). Under that scenario, somewhere between 100,000 and 150,000 people may be forced to leave the coastal zone because of the increased frequency of inundation. Figure 7.55 indicates that although the coastal zone shows negative climate net migration, magnitudes vary. This variation is most likely because of sea level rise impacts as the main drivers, and the larger impacts will occur closer to Accra.

Figure 7.54 Projected Coastal Climate Migrants, Ghana, 2020–50

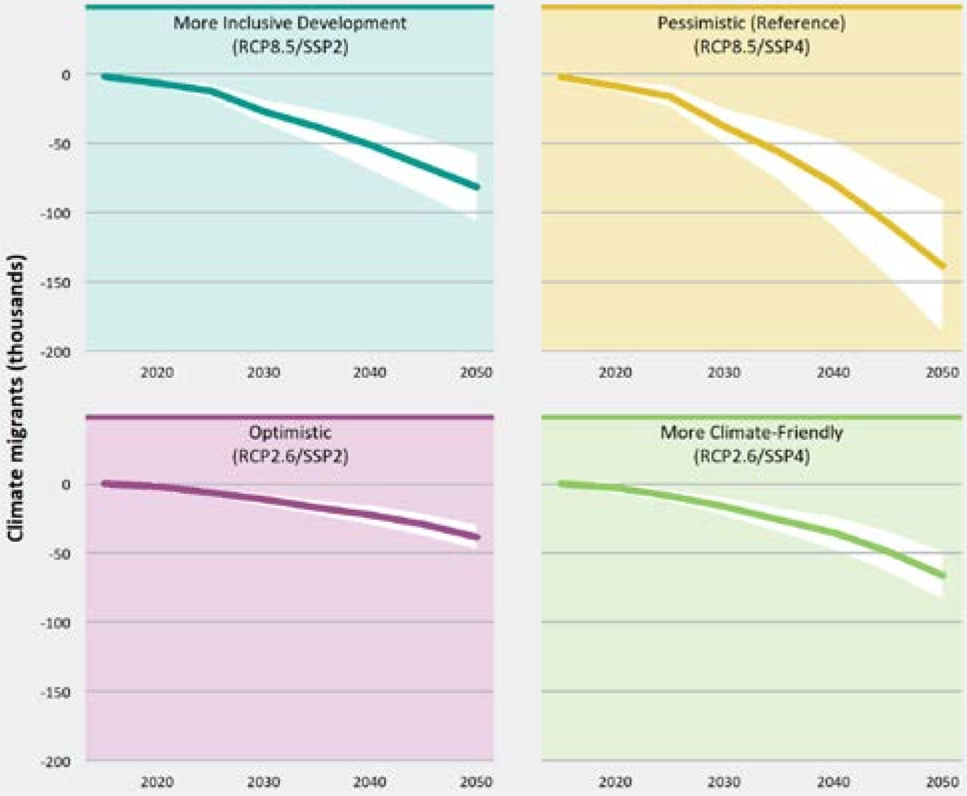
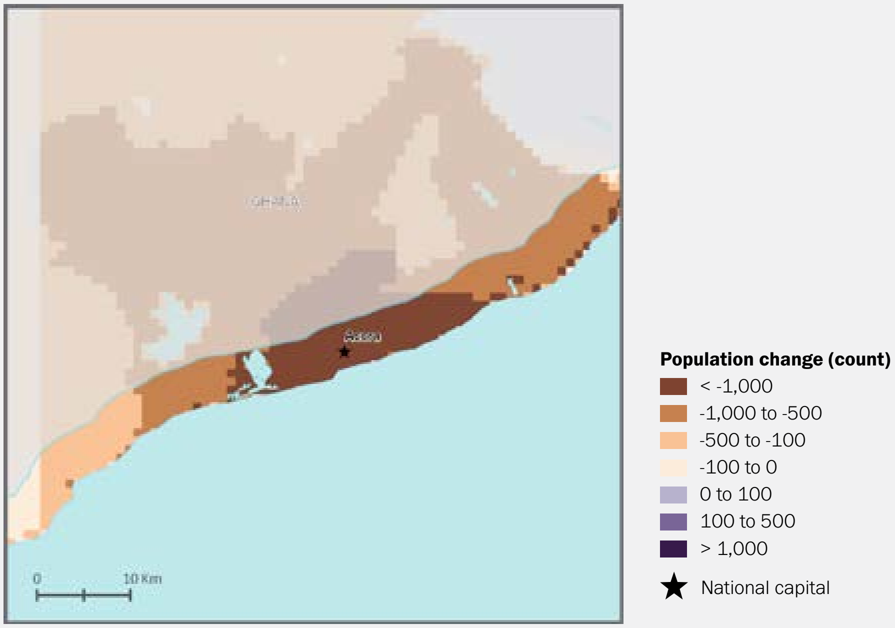


Figure 7.55 Projected Population Change Due to Climate Migration for the Coastal Zone of Ghana, 2050

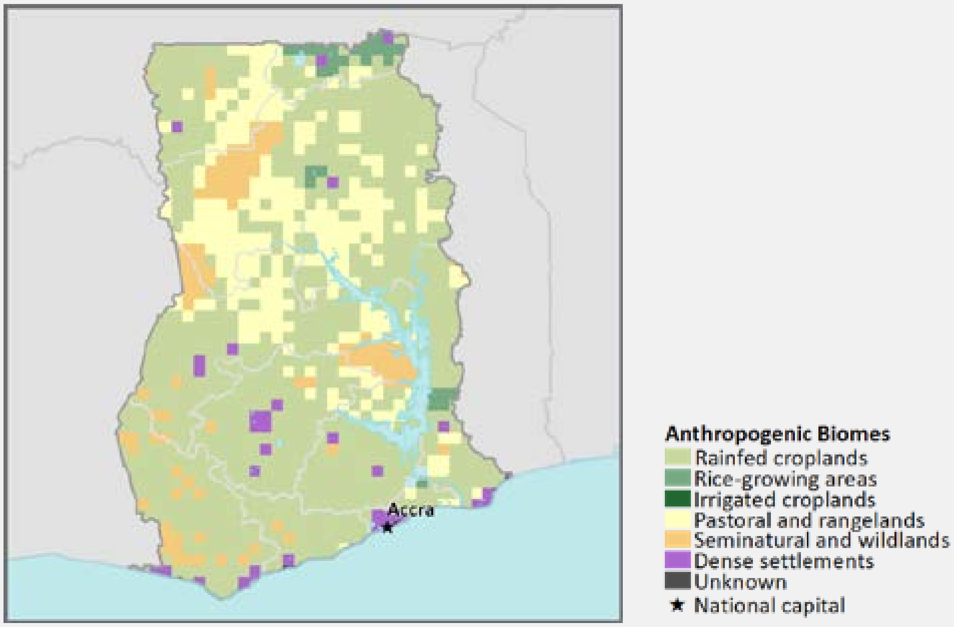


Note: Estimations calculated per square kilometer, pessimistic scenario.

Climate Migration by Livelihood Zone

Figure 7.56 displays the distribution of livelihood zones in Ghana. Rainfed croplands and pastoral and rangelands make up most of Ghana's zones. Table 7.11 provides projections of net climate migration in each of the livelihood zones by decade.

Figure 7.56 Livelihood Zones, Ghana



Because of the large concentration of population in dense settlements exposed to sea level rise, sense settlements see the largest out-migration, up to minus 123,000 under the pessimistic scenario in 2050. Pastoral zones see climate out-migration across most scenarios. Rainfed croplands and rice-growing areas see climate in-migration.

Table 7.11 Net Climate Migration by Scenario, Livelihood Zone, and Decade, Ghana, 2030, 2040, 2050

Year and livelihood zone	Scenario			
	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/ SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
2030				
Dense settlements	−17,018	−24,317	−11,778	−34,275
Irrigated croplands	361	535	345	560
Pastoral and rangelands	1,004	3,494	3,908	−2,419
Rainfed croplands	10,718	16,973	3,107	31,577
Rice-growing areas	5,893	5,383	5,369	6,166
Seminatural and wildlands	625	343	106	1,887
Unknown	−1,584	−2,411	−1,057	−3,496
2040				
Dense settlements	−28,789	−45,228	−18,639	−70,163
Irrigated croplands	593	1,068	524	1,100
Pastoral and rangelands	−6,320	3,160	244	−11,023
Rainfed croplands	26,882	31,182	11,190	68,377
Rice-growing areas	9,154	13,125	7,939	15,136
Seminatural and wildlands	1,594	1,113	627	3,775
Unknown	−3,113	−4,420	−1,885	−7,203
2050				
Dense settlements	−47,926	−73,163	−28,819	−123,381
Irrigated croplands	914	1,665	715	1,715
Pastoral and rangelands	−19,208	2,839	−4,810	−26,356
Rainfed croplands	55,426	52,524	24,074	128,747
Rice-growing areas	13,293	20,629	10,529	25,041
Seminatural and wildlands	3,132	2,481	1,457	7,066
Unknown	−5,631	−6,976	−3,146	−12,832

Figure 7.57 and table 7.12 display net climate migration for 2050, by province. The northern regions generally see a net gain (Northern, Upper East, and Upper West), whereas the coastal regions are net losers (Greater Accra, Volta). This is largely because of increased water availability in the north and corresponding decreases in the south, with particularly strong declines under some model runs around Accra. Declines in Accra would likely have been even stronger were it not for the effect of a high median age in the region (24 compared to 17 in the north), which draws migrants (see discussion in appendix D). The other provinces have a mix of climate in- and out-migration across scenarios, and the uncertainty bars often run from negative to positive, making the results less conclusive.

Andrea Borgarello / World Bank

Figure 7.57 Projected Net Climate Migration by Province and Scenario for Ghana, 2050

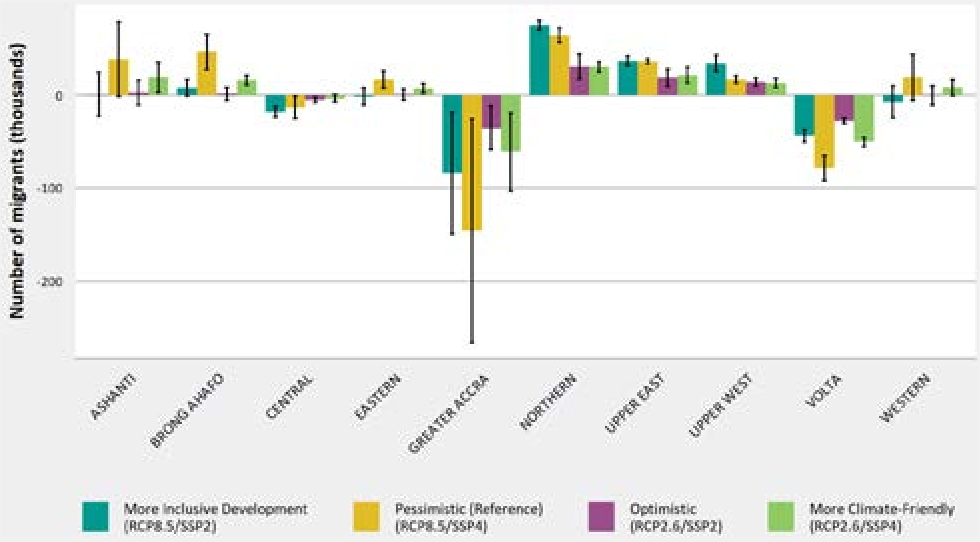


Table 7.12 Projected Net Climate Migration by Scenario and Province, Ghana, 2050

Scenario averages

Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Ashanti	19,173	913	2,522	38,499
Brong Ahafo	15,997	7,801	1,452	46,319
Central	–3,267	–17,756	–5,046	–13,088
Eastern	7,398	–1,593	978	16,853
Greater Accra	–61,177	–84,058	–35,398	–145,516
Northern	30,298	74,767	30,561	64,071
Upper East	21,369	36,893	18,781	35,972
Upper West	12,862	34,302	13,940	16,877
Volta	–50,924	–44,096	–27,494	–78,975
Western	8,271	–7,172	–296	18,987

7.4 MAURITANIA

7.4.1 Population and Development Context

Mauritania is an LIC with a history of political instability and economic debt. In recent years, however, the country's political and security situation has stabilized considerably, and socioeconomic conditions have followed suit (AfDB 2016). The country has seen increased economic opportunity and a growth in GDP since 2015. AfDB (2019b) report a real GDP growth of 3.5 percent in 2018, up from 1.8 percent in 2016.

Developments across multiple industries, including irrigated agriculture, fishing, metalwork, construction, and manufacturing, should continue to improve the national GDP. Due to a heavy reliance on iron, gold, and copper exports, income is highly susceptible to price fluctuations, and economic growth often fails to reach the entire population due to inequality. When accounting for inequality, Mauritania's 2017 HDI of 0.520 falls 33 percent to 0.348 (UNDP 2018).

Population growth poses an additional challenge to poverty reduction given the continued dominance of extractive industry, and slow, recent economic recovery. At 2.8 percent, the average annual population growth is slightly higher than the regional average of 2.7 percent.[75] There are an estimated 4.5 million residents (PRB 2018). Although Mauritania's population density is low (four persons per square kilometer), the population per square kilometer of arable land, at 1,099 persons, is more than double the regional average of 445 persons (PRB 2018). Much of the population is clustered in the country's major cities (Nouakchott and Nouadhibou) and in the southern region (figure 7.58, panels a and b). Environmental concerns such as drought threaten the food supply: in 2012, 32.3 percent of Mauritanian households were considered food insecure, 80 percent of which lived in rural areas (AfDB 2016).

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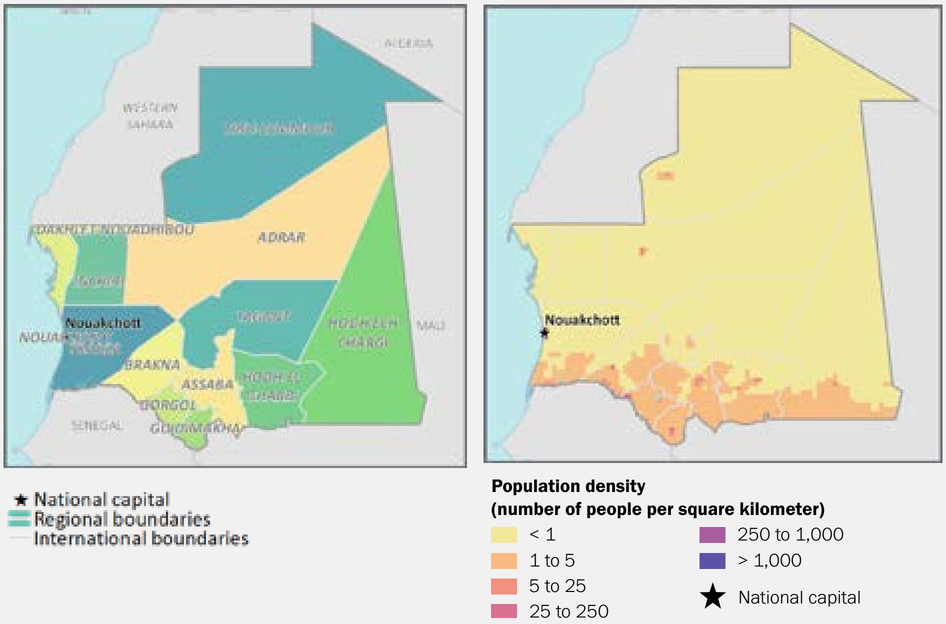
[75] See United Nations Development Programme, Mauritania, at https://www.adaptation-undp.org/explore/western-africa/mauritania.

Figure 7.58 Reference and Population Density Maps, Mauritania, 2010


a. Reference

b. Population density

Mauritania has a young population, with over half of its inhabitants under the age of 25 (UN DESA 2019). Immigration exceeded emigration between 2010 and 2020 such that the country sees an average influx of immigrants of around 5,000 per year. Despite continued inequality, the proportion of the country classified as poor fell from 44.5 percent in 2008 to 33 percent in 2014, and standard of living has improved. In the capital city of Nouakchott, where the greatest number of migrants move, poverty remains high.[76]

Mauritania is projected to face the highest relative sea level rise in West Africa over the course of this century because of coastal subsidence. Parts of Nouakchott already prone to flooding from seawater intrusion and rising groundwater are projected to experience climate out-migration as early as 2030.

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[76] See the World Bank in Mauritania at https://www.worldbank.org/en/country/mauritania/overview.

Table 7.13 Development Indicators for Mauritania

Population	
Population (millions)	4.4
Annual population growth (%)	2.8
Population in 2050 under SSP2 (millions)	6.3
Population in 2050 under SSP4 (millions)	7.2
Urban share of population (%)	53.7
Employment in agriculture (% of total employment) (2019)	55.0
GDP	
GDP (current US$ billions)	5.2
Annual GDP growth (%)	3.6
GDP per capita (current US$)	1,188.80
Value added of agriculture (% GDP) (2019)	25.9
Poverty	
Poverty headcount ratio at US$1.90 a day (PPP, 2011) (% of population) (2014)	6.0
Climate and disaster risk indexes	
ND GAIN Index (2017)	
Rank	154
Score	36

Source: WDI database;[77] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better.

Note: All figures are for 2018 except where otherwise indicated. GDP = gross domestic product; ND GAIN = Notre Dame Global Adaptation Index; SSP = Shared Socioeconomic Pathway.

7.4.2 Historical and Current Migration Patterns

Internal migration

The primary internal migration pattern has been rural to urban. According to the 2013 census (ONS 2015), there were 710,101 internal migrants, or 20.5 percent of the sedentary (as opposed to nomadic) population. Because of the decline in nomadic activity, the population seems to be less mobile than in the past (Saleh 2009). After the droughts of the 1970s and 1980s and the ensuing rural exodus, the population went from 9 percent urban in 1965 to 88 percent in 2013, totaling 1.7 million urban residents (ONS 2015). Regions with the largest number of migrants as a percentage of the population are Inchiri (53.6 percent), with its copper mines; Dakhlette Nouadhibou (52.1 percent), with its oil and gas production; and the capital, Nouakchott (47 percent). The majority of migrants in these areas are male.

International migration

Estimates of Mauritanians living abroad vary from 100,000 to 250,000, or from 3 percent to 8 percent of the population, respectively (Schefran et al. 2012). Migration from Mauritania is largely economically driven. Labor emigration of the unskilled and unemployed youth is driven by the few and decreasing opportunities in Mauritania's national economy and an overloaded informal sector (Bruni et al. 2017; Saleh 2009). Immigration is not very significant. In 2015, the stock of immigrants was 60,768, representing just 1.4 percent of the total population and about half of the emigrant numbers (Bruni et al. 2017). Most of the country's immigrants are from Senegal, Mali, and Guinea, and most work in the urban service sector (domestic workers, petty traders, and drivers). A smaller fraction work in agriculture and fisheries. In the

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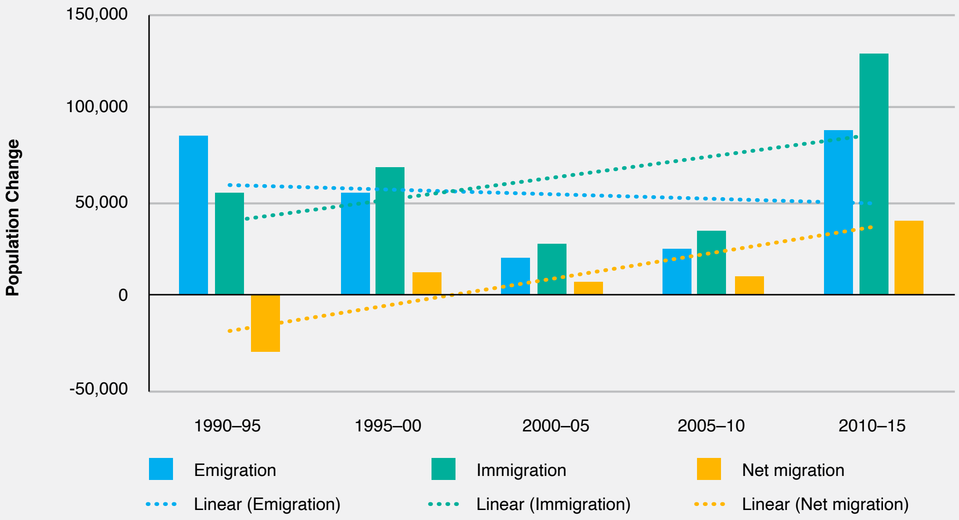
[77] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

past four years, Mauritania has become a net immigration country (figure 7.59). This may be due to the rise in oil and mineral exploitation in the northwest corner of the country. A 2019 survey of international migrants and refugees in Nouadhibou finds that they number around 10,000, are mostly male and mostly from Mali, and work in the construction and fishing industries (UNHCR 2019a).

Figure 7.59 International Migration Trends, Mauritania, 1990–2015

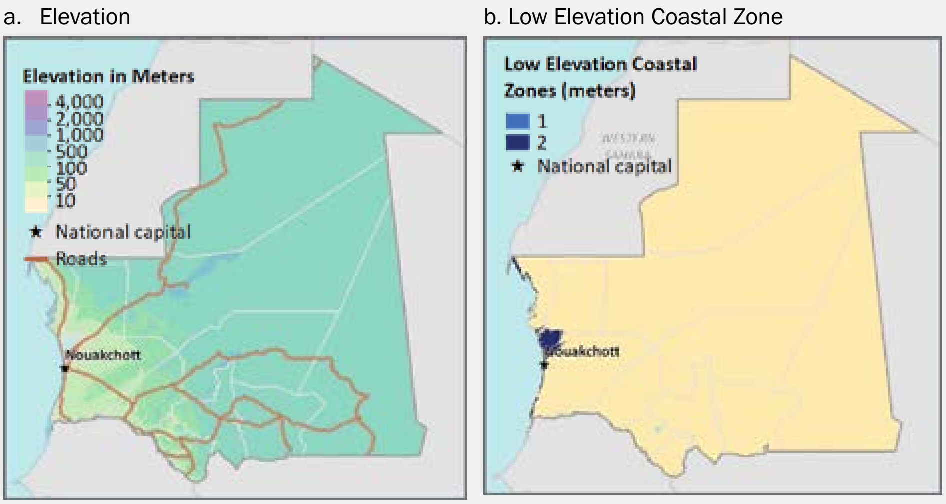


Source: Abel and Cohen 2019.

Environmental migration

Droughts of the early 1970s and 1980s resulted in migration waves from the rural areas to informal settlements in the capital, Nouakchott, as well as along the principal east-west highway (*la route de l'espoir,* or the road of hope) (Retaillé 1995). This pattern was similar to that of many Sahelian countries. The migrants included smallholder agriculturalists and nomadic pastoralists. According to data from the 2013 census (IADD 2019c; ONS 2015), nomads represented 70 percent of the population in 1965, as opposed to just 5 percent in 2013. This could be thought of as a first wave of climate-induced migration in the country, although the great Sahelian droughts were driven more by decadal variation than climate change. See figure 7.60, panels a and b, for elevation and low elevation coastal zone maps.

Figure 7.60 Elevation and Low Elevation Coastal Zone Maps, Mauritania



a. Elevation

b. Low Elevation Coastal Zone

Few studies have been conducted recently on the environmental determinants of migration in Mauritania. Kienberger et al. (2016) conducted climate vulnerability mapping for two regions of southern Mauritania, but without reference to migration. Schefran et al. (2012) examined international migration as a resilience building mechanism in a Soninké village in southwestern Mauritania, a region known for high levels of outmigration. The focus was on the impact of remittances and migrant associations on local development Schefran et al. (2012, 126) conclude:

De Sherbinin (1989) examined the impact of remittances on development in the Soninké-speaking region of Mauritania, finding that on balance it is economically positive for those left behind.

7.4.3 Climate Trends and Projections

A northwestern African country off the Atlantic coast, Mauritania sits at the border of the arid Maghreb, which constitutes three-quarters of the territory, and the Sahel, which is the southern shore of the Sahara Desert.[78] Three currents affect the climate: marine trade winds, continental trade winds, and the summer monsoon. The country is characterized by arid and semiarid climates (AfDB 2019b).

A brief wet season lasts from July through September, but variable precipitation rates tend to be low and concentrated in the southern portion of the country. In the large Sahara region, average annual rainfall is around 56 millimeters per year, and the average temperature is around 27°C (AfDB 2019a). In the Sahel region, the average annual rainfall is a bit higher, but still only reaches 200 millimeters per year and an average temperature of 29°C. The relatively wet Senegal River region sees around 750 millimeters per year and an average temperature of 28°C. In the latter two regions, the temperature is seasonal and has interannual variability of 9°C to 12°C.

Given the arid climate, populations cluster along the coast and southern portion of the country. The district of Nouakchott, for example, makes up only 1 percent of the country's surface area but is home to 22 percent of its population[79]. Coastal residents, who make up almost one-third of the population, are at risk from rising sea levels and an increase in extreme weather events (UNFCC 2015). Annual rainfall is expected to increase, particularly in the form of extreme precipitation. The propensity toward

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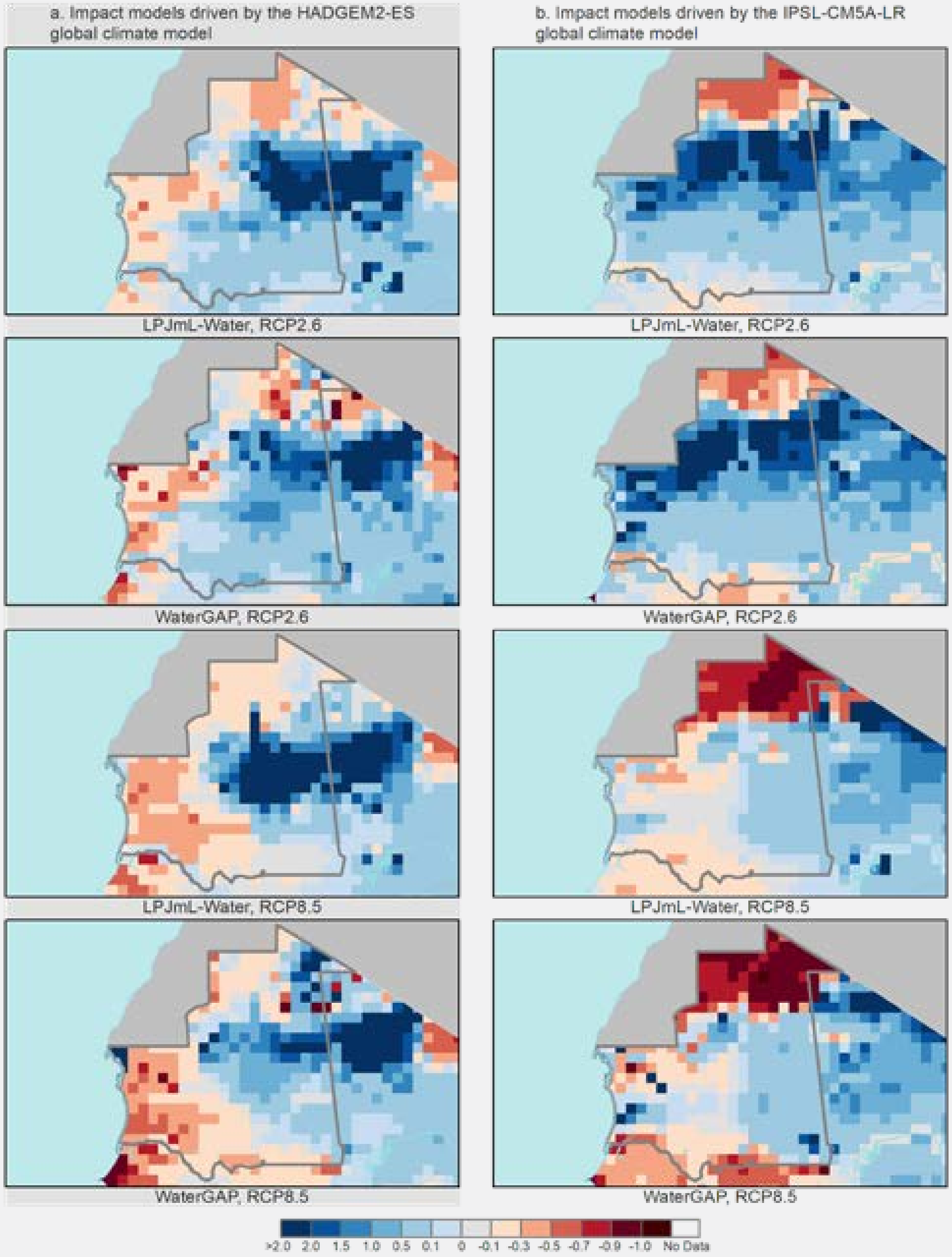
[78] See United Nations Development Programme, Mauritania, at https://www.adaptation-undp.org/explore/western-africa/mauritania.

[79] See United Nations Development Programme, Mauritania, at https://www.adaptation-undp.org/explore/western-africa/mauritania.

long dry spells, however, makes the country vulnerable to drought and desertification. Between 1979 and 2015, the mean average temperature has increased between 0.16°C per decade in the Senegal River headwaters to 0.38°C per decade in the Sahara region (AfDB 2019b). This upward trend in temperature is expected to increase by as much as 1°C to 3°C by 2050.

In this work, the population gravity model calibration finds that the coefficients are highest for water availability. This means that past shifts in water availability played a greater role than the other input variables in explaining past shifts in population distribution. Panels in figures 7.61 to 7.63 show the average projected changes in water availability, crop production, and NPP for the 2010–50 time period, respectively. NPP is used to gap-fill areas where there is no crop production. The coefficient for rural water availability is around 2.75 times higher than that of either crops or NPP, and it is the only climate factor other than flood risk and sea level rise influencing future urban population distribution. This finding means that water availability has a far greater influence on future population distribution than most other climate variables. Results suggest that Mauritania will become drier in the western coastal areas under the Had-GEM2-ES global climate model, and that water availability will more than triple in some of the arid interior areas, but against a very low baseline such that changes may not be that significant from a livelihoods perspective. The dramatic changes in NPP are similarly against a very low baseline, which should influence interpretation. In the south, crop production declines under most model runs.

Figure 7.61 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Mauritania, 2010–50



a. Impact models driven by the HADGEM2-ES global climate model

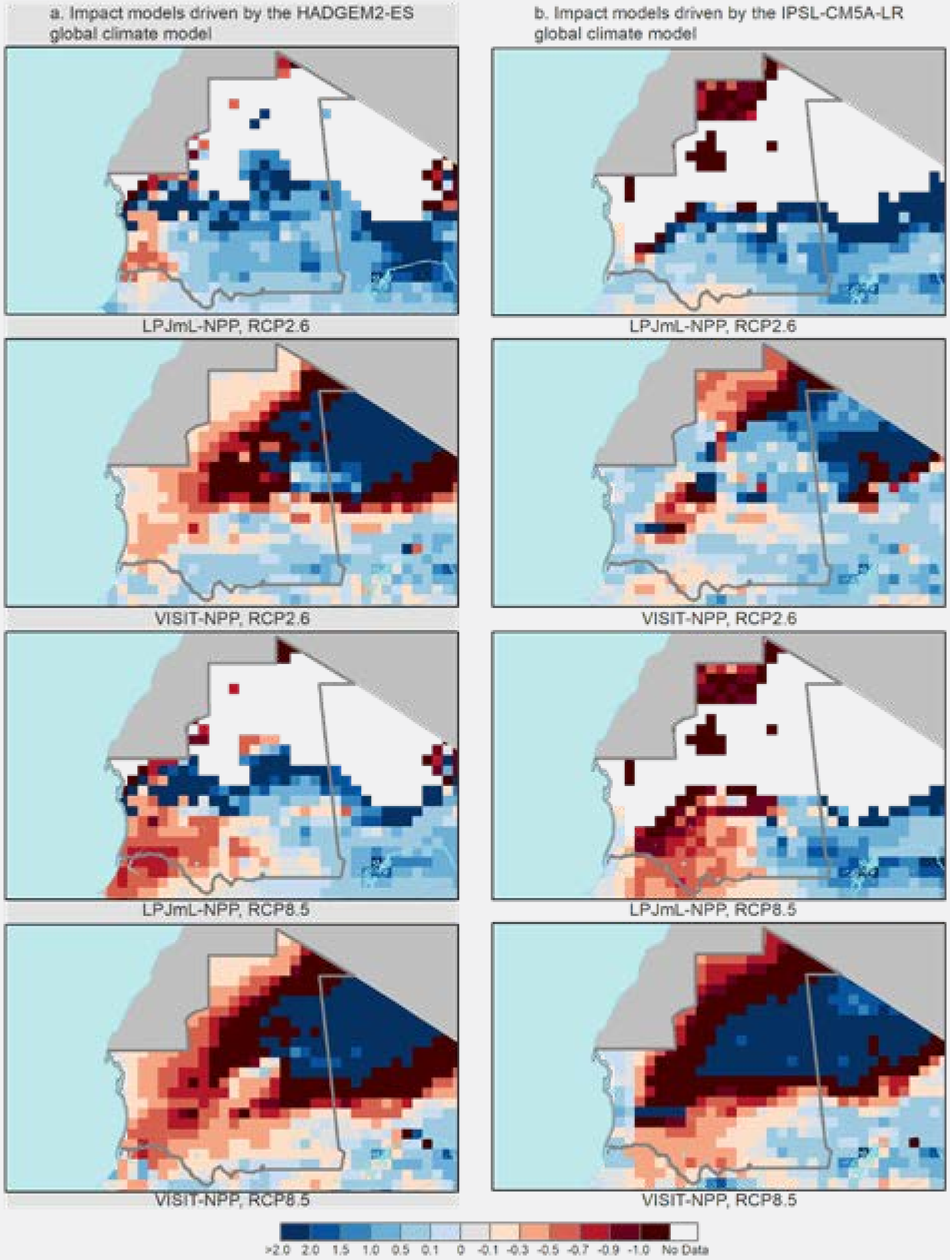
b. Impact models driven by the IPSL-CM5A-LR global climate model

Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.62 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Mauritania, 2010–50

Note: Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production. White areas have no crop production and are gap-filled with NPP. NPP = net primary productivity.

Figure 7.63 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Mauritania, 2010–50



Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP = net primary productivity.

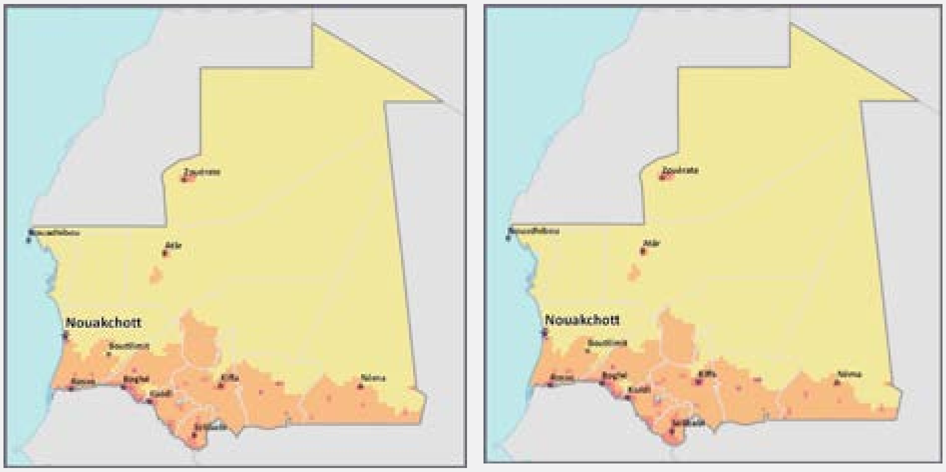
7.4.4 Coastal Trends and Projections

The primary risk to populations because of sea level rise and coastal erosion is around Nouakchott, which grew rapidly from the 1970s onward in part because of rural-urban migration associated with the two Sahelian droughts of the 1970s and 1980s. The city has a littoral depression, a belt of low-lying lands at risk of saltwater inundation between the coastal sandbar (or dunes) and the main city (Wu 2007), as well as a far larger depression to the north, known as the Sebkha de Ndramcha (figure 7.60). The city suffers from periodic flooding. Its rapidly growing urban areas extend into low-lying portions, putting more inhabitants of the capital at risk (Cheikh et al. 2007).

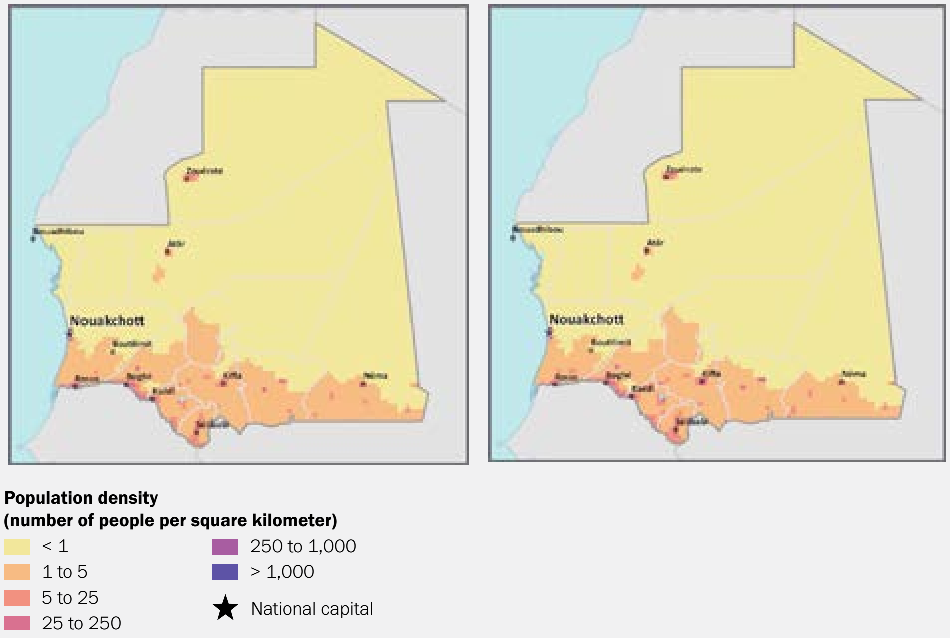
7.4.5 Projected Changes in Population

The projected population of Mauritania in 2050 is 7.6 million under SSP2 and 8.3 million under SSP4. The latter represents a close to doubling from current levels. Projected population distributions in figure 7.65, panels a–d, suggest a high degree of conformity across projections, but with slightly higher densities under SSP4 (right panels).

Figure 7.64 Projected Population under the Four Scenarios, Mauritania, by 2050


a. Inclusive development (SSP2 and RCP8.5)

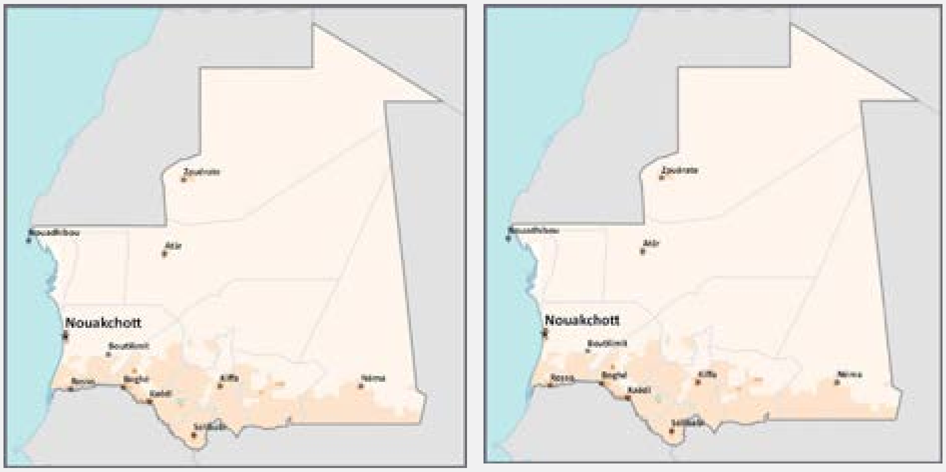
b. Pessimistic (reference) (SSP4 and RCP8.5)


c. Optimistic (SSP2 and RCP2.6)

d. Climate-friendly (SSP4 and RCP2.6)

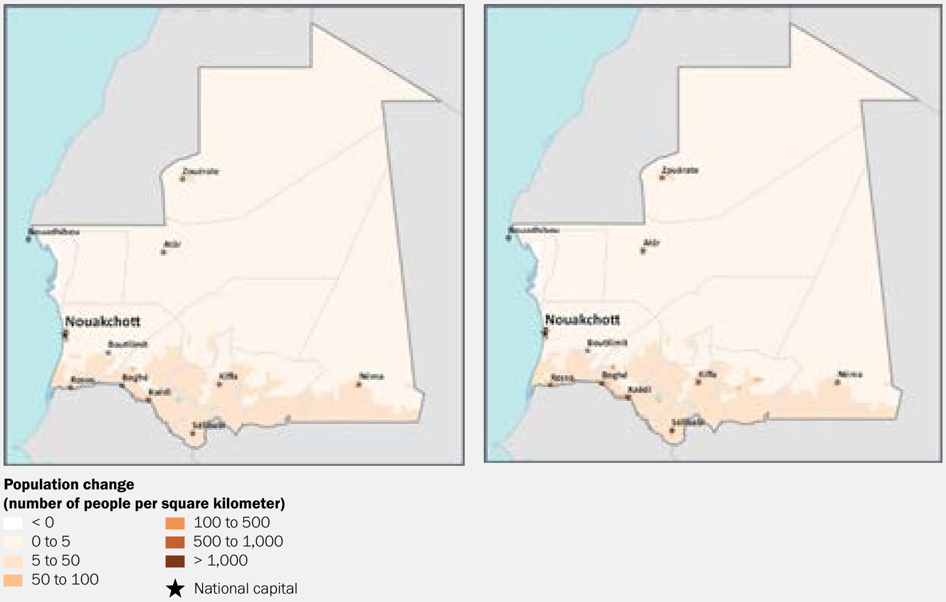
Figure 7.65, panels a–d, shows the projected change in population density under the four scenarios (2010–50). The major difference is in the higher population projections in secondary cities such as Selibaby, Kaedi, Aleg, and Kiffa under SSP4.

Figure 7.65 Projected Change in Population Density under the Four Scenarios, Mauritania, 2010–50



a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

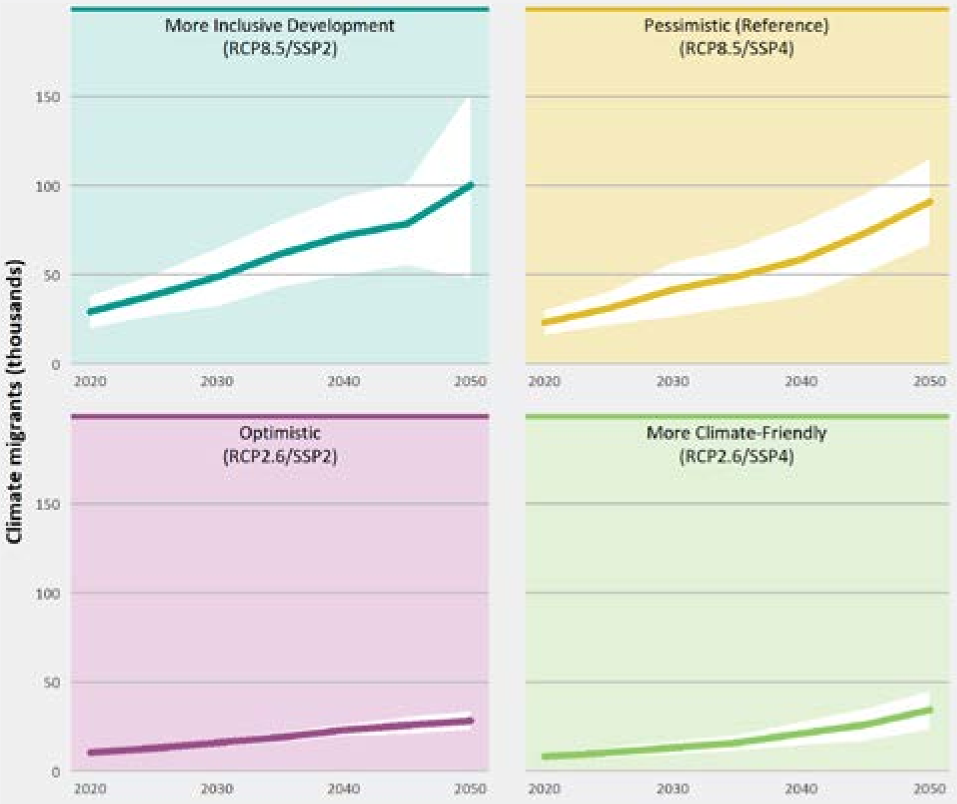
d. Climate-friendly (SSP4 and RCP2.6)

7.4.6 Climate Migration Futures and Trends

Scale and Trajectory of Internal Climate Migration

Given Mauritania's relatively small population, the levels of climate migration are significant under the high emission, more inclusive development and pessimistic scenarios (figure 7.67, panels a–d). Levels are higher under the former scenario, averaging around 100,000 migrants and reaching as high as 150,000. This represents 2.4 percent of the population at the high end. However, figure 7.68, panels a–d, shows that climate migration reaches nearly the same level as other migrants under the pessimistic scenario, mostly because of the very low levels of other internal migration under SSP4. The low emissions scenarios show climate migration is roughly half the levels of the high emissions scenarios. Table 7.14 shows projected total climate migrants by 2050 by scenario.

Figure 7.66 Projected Total Climate Migrants, Mauritania, 2020–50



Climate migrants as a percentage of the total population

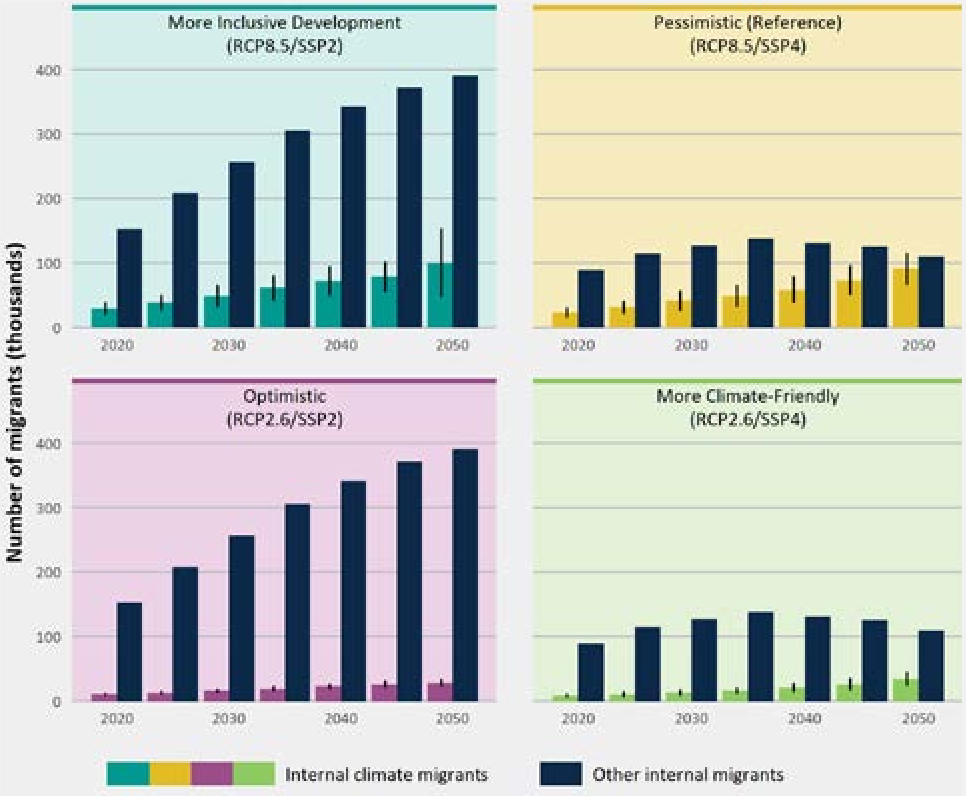
Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.69	0.97	1.26	1.6	0.54	0.79	0.94	1.27

Year	2020	2030	2040	2050	2020	2030	2040	2050
%	0.25	0.32	0.4	0.45	0.19	0.25	0.34	0.48

Table 7.14 Total Climate Migrants for Mauritania by 2050

	Scenario							
	Pessimistic (reference)		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	0.091		0.100		0.034		0.029	
Min. (left) and max. (right) (millions)	0.067	0.115	0.048	0.152	0.024	0.045	0.024	0.033
Internal climate migrants as % of pop.	1.27		1.6		0.48		0.45	
Min. (left) and max. (right) (%)	0.94	1.6	0.77	2.43	0.33	0.63	0.38	0.53

Figure 7.67 Estimates of Climate Compared to Other Internal Migrants, Mauritania, 2020–50



Internal Climate Migration Hotspots

Climate migration is driven by changes in water availability and NPP, and not so much by crop production (which is limited to the southernmost part of the country). The projections suggest that climate change impacts may encourage population growth above what it would otherwise be in the Assaba, Gorgol, and Brackna regions (south-central), with some growth to the west of Nema (in the far east) by 2050 (figure 7.69). Conversely, the low elevation zone north of Nouakchott is likely to experience climate out-migration because of flooding. The southwestern portion of the country, from the Senegal River Delta to Rosso and Podor, are likely to experience out-migration because of reduced water availability and crop production, as are selected areas further east in the Ghidimaka and Hodh El Gharbi regions. Figure 7.69, panels a and b, shows that the out-migration hotspots of the south start earlier and cover a larger territorial extent than the in-migration hotspots.

Figure 7.68 Projected Hotspots of Climate In- and Out-Migration, Mauritania, 2050

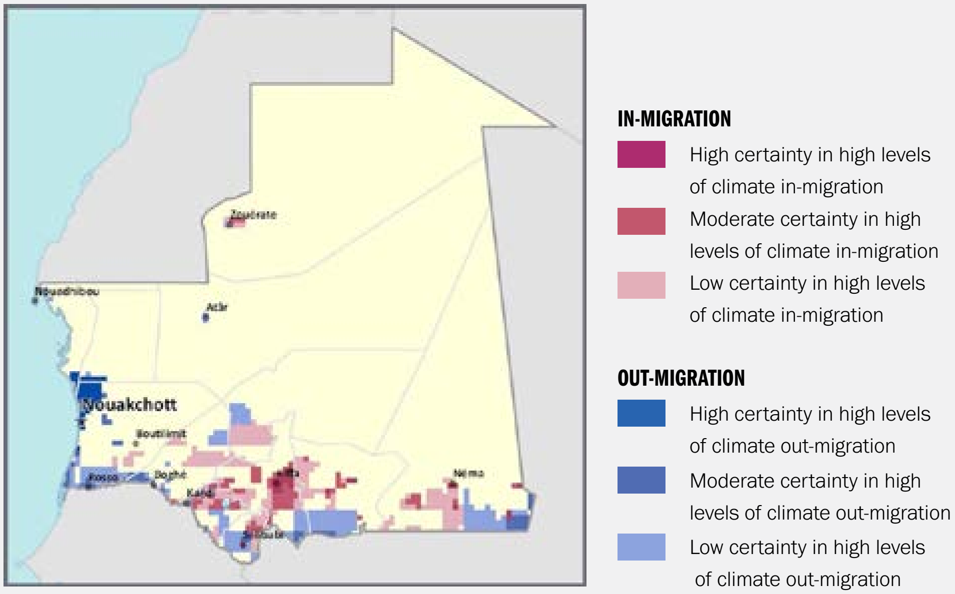
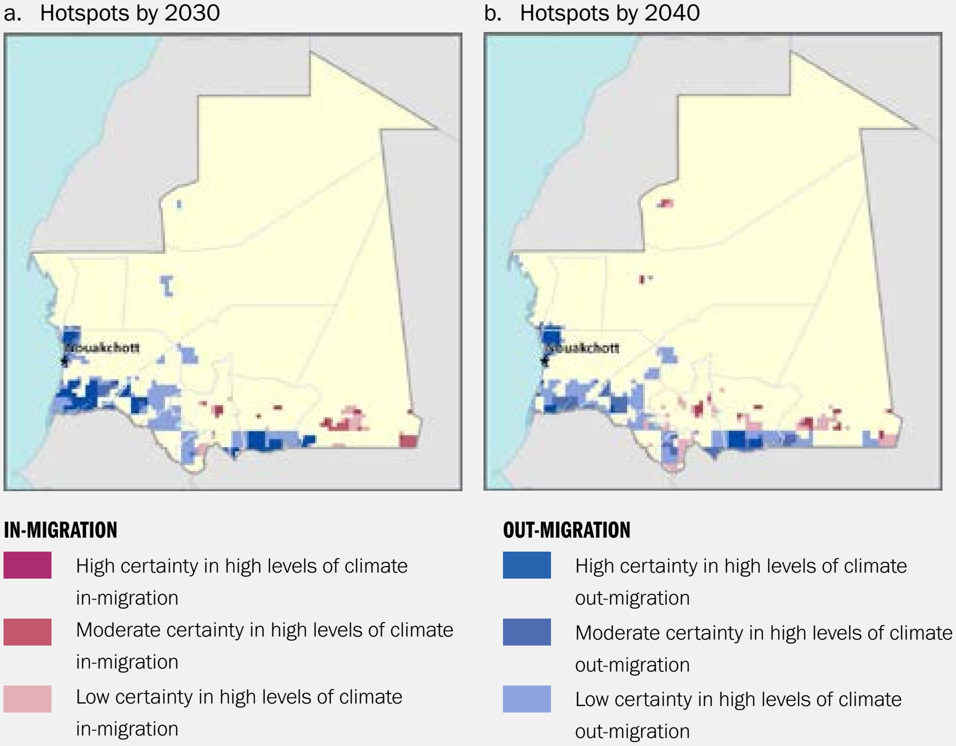


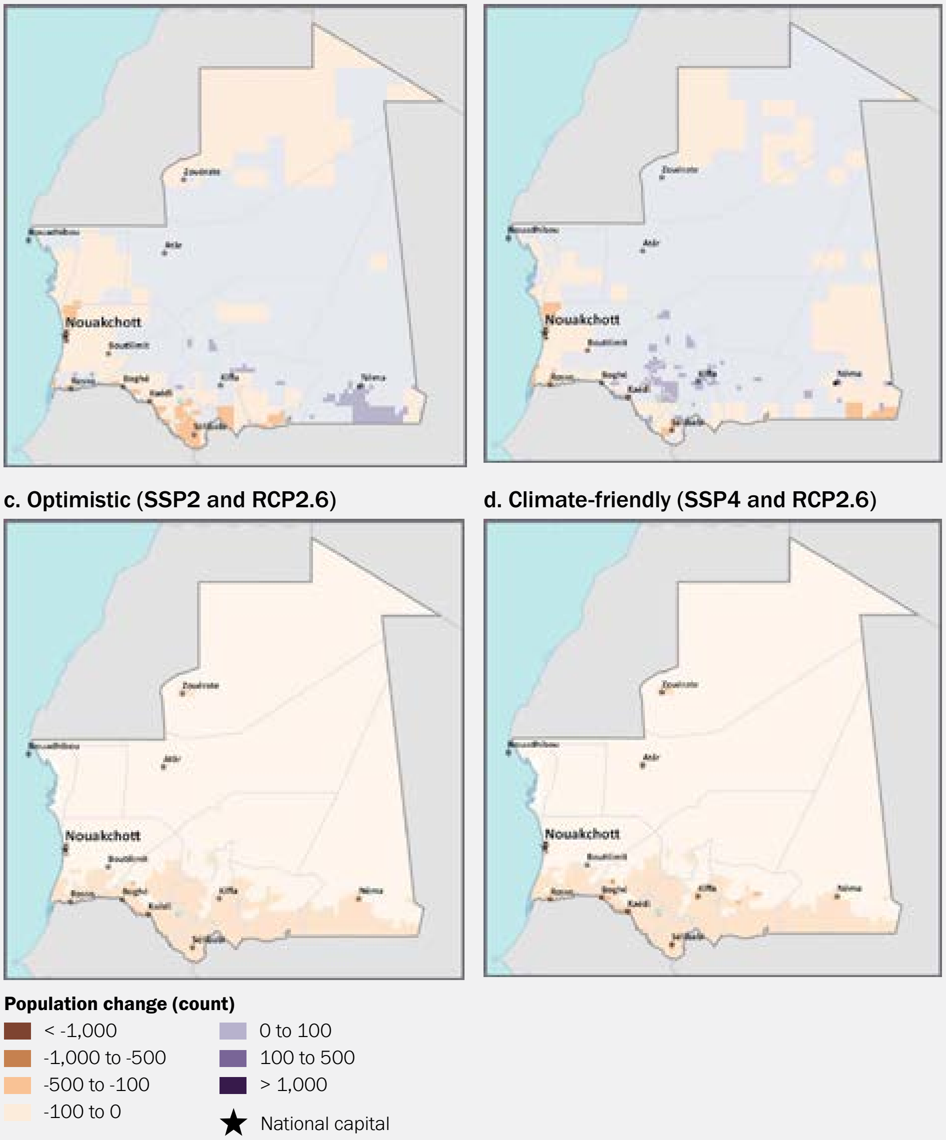
Figure 7.69 Projected Hotspots of Climate In- and Out-Migration, Mauritania, 2030 and 2040


a. Hotspots by 2030

b. Hotspots by 2040

Climate out-migration north of Nouakchott shows up under the high emission scenarios (top panels), as well as denser climate in migration in the regions of Brakna, Tagant, and Assaba (figure 7.71, panels a–d). Only the inclusive development scenario shows higher climate in-migration south of Nema.

Figure 7.70 Projected Population Change Because of Climate Migration, Mauritania, 2050


a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6)

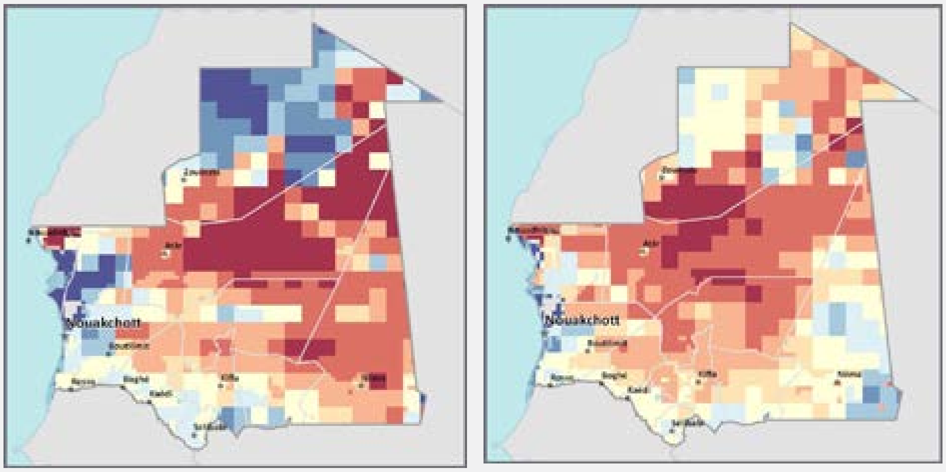
d. Climate-friendly (SSP4 and RCP2.6)

Note: Calculations based on per square kilometer under the pessimistic scenario.

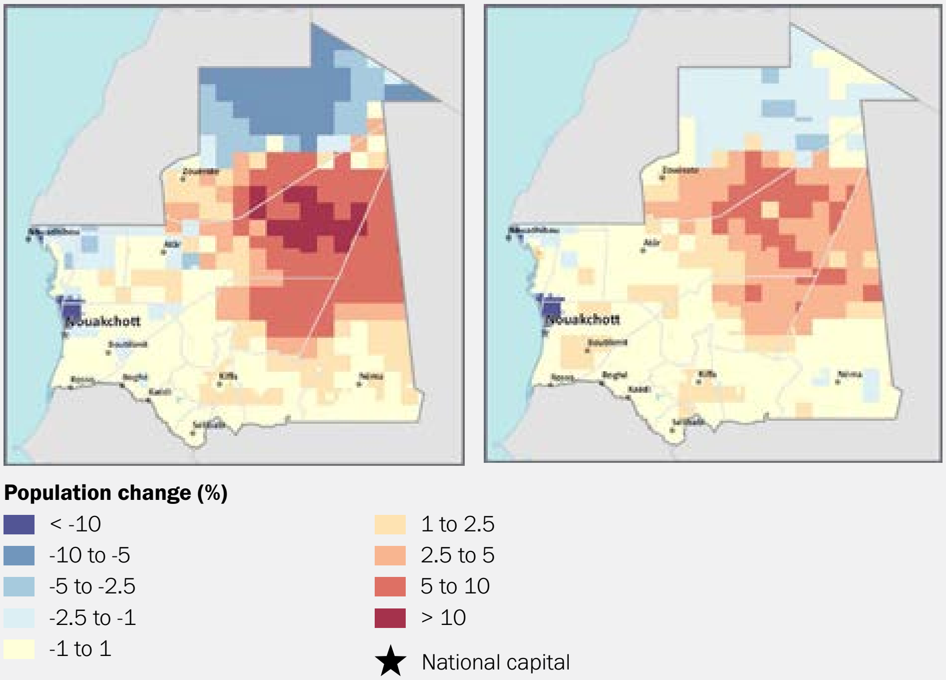
Percentage differences in population per square kilometer between the climate impacts and no climate impact (SSP-only) scenarios are shown in figure 7.72, panels a–d. The differences are extreme in many parts of Mauritania given the very low population densities that prevail over most of the territory, particularly in the far north. Favorable climate impacts on water and NPP result in high percentage increases in the arid interior, particularly under the high emission (RCP8.5) scenarios.

Figure 7.71 Projected Percentage of Difference in Population Change Due to Climate Migration, in Percentage of Population in No Climate Scenario, Mauritania, 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)



Note: Calculations based on per square kilometer.

Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

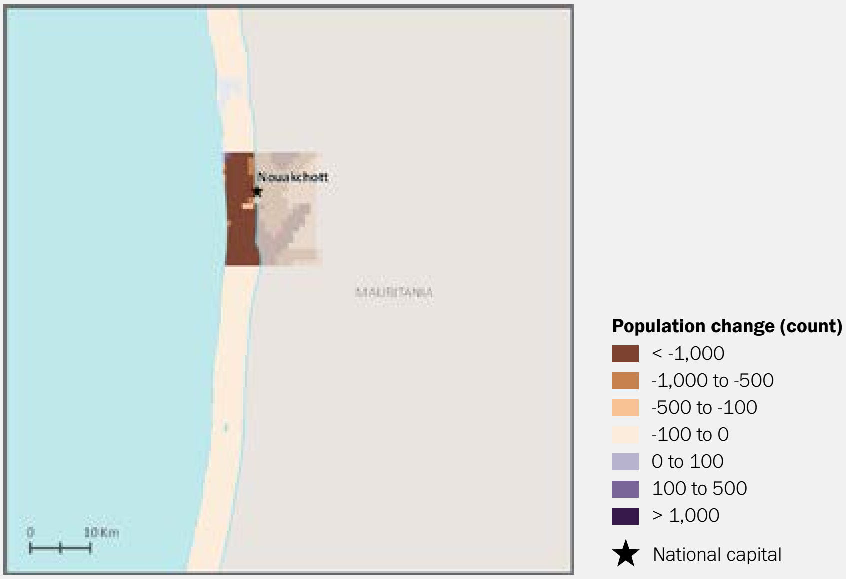
Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, we processed the coastal climate migration with the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level. See figure 7.73, panels a–d.

For one of the demographically smallest countries in West Africa (after Cabo Verde, Guinea-Bissau, and The Gambia), Mauritania could see a relatively large level of climate migration out of the coastal zone: up to 300,000 climate out-migrants under the pessimistic scenario. The main impacted area is the flood plain surrounding and to the north of Nouakchott, the capital. However, under the low emissions scenarios, the level of climate out-migration is between 50,000 and 60,000. See figure 7.73.

Figure 7.72 Projected Coastal Climate Net Migration, Mauritania, 2020–50

Figure 7.73 Projected Population Change Due to Climate Migration, Coastal Zone of Mauritania, 2050



Note: Calculations based on per square kilometer.

Climate Migration by Livelihood Zone

By 2050, dense settlements will not grow as quickly as they otherwise would have because of climate impacts, leading to out-migration, driven mostly by impacts in the Nouakchott area (Figure 7.75, table 7.15). Conversely, pastoral and rangelands areas are likely to grow more than they would otherwise because of climate in-migration. The signal across rainfed croplands is mixed, with the high emissions scenarios showing out-migration and the low emissions scenarios showing modest in-migration.

Figure 7.74 Livelihood Zones Map, Mauritania

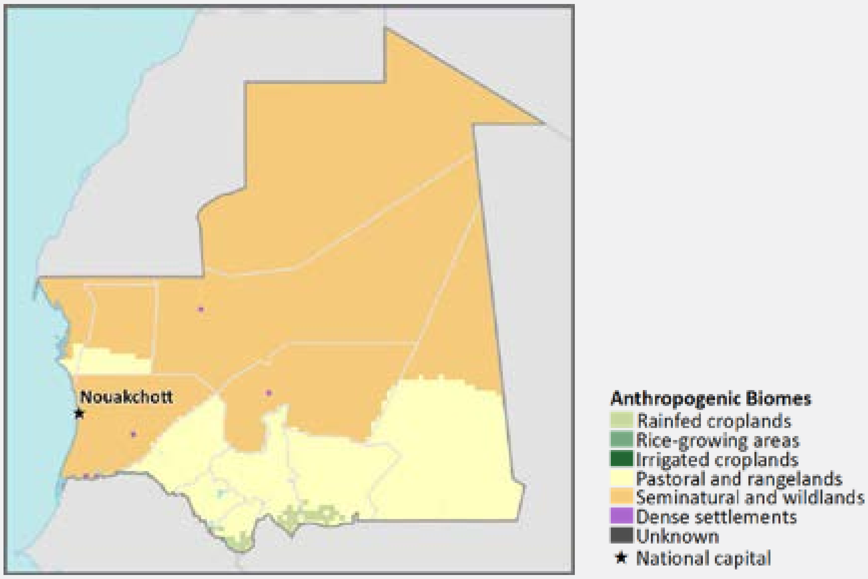


Table 7.15 Projected Net Climate Migration by Scenario, Livelihood Zone, and Decade, Mauritania, 2030, 2040, 2050 (number of people)

Year and livelihood zone	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
2030				
Dense settlements	−3,957	−3,559	−2,230	−6,121
Irrigated croplands	8	40	−2	43
Pastoral and rangelands	6,260	3,385	5,311	7,568
Rainfed croplands	−69	−2,137	−356	−1,312
Rice-growing areas	0	31	−5	25
Seminatural and wildlands	−2,286	1,884	−2,732	−856
Unknown	43	356	14	653
2040				
Dense settlements	−9,046	−6,392	−4,767	−11,873
Irrigated croplands	20	94	−12	60
Pastoral and rangelands	11,104	8,466	7,181	10,224
Rainfed croplands	498.30	−2,027	−399	−2,779
Rice-growing areas	16.94	57	−10	−8
Seminatural and wildlands	−2,659.17	−985	−2,006	2,847
Unknown	65.76	787	13	1,529
2050				
Dense settlements	−15,625	−12,432	−7,483	−25,747
Irrigated croplands	45	-61	-0.46	102
Pastoral and rangelands	16,441	17,578	10,775	27,178
Rainfed croplands	958.05	−4,854	−121	−1,308
Rice-growing areas	26.34	−118	-5	−34
Seminatural and wildlands	−2,012.12	−1,195	−3,212	−2,450
Unknown	167.13	1,083	47	2,260

Climate Migration by Region

Climate migration by region is mixed, with Nouakchott showing high levels of out-migration, driven by declining water availability and sea level rise impacts, followed by the wilaya (region) of Trarza, which surrounds Nouakchott and extends to Mauritania's southwest (driven by the same factors). The only wilayas with relatively consistent in-migration across scenarios include Asaba and Tagant, which are projected to get wetter. Flood risk mostly draws migrants toward Nouakchott owing to the calibration process. With nonclimatic variables, median age does not vary within the country because of a lack of subnational data on age distribution. The sex ratio is high in the northwest corner of Mauritania in the wilayas of Dakhlet-Noudhibou and Inchiri, most likely because of a high concentration of mining and oil and gas extraction industries. But this does not appear to be affecting in-migration, since these wilayas are projected to see declines in water availability.

Figure 7.75 Projected Net Climate Migration by Province and Scenario for Mauritania, 2050

Table 7.16 Projected Net Climate Migration by Scenario and Province, Mauritania, 2050

Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Adrar	1,160	6,671	1,893	6,232
Assaba	5,232	-686	3,353	11,895
Brakna	1,796	3,394	–723	8,311
Dakhlet Nouadhibou	–1,593	1,449	–1,093	3,899
Gorgol	4,000	–6,342	1,644	1,806
Guidimagha	3,113	–5,592	751	–480
Hodh Chargui	1,020	22,585	4,732	–584
Hodh El Gharbi	3,112	1,610	2,504	5,612
Inchiri	–265	–2,564	–621	677
Nouakchott	–14,199	–12,806	–6,693	–26,977
Tagant	674	5,955	1,218	9,206
Tiris Zemmour	1,609	–642	206	1,007
Trarza	–5,660	–13,032	–7,172	–20,604

7.5 SÃO TOMÉ AND PRÍNCIPE

7.5.1 Population and Development Context

The archipelago of São Tomé and Príncipe is made up of two islands and four islets of the western coast of Africa in the Gulf of Guinea. The island nation has a population of 200,000, which is expected to grow to around 300,000 by 2050 (PRB 2018), though the SSP scenarios suggest even more modest growth to just over 200,000 by 2050 (table 7.17). See reference and population density maps in figure 7.76, panels a and b, respectively. See figure 7.78 for elevation map and low elevation coastal zone, panels a and b, respectively.

Figure 7.76 Reference and Population Density Maps, São Tomé and Príncipe, 2010

a. Population density

b. Reference

Table 7.17 Development Statistics, São Tomé and Príncipe

Population	
Population (thousands)	211
Annual population growth (%)	1.9
Population in 2050 under SSP2 (thousands)	211.2
Population in 2050 under SSP4 (thousands)	239.7
Urban share of population (%)	72.8
Employment in agriculture (% of total employment) (2019)	23.4
GDP	
GDP (current US$ billions)	0.4
Annual GDP growth (%)	2.7
GDP per capita (current US$)	2001.1
Value added of agriculture (% GDP)	11.4
Poverty	
Poverty headcount ratio at US$1.90 a day (2011 PPP) (% of population) (2010)	32.3
Climate and disaster risk indexes	
ND GAIN Index (2017)	
Rank	116
Score	42.4

Source: WDI database;[80] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better

Note: All figures are for 2018 except where otherwise indicated. GDP = gross domestic product; ND GAIN = Notre Dame Global Adaptation Index; SSP = Shared Socioeconomic Pathway.

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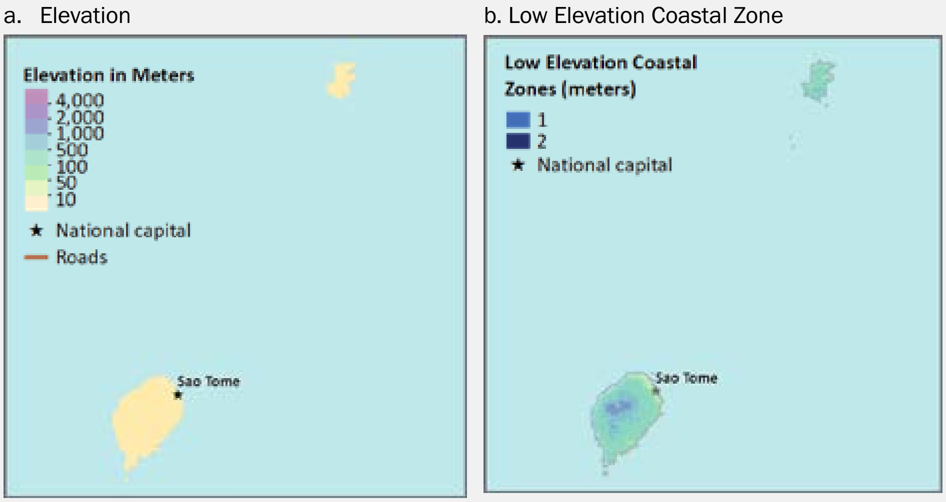
[80] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

7.5.2 Historical and Current Migration Patterns

Internal Migration

The net rate of international migration is around minus 5 persons per 1,000 per year (PRB 2018). Figure 7.78 shows that this level of net out-migration has remained relatively constant since the early 1990s. There is little research on migration patterns within the country, except that mobility rates are presumed to be low given the small territory (roughly 1,000 square kilometers).

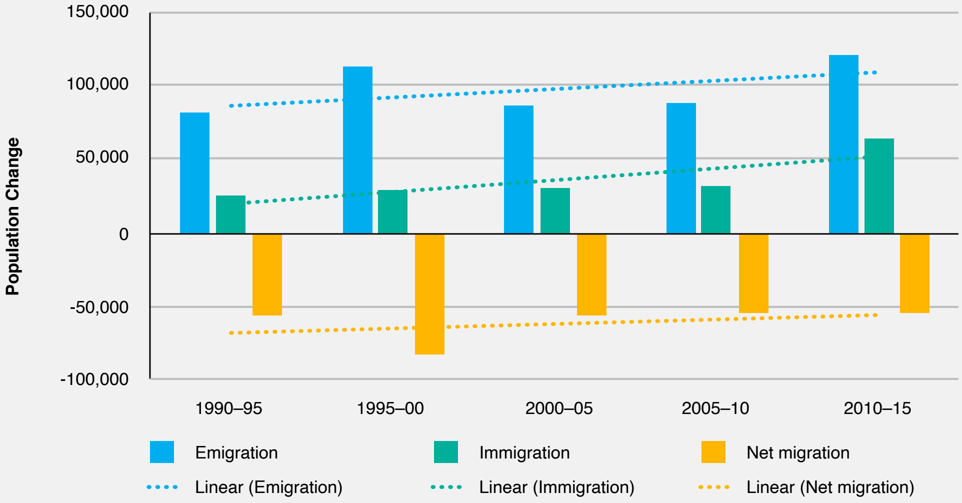
Figure 7.77 Elevation and Low Elevation Coastal Zone Maps, São Tomé and Príncipe, 2010



a. Elevation

b. Low Elevation Coastal Zone

Figure 7.78 International Migration Trends, São Tomé and Príncipe, 1990–2015



7.5.3 Climate Trends and Projections

São Tomé and Príncipe's humid tropical climate provides the islands with abundant rain throughout the year, except for a decrease in temperature and precipitation from June through August. This drier, cooler period coincides with the northward movement of the ITCZ. Average annual rainfall is around 900 millimeters per year, with variation among regions; and mean temperature ranges from 22°C to 26°C.[81]

While water is one of the archipelago's most important resources, extreme weather events and flooding threaten the island's social, agricultural, and economic well-being, particularly along the coast (World Bank 2019c). The trend, however, has been toward increased temperatures and decreased precipitation. Temperatures have risen by about 1.5°C from 1951 and 2010, with more rapid temperature increase in Príncipe than in São Tomé. Average annual precipitation has decreased in that same period at a rate of around 1.7 millimeters less rainfall per year. The dry season has been prolonged, which is likely to continue (World Bank 2019c).

In São Tomé and Príncipe, the ISIMIP climate impact models are too coarse to provide results for subregions. The results do not suggest major shifts. Panels in figures 7.79 and 7.80 show the average projected changes in water availability and NPP for the 2010–50 time period, respectively. The crop models do not include São Tomé and Príncipe, and of the two ecosystem models, only LPjML models future NPP. The coefficient for water availability in rural areas is around 2.75 times higher than that of either crops or NPP. It is the only climate factor other than flood risk and sea level rise influencing future urban population distribution, meaning it has a far greater influence on future population distribution than most other climate variables. Given the small size of the country, the islands fit within one or more grid cells with identical values that show slight increases in water availability and NPP. Therefore, these variables have little impact on São Tomé and Príncipe's future population distribution, and only sea level rise has a significant effect.

In São Tomé and Príncipe, future sea level rise will have a strong impact on communities which are located a few meters above sea level, as will flash floods from neighboring rivers.

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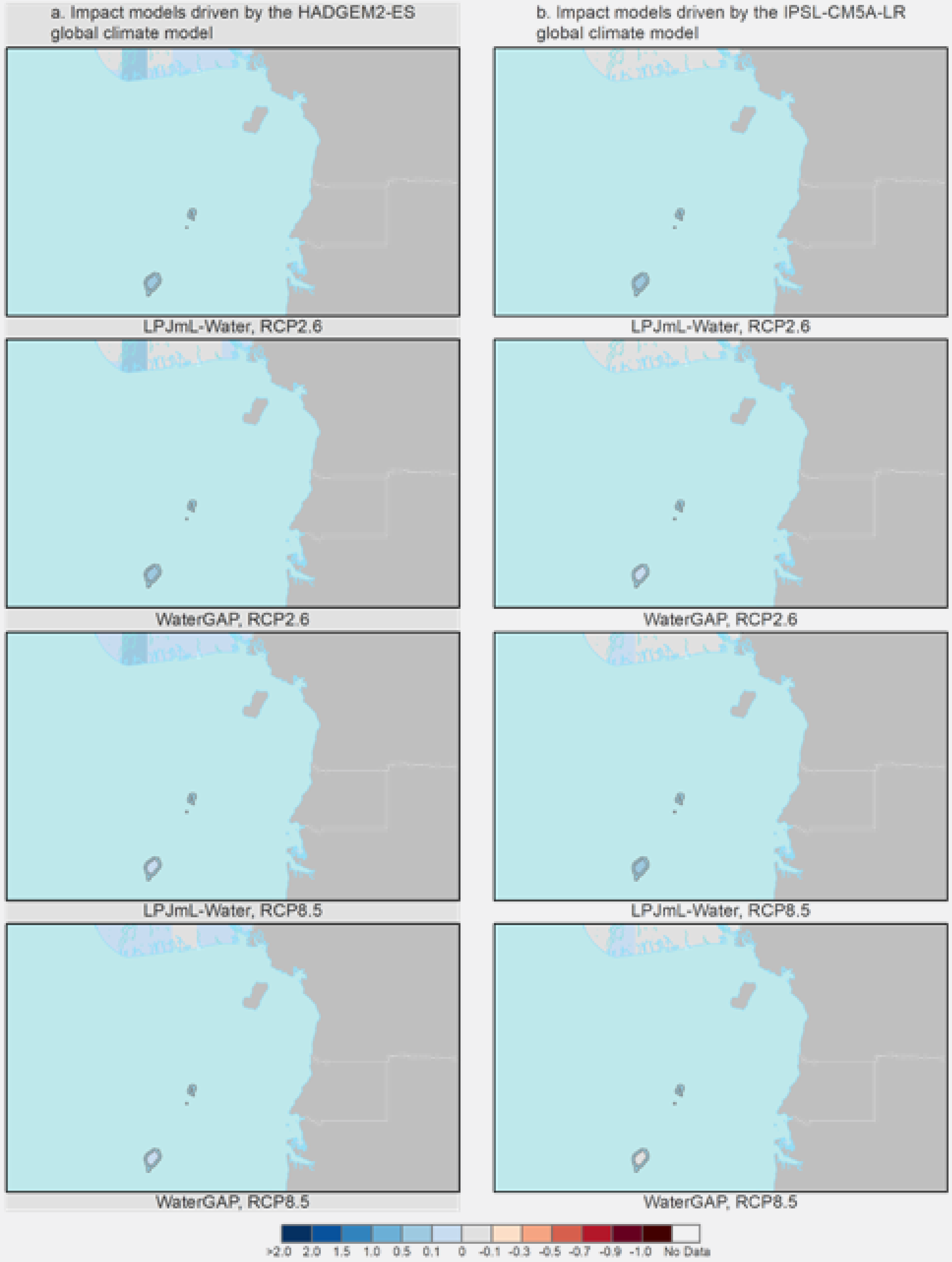
[81] See World Bank, Climate Change Knowledge Portal, Climate Data—São Tomé and Príncipe, at https://climateknowledgeportal.worldbank.org/country/sao-tome-and-principe.

Figure 7.79 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, São Tomé and Príncipe, 2010–50



Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.80 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, São Tomé and Príncipe, 2010–50

Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is used to gap-fill crop production, and therefore is not used to model future population distribution. NPP = net primary productivity.

7.5.4 Coastal Trends

There are relatively few studies of coastal processes in São Tomé and Príncipe. Giardino et al. (2011) studied Ribeira Afonso and Santa Catarina, on the east and west of the main island, respectively. They find that the main issue for both communities appears to be river flooding followed by flooding from the sea, and in Santa Catarina, also coastal erosion. Future sea level rise will have a strong impact on these communities, which are located a few meters above sea level, as will flash floods from neighboring rivers.

7.5.5 Projected Changes in Population Distribution

Projected population to 2050 under the four scenarios does not vary significantly except for modest differences on the western side of São Tomé island (figure 7.82, panels a–d). Most of the change in population density is projected to be in the capital, São Tomé. Again, variations across the scenarios are small. See also figure 7.83, panels a–d.

Figure 7.81 Projected Population under the Four Scenarios, São Tomé and Príncipe, by 2050

a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6)

d. Climate-friendly (SSP4 and RCP2.6)

Figure 7.82 Projected Change in Population Density under the Four Scenarios, São Tomé and Príncipe, 2010–50

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)

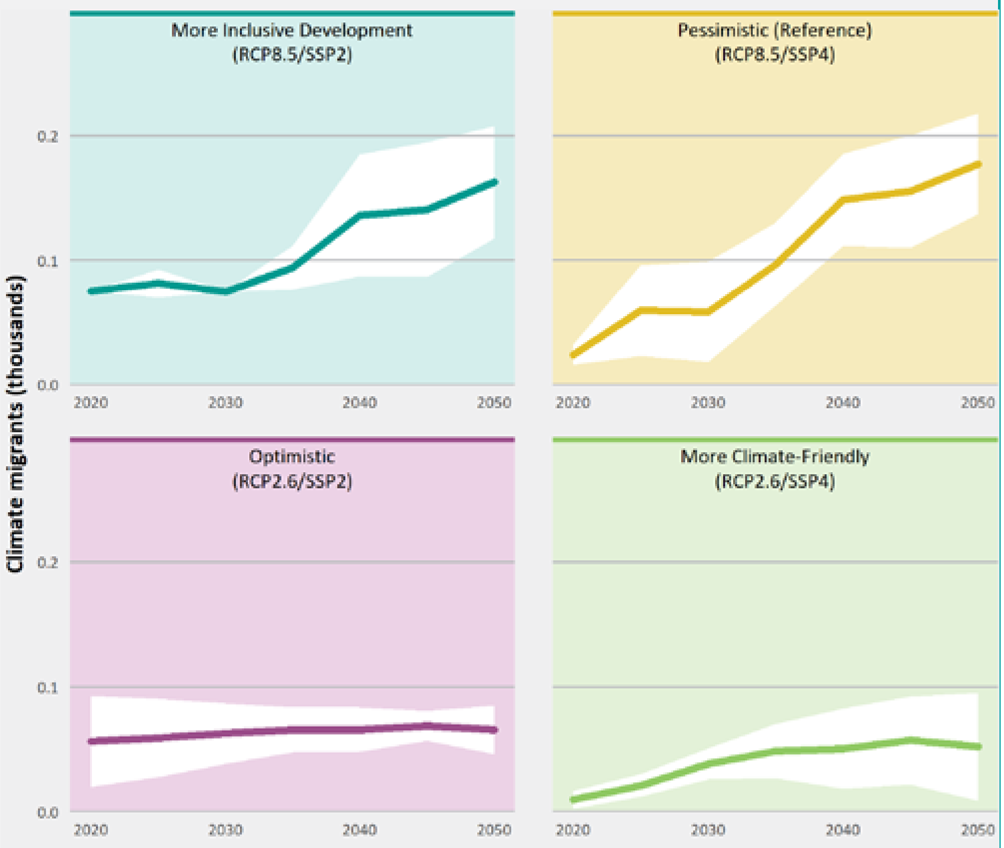
c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

7.5.6 Internal Climate Migration Scale and Trends

Scale and Trajectory of Internal Climate Migration

There is a spatial mismatch between the scale of this modeling effort and a country the size of São Tomé and Príncipe, so results need to be treated with caution. Unlike the other countries in the region, results were not aggregated to 15-kilometer resolution but were analyzed at their native 1-kilometer resolution. Therefore, numbers are not directly comparable with other country results. Climate migration levels are about a few hundred migrants, depending on the scenario, with high variability. As with those of other countries, numbers tend to be highest (up to 200 migrants by 2050) under the pessimistic scenario (figure 7.84, panels a–d). They are a tiny fraction of the other (development) internal migration (figure 7.85, panels a–d). Table 7.18 shows total climate migrants by scenario by 2050.

Figure 7.83 Projected Total Climate Migrants, São Tomé and Príncipe, 2020–50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050
%	0.04	0.04	0.07	0.08

2020	2030	2040	2050
0.01	0.03	0.07	0.07

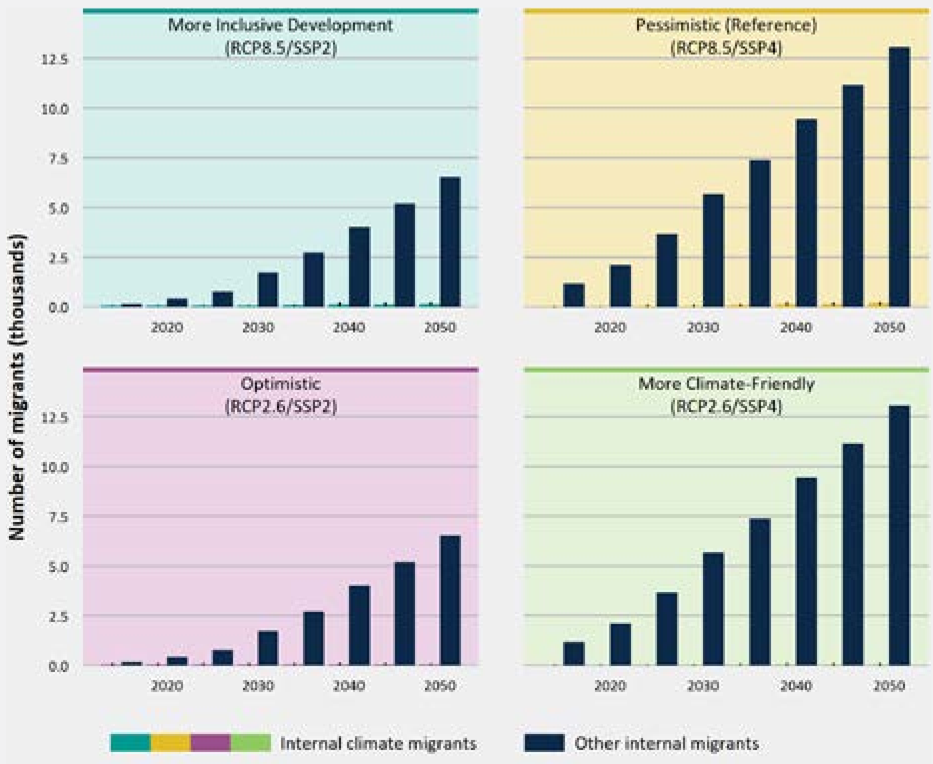
Year	2020	2030	2040	2050
%	0.03	0.03	0.03	0.03

2020	2030	2040	2050
0.01	0.02	0.02	0.02

Table 7.18 Projected Total Climate Migrants for São Tomé and Príncipe by 2050

	Scenario							
	Pessimistic reference		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	177		162		52		65	
Min. (left) and max. (right) (millions)	137	218	118	208	9	95	46	85
Internal climate migrants as % of pop.	0.07		0.08		0.02		0.03	
Min. (left) and max. (right) (%)	0.06	0.09	0.06	0.1	0	0.04	0.02	0.04

Figure 7.84 Estimates of Climate Compared to Other Internal Migrants, São Tomé and Príncipe, 2020–50



Internal Climate Migration Hotspots

Migration modeling results need to be treated with caution for a country this size. The hotspots map shows some climate in-migration around the capital of São Tomé, and some climate out-migration on the southern side of the island of Príncipe by 2050 (figure 7.86).

Figure 7.85 Projected Hotspots of Climate In- and Out-Migration, São Tomé and Príncipe, 2050

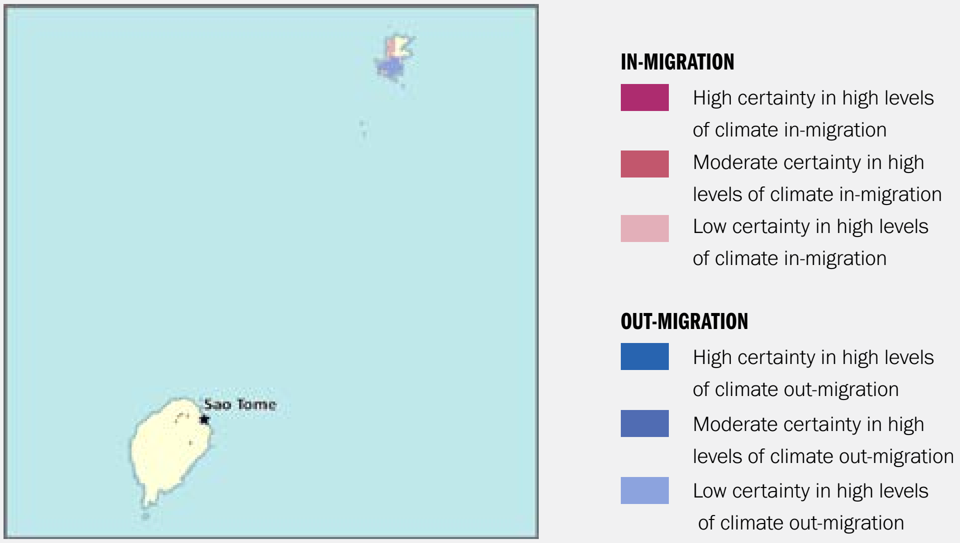
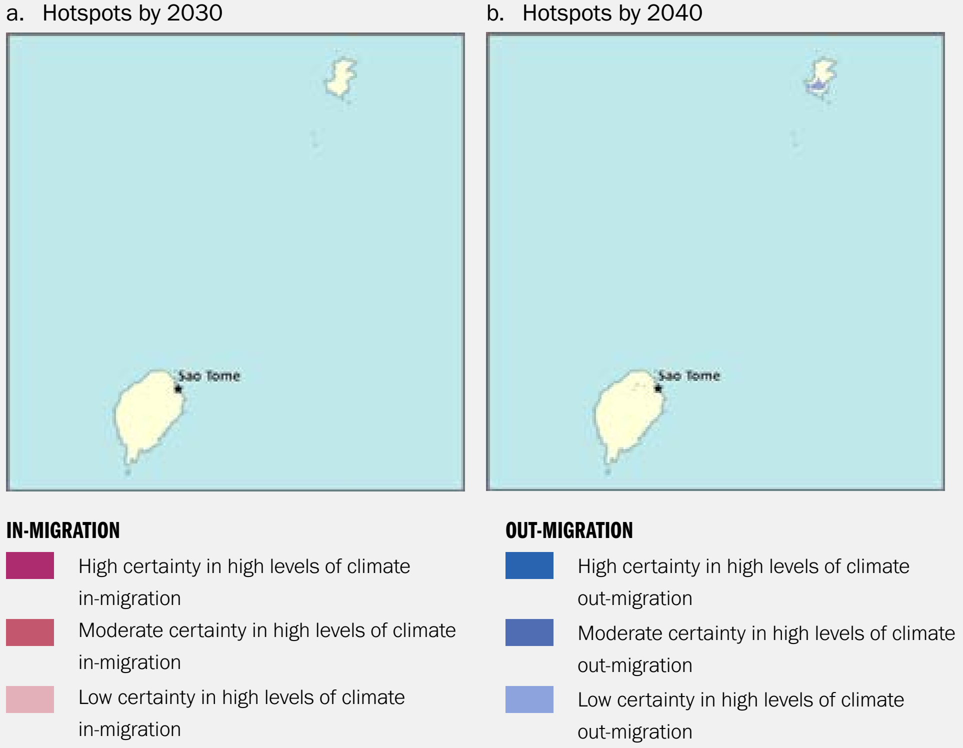


Figure 7.86 Projected Hotspots of Climate In- and Out-Migration, São Tomé and Príncipe, 2030 and 2040

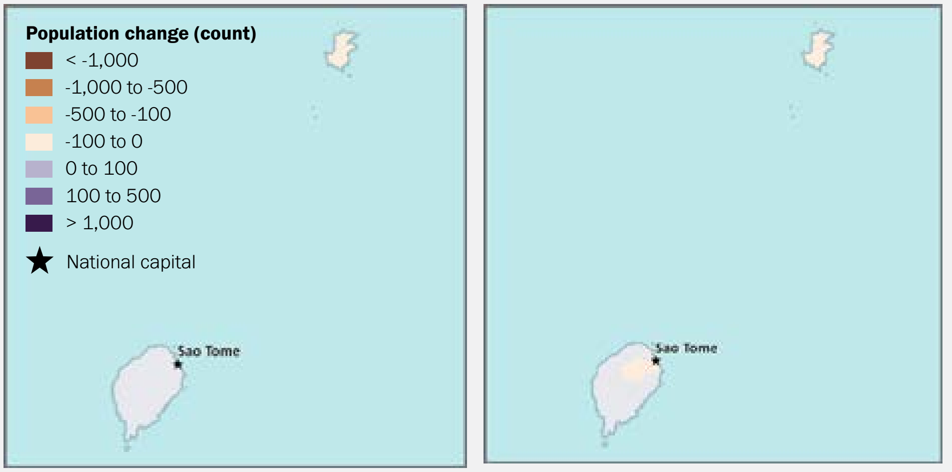


a. Hotspots by 2030

b. Hotspots by 2040

Population differences between the climate impacts and the no climate impacts scenarios (figure 7.88, panels a–d) suggest slight increases in population on São Tomé Island, generally under 100 persons per square kilometer. The figure on the percentage difference between the climate impact scenarios and the respective no climate impact (SSP-only) scenario is not included because there are no noticeable patterns at this scale.

Figure 7.87 Projected Absolute Difference Between Climate Impact Scenarios and Respective No Climate Impact (SSP-Only) Scenario, São Tomé and Príncipe, 2050


a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

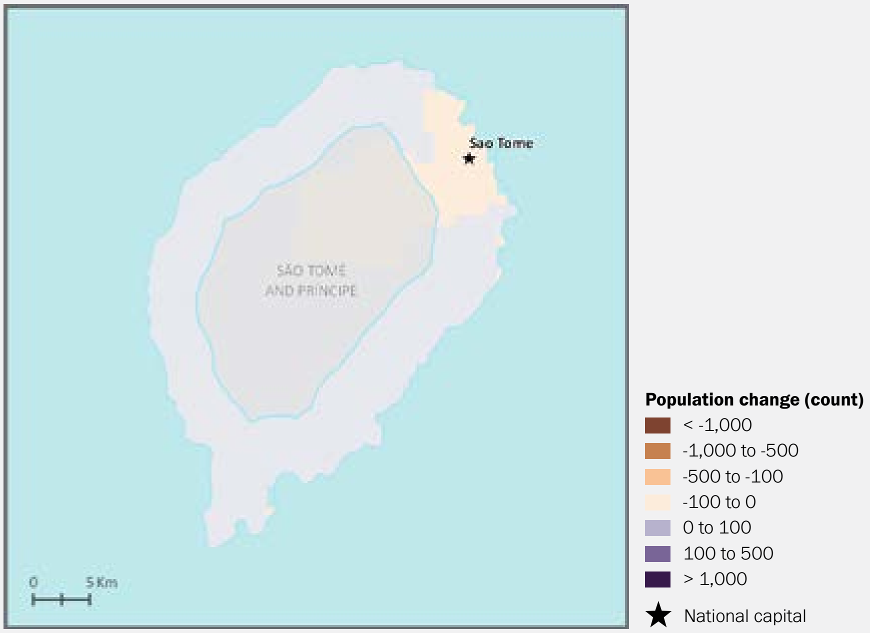
Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, we processed coastal climate migration with the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level.

Given the small size of the country, much of the population resides in the coastal areas. Sea level rise impacts are not expected to affect population distribution within the 5-kilometer coastal buffer (figure 7.89) because the volcanic origins of the islands mean the coastline rises sharply from the shore, and there are few other places for the population to retreat. The modeling work suggests that at most net out-migration will be about 0 to 50 people, but there is a scale mismatch between the modeling work and the size of the islands.

Figure 7.88 Projected Population Change Because of Climate Migration for Coastal Zone of São Tomé and Príncipe, 2050



Note: Calculations based on per square kilometer under the pessimistic scenario.

Climate Migration by Province

Under the high climate impacts scenarios (pessimistic and more inclusive development), there is a slightly higher negative out-migration from Príncipe but at very low levels (table 7.19).

Table 7.19 Projected Net Climate Migration by Scenario and Province, São Tomé and Príncipe, 2050 (number of people)

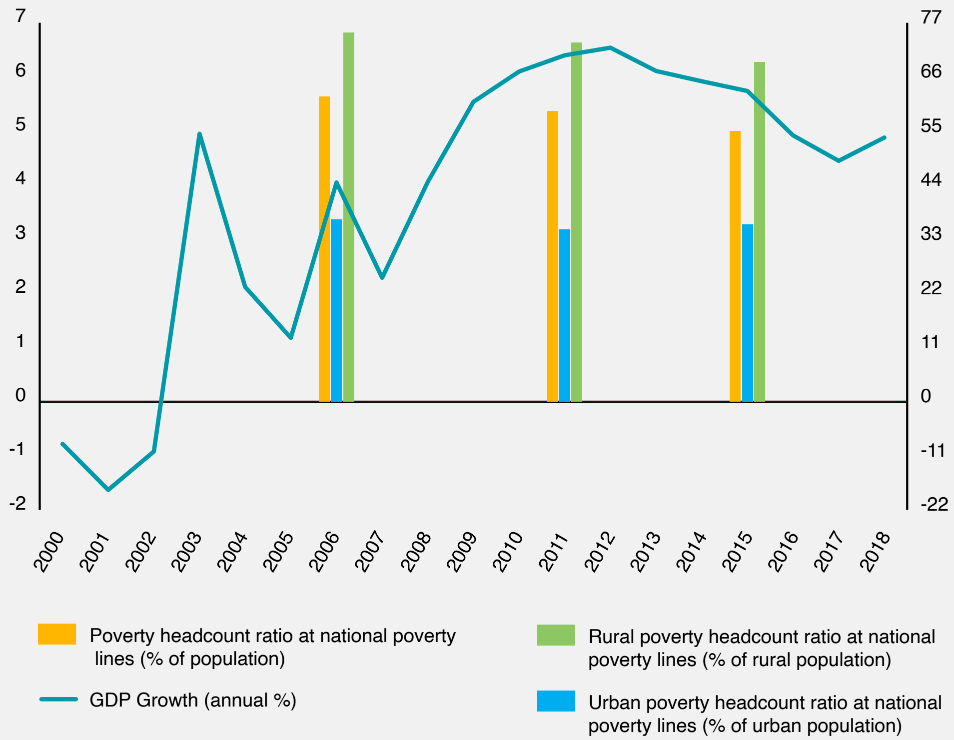
Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Príncipe	36	–49	33	–82
São Tomé	–37	198	78	81

7.6 TOGO

7.6.1 Population and Development Context

Classified by the World Bank as a low-income economy, Togo has experienced fluctuations in its economic growth in the last decade, with a decline in GDP growth since 2012 after steady increase between 2007 and 2012 (figure 7.89). In 2018, the primary sector (including agriculture and fisheries) showed a better performance than the industrial and tertiary sectors, which were more affected by the 2017 political crisis (AfDB 2019a). Informality remains high in all economic sectors, representing about 40 percent of the GDP (Medina et al. 2017).

Figure 7.89 Socioeconomic Trends, Togo, 1990–2018



Source: WDI database.[82]

Similar to Benin, Togo is a trading hub for both formal and informal international operations, and Nigeria is the most important market. However, it is in a less favorable trading position because of its location (unlike Benin, Togo does not share a border with Nigeria) (Golub 2012).

Poverty levels[83] have remained high despite a declining trend between 2006 and 2016 (figure 7.89 and table 7.20). The poverty gap between urban and rural areas remains high, and inequality has increased in both areas (Ametoglo and Guo Ping 2016). Moreover, poverty is higher among female-headed households, most likely because women have fewer economic opportunities and little representation in decision-making at high levels.[84] Female-headed households represented 27 percent of all Togo's households in 2014.[85]

Togo's northwestern corner and the south-central region could see climate in-migration while the low-lying coastal areas, including Lomé, could see climate out-migration due to sea level rise.

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82. See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators
83. Poverty measured as poverty headcount ratio at national poverty line (percentage of population).
84. See the World Bank in Togo at https://www.worldbank.org/en/country/togo/overview.
85. See World Development Indicators, Togo Profile, at https://data.worldbank.org/country/togo.

Table 7.20 Development Indicators, Togo

Population	
Population (millions)	7.9
Annual population growth (%)	2.4
Population in 2050 under SSP2 (millions)	10.3
Population in 2050 under SSP4 (millions)	11.1
Urban share of population (%)	41.7
Employment in agriculture (% of total employment) (2019)	34.1
GDP	
GDP (current US$ billions)	5.4
Annual GDP growth (%)	4.9
GDP per capita (current US$)	679.3
Value added of agriculture (% GDP)	23.4
Poverty	
Poverty headcount ratio at US$1.90 a day (2011 PPP) (% of population) (2015)	49.2
Climate and disaster risk indexes	
ND GAIN Index (2017)	
Rank	145
Score	37.9

Source: WDI database;[86] ND-GAIN Country Index 2018

Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better

Note: All figures are for 2018 except where otherwise indicated. GDP = gross domestic product; ND GAIN = Notre Dame Global Adaptation Index; SSP = Shared Socioeconomic Pathway.

Togo's population reached 7.8 million in 2017, and—as Africa as a whole—its 2017 annual growth rate was 2.5 percent. At this rate, population would double by 2045. However, future population size to 2050 depends on the scenario under consideration: 13.2 million under SSP2 and 14.3 million under SSP4. This is because population growth is slowing in Togo, and annual rates are projected to decline to 1.75 percent by 2045–50, and to 0.64 percent by 2095–2100 (UN DESA 2019).

Togo's population is quite young, with a median age of 18.8 years in 2015. As growth rates decline and life expectancy increases (it is projected to rise from 60.53 years today to 67.41 by mid-century), the population will start to grow older, with median ages of 24.4 in 2050 and 33.7 in 2100. The sex ratio (males per 1,000 females) was 98.8 in 2015, close to the African ratio of 99.7 (IADD 2019e; UN DESA 2019).

Population distribution is unequal, with clusters of higher density in the southern coastal area (where the capital, Lomé, is located), east-central, and northwest (figure 7.91, panels a and b). Large intracountry disparities in population growth (likely linked to internal migration) could explain this distribution pattern (IADD 2019e). The country's proportion of urban population was 41 percent in 2017, and Togo will be well over the urban transition by 2050, when the proportion urban is expected to be 60.6 percent. The most populous city is Lomé, with about 1.6 million inhabitants in 2015 (20 percent of Togo's total population), which is projected to reach 2.5 million by 2030.[87]

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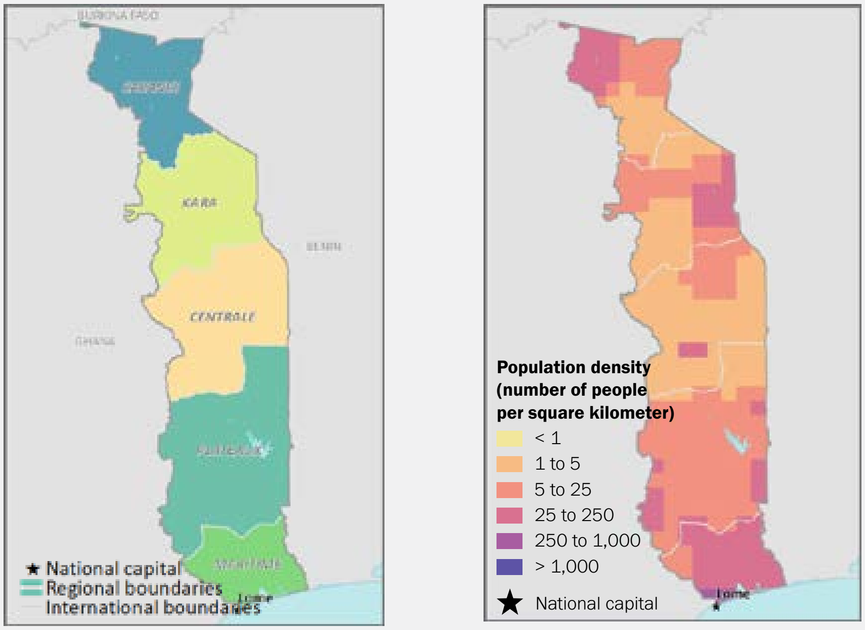
[86] See the World Bank Development Indicators (WDI) database, https://datacatalog.worldbank.org/dataset/world-development-indicators

[87] See the UN DESA (United Nations Department of Economic and Social Affairs), Population Division, World Urbanization Prospects 2018 at https://population.un.org/wup.

Figure 7.90 Reference and Population Density Maps, Togo, 2010



a. Districts

b. Population density

7.6.2 Historical and Current Migration Patterns

Internal migration

Togo has intense internal migration, in which internal migrants represented 18 percent of the population in 2010. Flows include rural-rural, rural-urban, and interregional moves, and migration to urban areas is the main driver behind urbanization. Main areas of origin include the administrative regions of Plateaux, Kara, and Savanes. The administrative region Centrale, the regional capitals (Aného, Kpalimé, Atakpamé, Sokodé, Kara, and Dapaong), and the commune of Lomé are the main destinations. About 52 percent of all internal migrants reside in the Lomé agglomeration (IADD 2019e; Segniagbeto and Kossi 2015). The composition of the flows shows a large proportion of women (sex ratio of the internal migration population was 90.2 in 2010) and young adults (42 percent of all internal migrants were 24 years old or younger in 2010) (IADD 2019e).

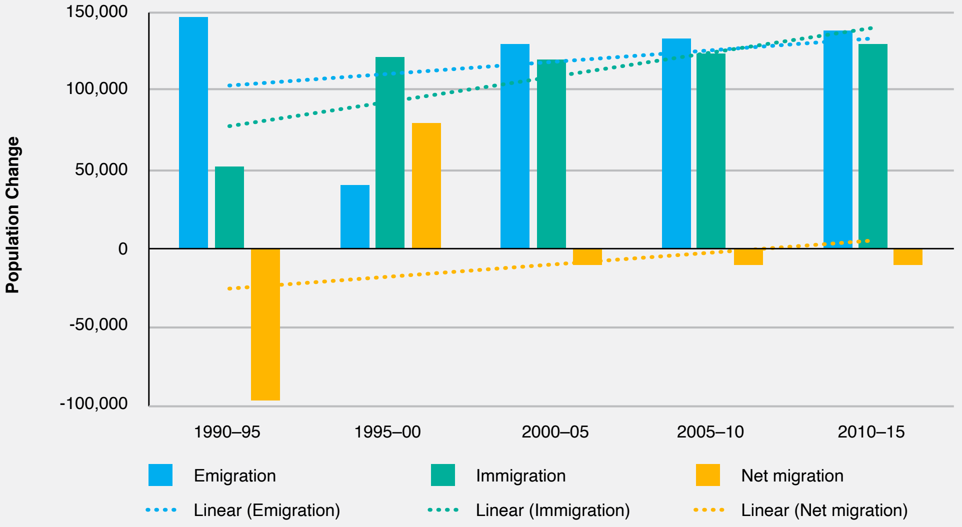
Agricultural policies in Togo aim to improve living conditions, reduce poverty, and create job opportunities for rural populations by 2030. They could help to reduce internal migration. However, these objectives could be disrupted because of the impacts of climate change on the primary sector (IADD 2019e), and this would result in a continuation and even intensification of internal migration.

International migration

These trends are displayed in figure 7.91. After an erratic trend in the 1990s (reflecting emigration due to the political crisis and then the return migration of exiles), emigration and immigration have grown at a similar pace since 2000, with net migration showing a small negative balance in the 2010–15 period. Main destinations of Togolese emigrants have consistently been the neighboring countries of Ghana and Benin, as well as other West African countries, such as Nigeria, Niger, and Côte d’Ivoire. Beyond countries in Africa, France is the main international destination. Remittances from international migrants represented 8.5 percent of Togo’s GDP in 2018.

Immigrants to Togo represented 5.6 percent of the country population in 2010. The main countries of origin are Ghana, Benin, Nigeria, Niger, and Côte d'Ivoire (Abel and Cohen 2019; IADD 2019e). Similar to that of internal migration, Lomé is the main destination area for international migrants, followed by the Maritime administrative region.

Figure 7.91 International Migration Trends, Togo, 1990–2015



Source: Abel and Cohen 2019.

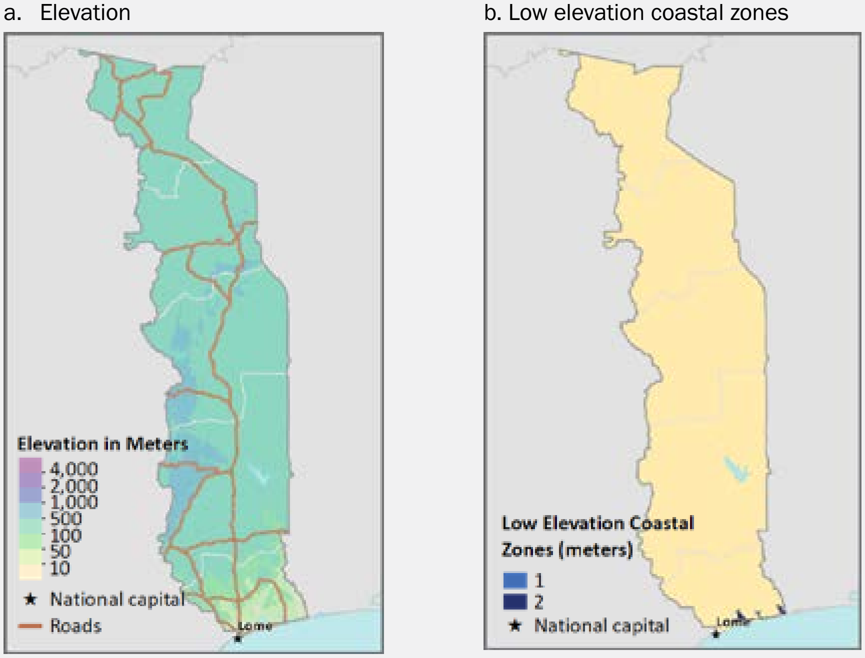
Environmental migration

Environmental migration, including climate migration, is linked to deteriorating natural resources and living conditions in the context of livelihoods heavily dependent on ecosystem services, such as agriculture, pastoralism, fisheries, and tourism. Projected climate change impacts (for example, flooding, coastal erosion, and droughts) will further affect these livelihoods. Commercial and subsistence crops and sedentary and transhumant extensive ranching (frequently associated with agriculture in the form of agropastoralist systems) will likely be affected by decreasing rains and soil degradation.

Coastal ecosystems, urban and rural populations (particularly the poor), internal migrants, livelihoods (for example, vegetable gardeners), housing, and infrastructure are exposed and vulnerable to the impacts of climate change. In the densely populated and low-lying area of Lomé (figure 7.93, panels and b), climate models indicate an increase in precipitation (10 percent to 2030) that could trigger flooding events resulting in population displacement. Coastal erosion and marine intrusion are expected to exacerbate under sea level rise, which is projected to be on average between 27 centimeters (RCP2.6) and 30 centimeters (RCP8.5) by 2050 (IADD 2019e). The estimated cost of coastal degradation is 6.4 percent of Togo's GDP in 2017 (Croitoru, Miranda, and Sarraf 2019, x).

Marine and inland fisheries constitute important natural resources, providing a livelihood to about 22,000 people (for example, fishers, processors, and traders) and contributing to food security, especially to the rural population (IADD 2019e). The maximum catch potential for Togolese marine fisheries is projected to decline between 22.6 percent and 30.6 percent (under RCP.6 and RCP8.5, respectively) by 2050 (World Bank 2019c). In addition, climate-induced changes in marine fisheries elsewhere could affect Togo's food security because of the country's reliance on imported fish for domestic consumption (Ding et al. 2017, 59).

Figure 7.92 Elevation and Low Elevation Coastal Zones, Togo, 2050


a. Elevation

b. Low elevation coastal zones

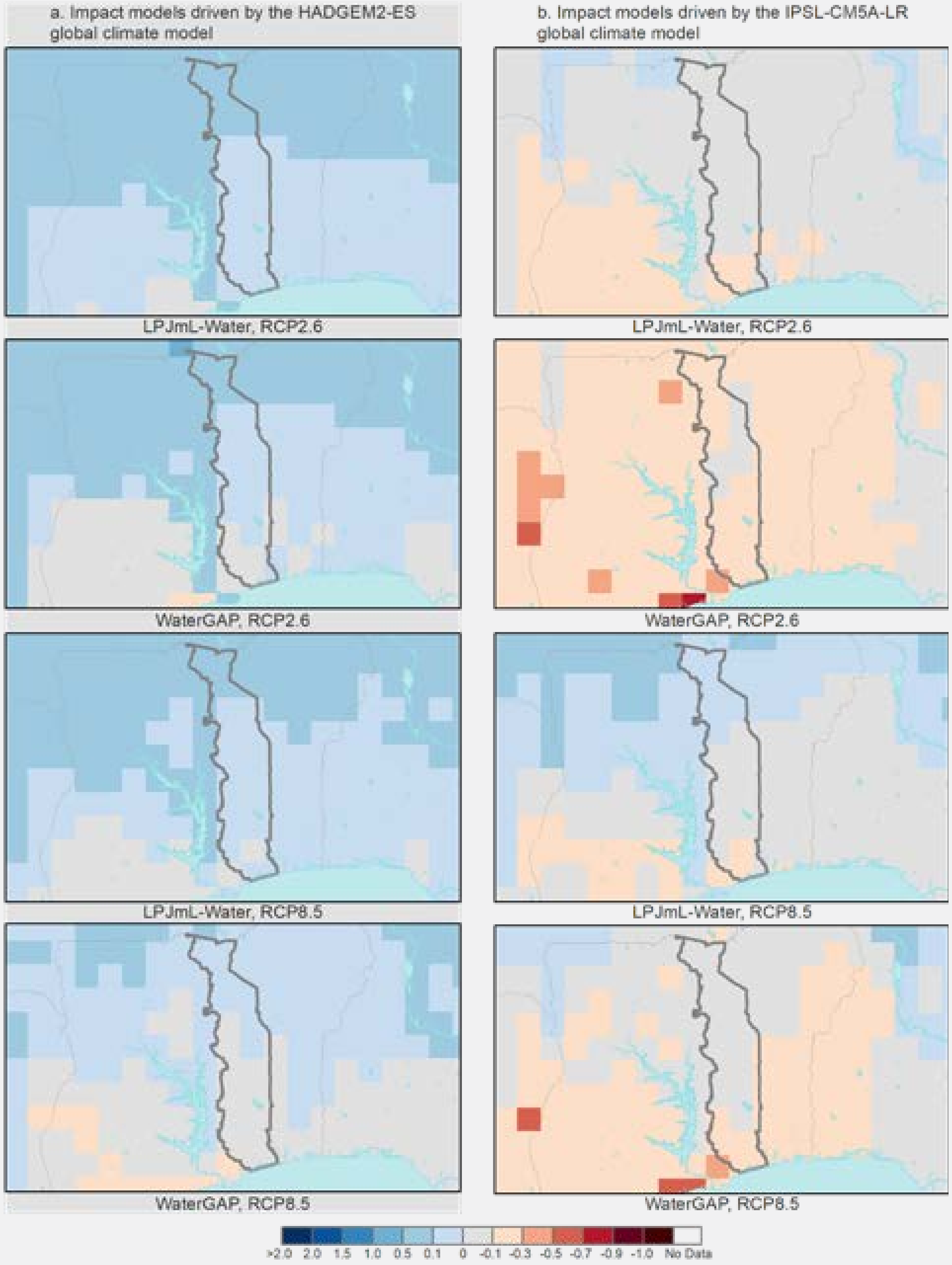
7.6.3 Climate Trends and Projections

Togo has a diverse topography ranging from rolling hills in the north to the Ouatchi Plateau and Lake Togo in the south to a low coastal plain characterized by lagoons and marshes. The climate varies between tropical and savanna. Southern Togo is humid and sees temperatures between 23°C and 32°C over its two rainfall seasons (World Bank 2011c). The north sees temperatures between 18°C and 38°C, and experiences cooler, drier weather because of the desert winds from the Harmattan. These can result in periodic droughts in the north, and an accelerated increase in average annual temperature.

In the past several decades, the average annual temperature has increased by 0.24°C (0.43°F) per decade, with an increase of around 0.31°C (0.88°F) in the drier northern regions (World Bank 2011c). Rainfall is variable, but an overall decreasing trend of around 2.4 percent per decade can be observed from 1960 to 2006. Climate projections suggest that temperatures will continue to rise, temperatures in coastal areas and smaller inland areas will see more extremes, and the country will be more vulnerable to drought, floods, violent winds, damaging rains, and coastal erosion.

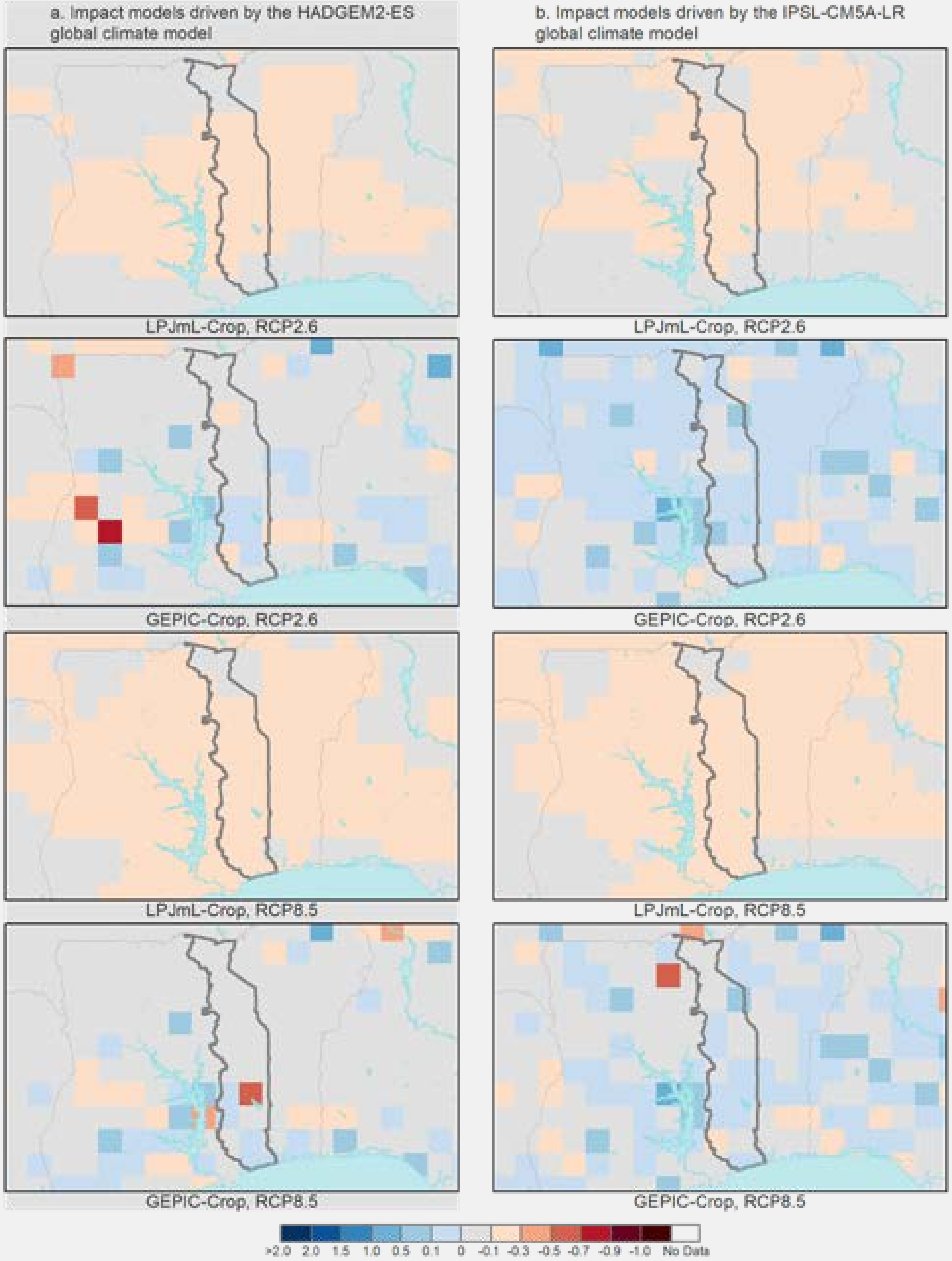
In this work, the population gravity model calibration finds that the coefficients are highest for water availability, meaning that past shifts in water availability play a greater role than the other input variables in explaining past shifts in population distribution. Panels in figures 7.93 to 7.95 show the average projected changes in water availability, crop production, and NPP for the 2010–050 time period, respectively. NPP is used to gap-fill areas where there is no crop production. The coefficient for water availability in rural areas is around 2.75 times higher than that of either crops or NPP, and it is the only climate factor other than flood risk and sea level rise influencing future urban population distribution. This result means that it has a far greater influence on future population distribution than most other climate variables. Togo will not likely be as affected by shifts in water availability as some other countries. Only under the IPSL-CM5A-LR global climate model coupled with WaterGAP are there up to 10 percent to 30 percent reductions in water availability compared to the historical baseline, with more frequent occurrences across models than in the north. There will be 10 percent to 30 percent declines in crop production in the central part of the country under the LPjML model, and a more mixed picture under the GEPIC model. The NPP model outputs are shown only for information purposes (there is no part of Togo without crop production), but the picture is one of largely increasing ecosystem productivity.

Figure 7.93 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Togo, 2010–50



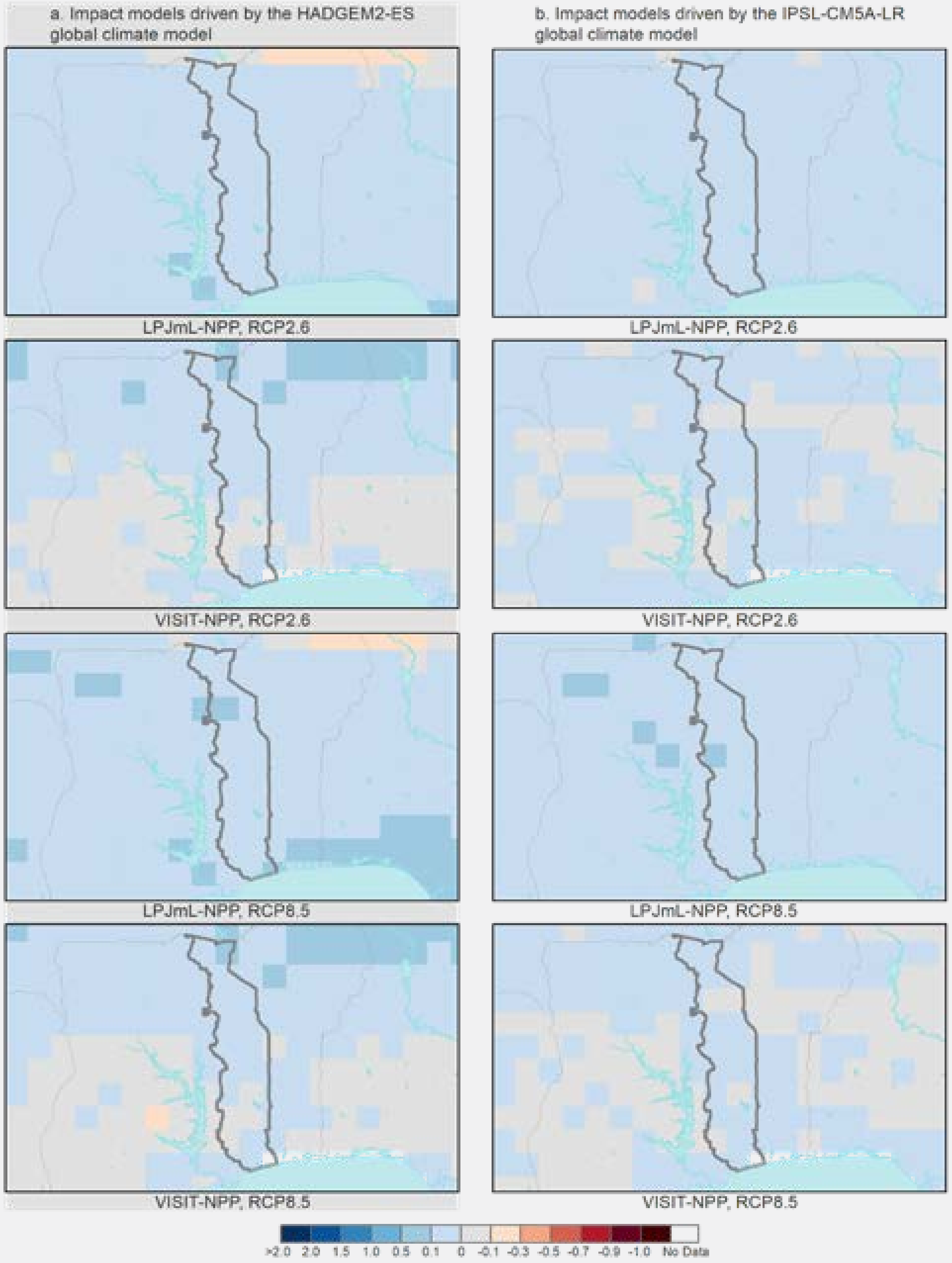
Note: Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.

Figure 7.94 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Togo, 2010–50



Note: Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production.

Figure 7.95 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Togo, 2010–50



Note: Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is used to gap-fill crop production, and therefore is not used to model future population distribution. NPP = net primary production.

7.6.4 Coastal Trends

For a country with a short coastline of only 50 kilometers, exposure to sea level rise and surge are very high along most of the coast (figure 7.93). While the coastline rises rather steeply and is often characterized by cliffs, erosion rates are also very high, ranging from 1.66 meters to 5.25 meters per year, depending on the location (Konko et al. 2018).

De Sherbinin et al. (2014) measured social vulnerability levels as a function of population density, population growth, subnational poverty, maternal education levels, market accessibility (travel time to markets), and political violence (figure 7.96). Results suggest that the Lomé metropolitan area exhibits the highest levels of social vulnerability. According to Croitoru, Miranda, and Sarraf (2019), the costs of coastal erosion amount to US$213 million, or 4.4 percent of GDP, in 2017, based on the value of assets and annual production per hectare and the value of the land.

Figure 7.96 Social Vulnerability Index for the Coastline of Togo, circa 2010

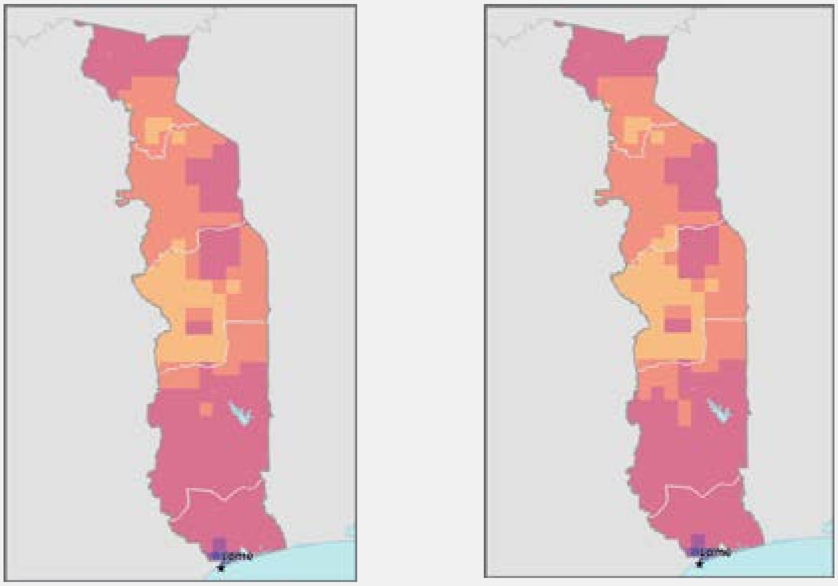
Source: de Sherbinin et al. 2014.

7.6.5 Projected Changes in Population

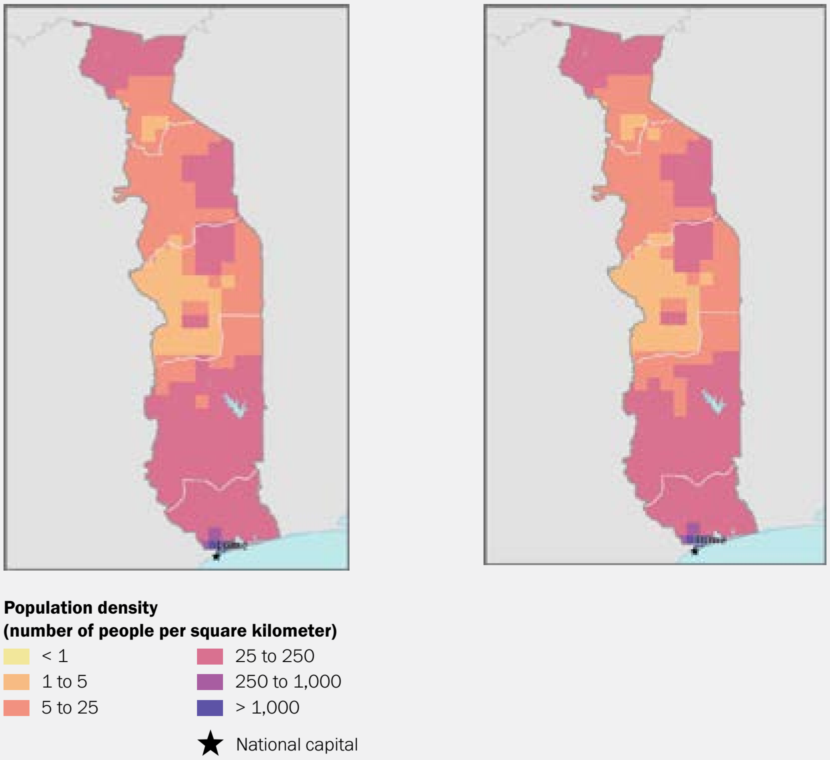
Total population to 2050 will be higher under the SSP4 scenario (14.3 million) compared with the SSP2 scenario (13.2 million). Figure 7.98, panels a–d, presents the projected population of Togo to 2050, displaying similar distribution patterns across the four scenarios. They show an intensification of the 2010 patterns, particularly along the east border with Benin, and in the Plateaux and Maritime administrative regions. The commune of Lomé and surrounding areas display the highest population densities.

Figure 7.97 Projected Population under the Four Scenarios, Togo, by 2050

a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)

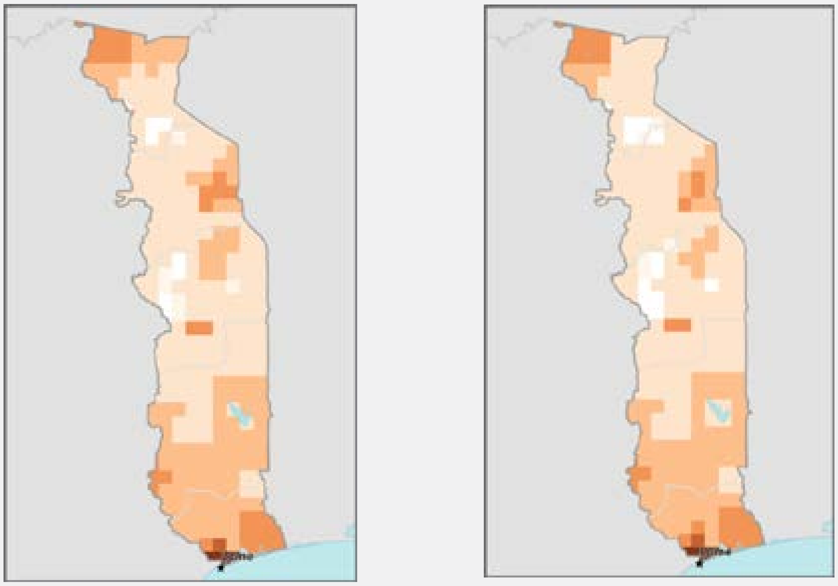


c. Optimistic (SSP2 and RCP2.6) d. Climate-friendly (SSP4 and RCP2.6)

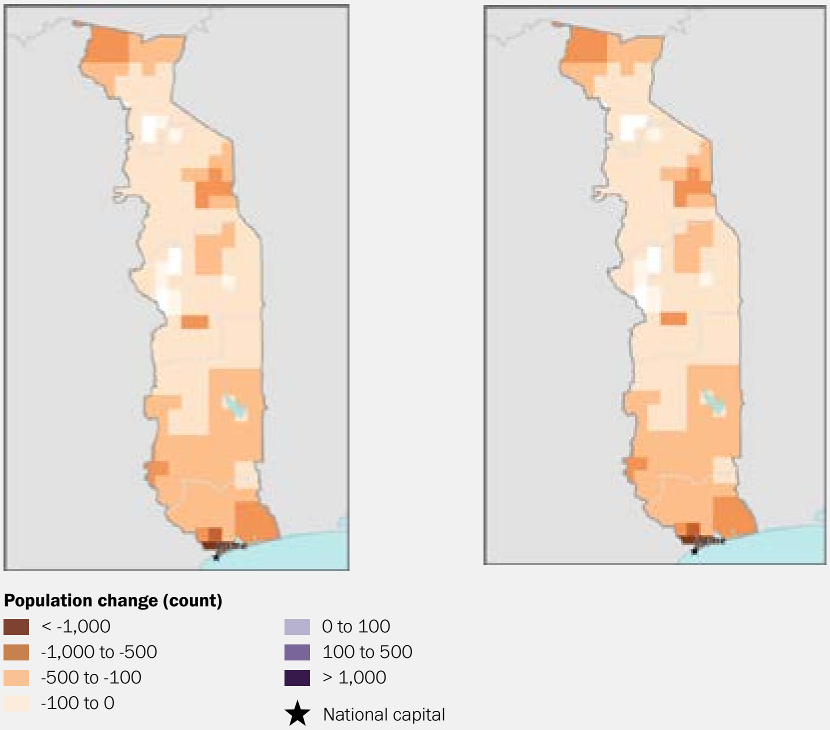


Changes in population density between 2010 and 2050 show similar spatial patterns across scenarios (figure 7.98, panels a–d). The largest changes correspond to the areas close to Lomé, currently the preferred destination for internal and international migrants. Other areas of positive change correspond to the northwest and southeast corners, in the Savanes and Maritime administrative regions, respectively, the southern part of Plateaux, and the east of Kara, in some cases overlapping with urban areas. Patches of very modest decline are visible in western Centrale and southern Savanes.

Figure 7.98 Projected Change in Population Density under the Four Scenarios, Togo, 2010–50



a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

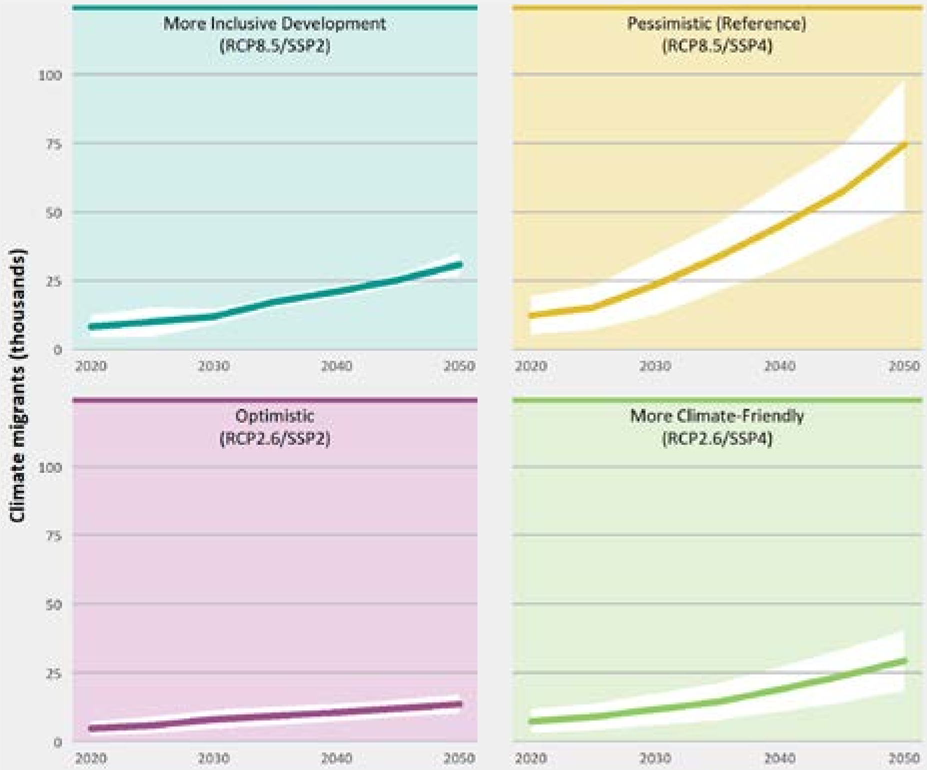
d. Climate-friendly (SSP4 and RCP2.6)

7.6.6 Internal Climate Migration Futures and Trends

Scale and Trajectory of Internal Climate Migration

Figure 7.99, panels a–d, presents the projected number of climate migrants by scenario and decade, from 2020 to 2050, and the country as a whole. Table 7.21 shows total climate migrants by scenario by 2050. The four scenarios display an upward trend with some differences. The pessimistic scenario projects substantially larger number of climate migrants than the other three scenarios, even after considering the confidence intervals. The number of climate migrants in the more inclusive development and more climate-friendly scenarios are similar (although the confidence intervals are slightly larger in the more climate-friendly scenario). These results are in-between those of the optimistic scenario (which present the lowest number) and the pessimistic scenarios. This would suggest that lower emissions (RCP2.6) or population growth (SSP2) could slow climate migration. Wider confidence intervals in the pessimistic and more climate-friendly scenarios (both including SSP4) could relate to larger population growth projected under this SSP. Figure 7.100, panels a–d, shows that climate migrants are far lower in numbers than other (development) migrants, suggesting that economic factors will still be the greatest drivers of migration.

Figure 7.99 Projected Total Climate Migrants, Togo, 2020–50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050
%	0.12	0.14	0.22	0.3

2020	2030	2040	2050
0.17	0.27	0.45	0.67

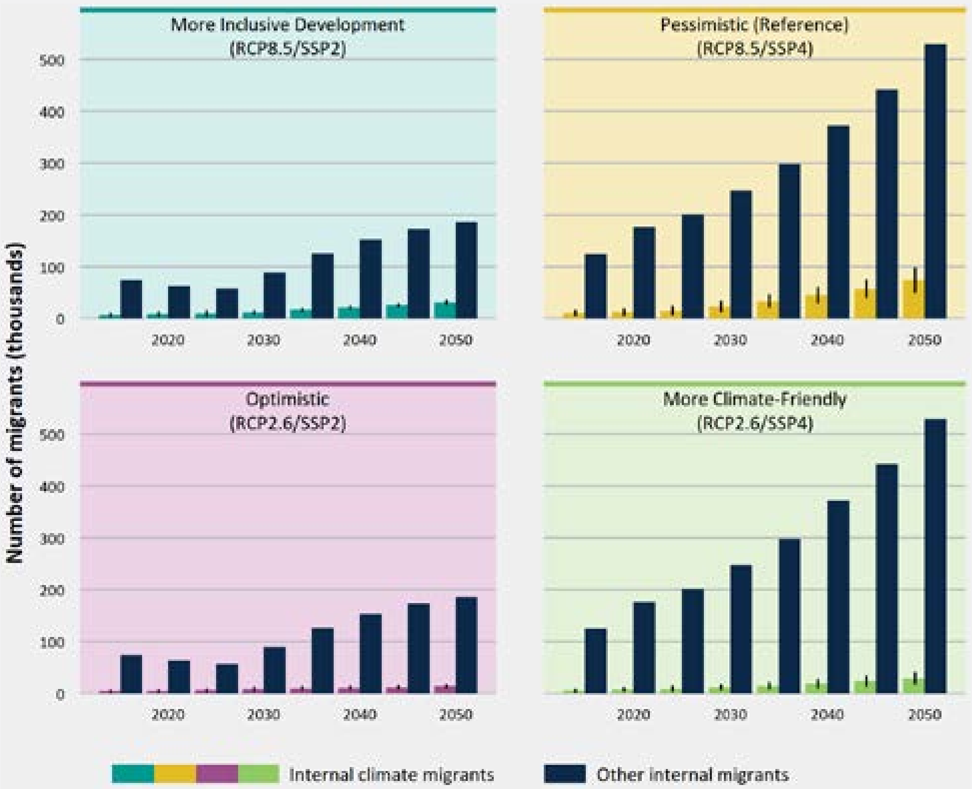
Year	2020	2030	2040	2050
%	0.07	0.1	0.11	0.13

2020	2030	2040	2050
0.1	0.14	0.19	0.27

Table 7.21 Projected Total Climate Migrants for Togo by 2050

	Scenario							
	Pessimistic (reference)		More inclusive development		More climate-friendly		Optimistic	
Average number of internal climate migrants by 2050 (millions)	0.075		0.031		0.029		0.014	
Min. (left) and max. (right) (millions)	0.051	0.098	0.027	0.035	0.019	0.040	0.010	0.017
Internal climate migrants as % of pop.	0.67		0.3		0.27		0.13	
Min. (left) and max. (right) (%)	0.46	0.89	0.26	0.34	0.17	0.36	0.1	0.17

Figure 7.100 Projected Climate Migrants Compared to Other Migrants, Togo, 2010–50



Internal Climate Migration Hotspots

Figure 7.101 displays the climate migration hotspots for 2050, and figure 7.102, panels a and b, for 2030 and 2040. There are few hotspots and they are small. They are mostly in the northwest corner, the east-central, and the south-southwest of Togo. Considering only high-certainty spots, the largest area of out-migration corresponds to the low-lying coastal areas likely to be affected by sea level rise, including the city of Lomé and surrounding region. Another small spot is in the northeast of Kara administrative region. Areas of in-migration are very small, one in the northwest corner by the border with Burkina Faso, another in the center of the country (in an area of higher elevation), and one in the south-central area close to the border with Benin (city of Tohoun). Figure 7.102, panels a and b, indicate that hotspots of out-migration appear earlier than in-migration hotspots, especially in the coastal area.

Figure 7.101 Projected Hotspots of Climate In- and Out-Migration, Togo, 2050

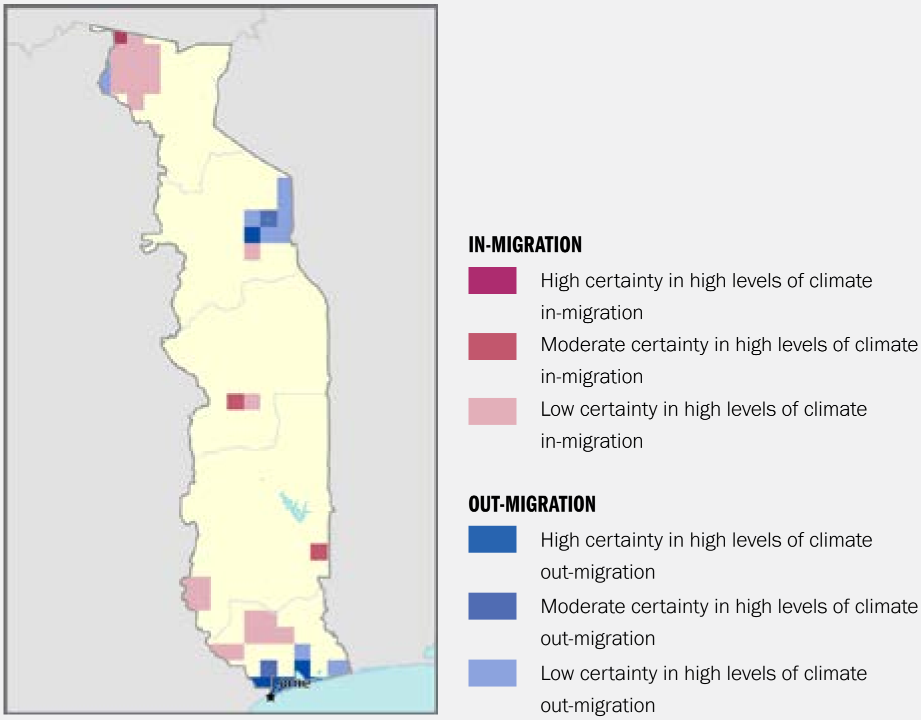
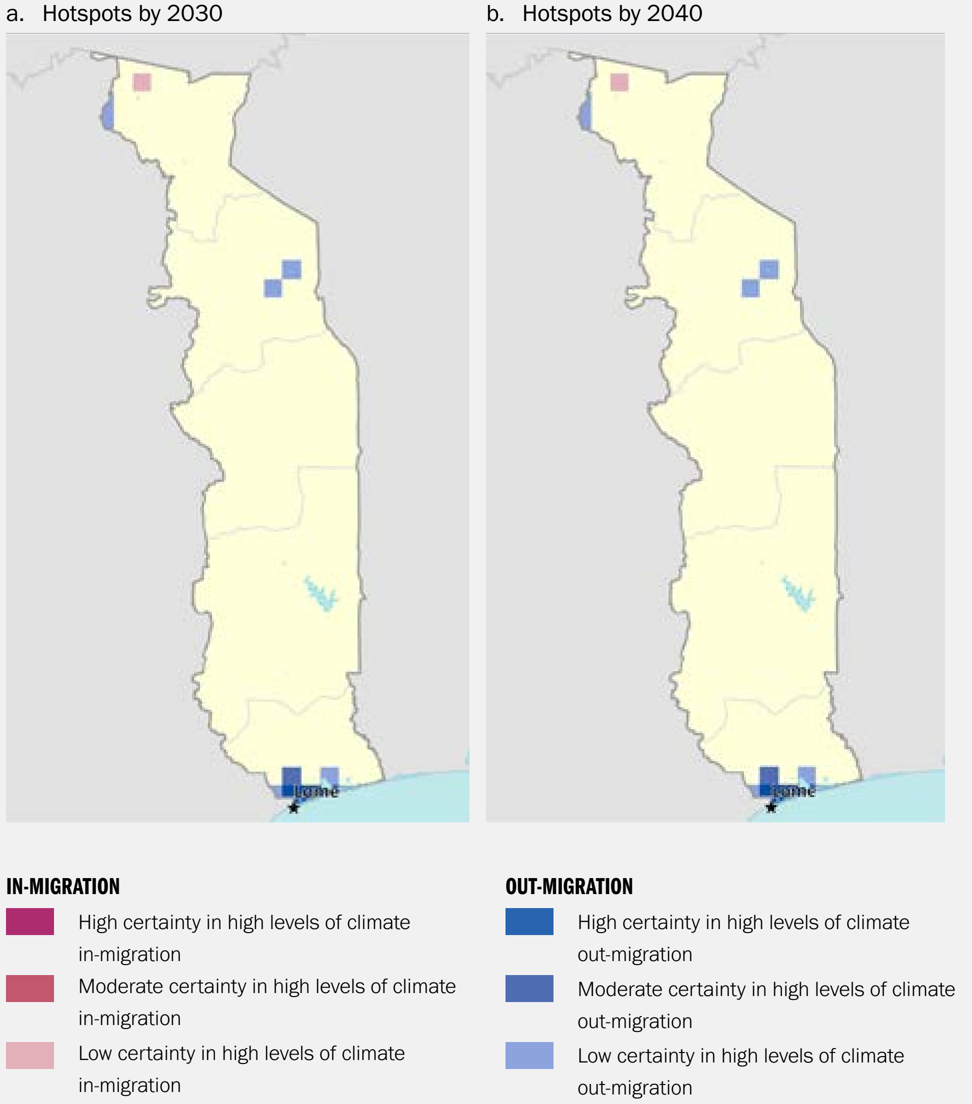


Figure 7.102 Projected Hotspots of Climate In- and Out-Migration, Togo, 2030 and 2040


a. Hotspots by 2030

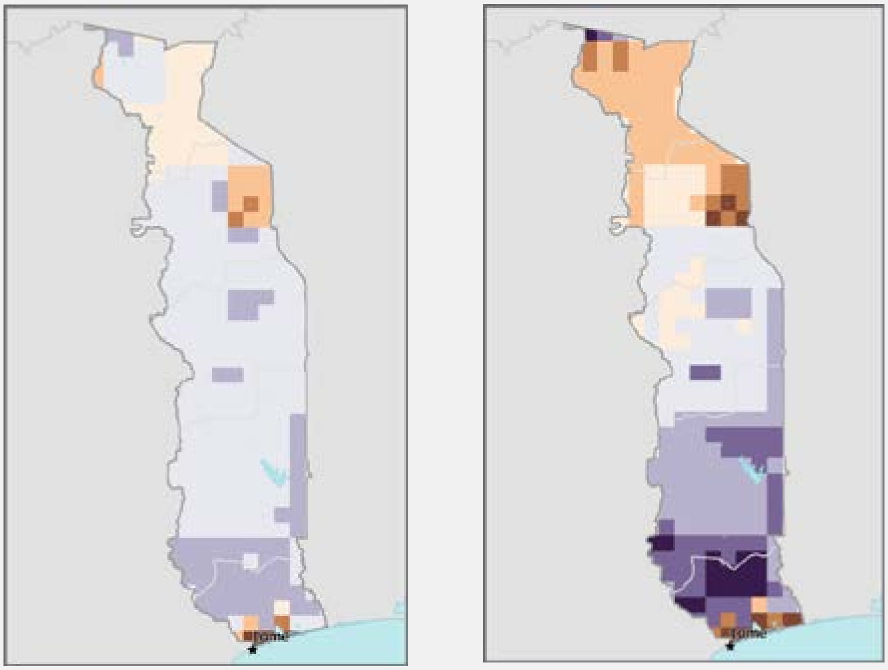
b. Hotspots by 2040

Figure 7.104, panels a–d, displays the absolute difference between the climate and no climate scenarios. The largest changes correspond to the pessimistic scenario, particularly in the south. Maritime administrative unit and the commune of Lomé alternate positive (pull) and negative (push) impacts of climate change, while the northern part of the country displays mostly negative impacts, except for the northernmost corner. The more inclusive development and the more climate-friendly scenarios also display this pattern in an attenuated fashion, while the optimistic scenario shows only the push impact of sea level rise at and around Lomé.

Figure 7.103 Projected Population Change Because of Climate Migration, Togo, 2050

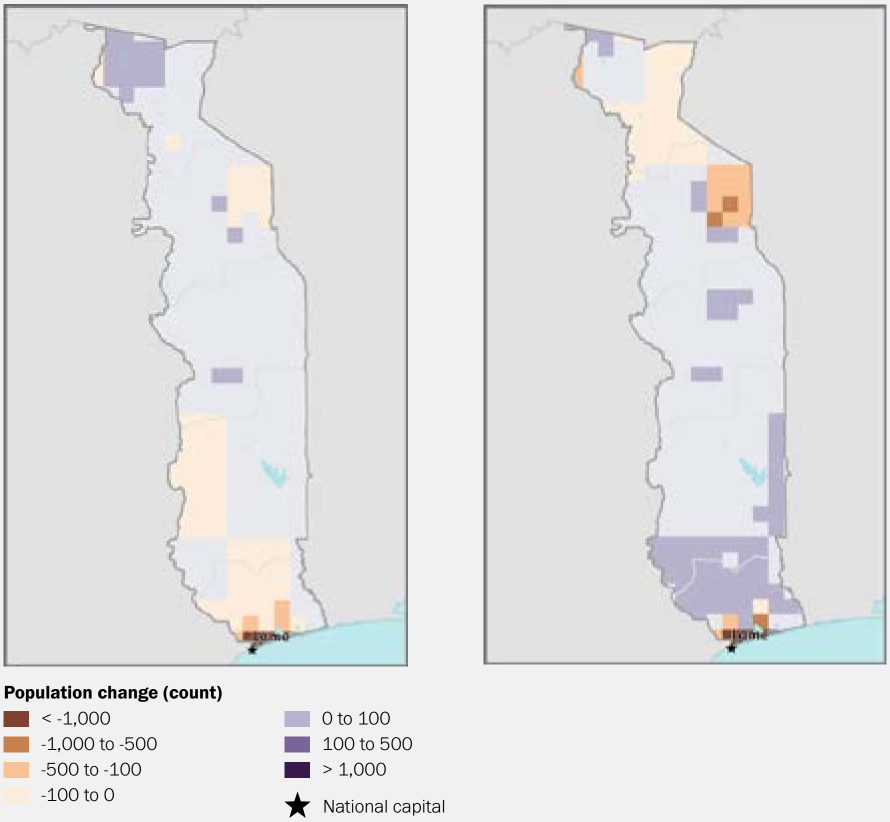
a. Inclusive development (SSP2 and RCP8.5)

b. Pessimistic (reference) (SSP4 and RCP8.5)



c. Optimistic (SSP2 and RCP2.6)

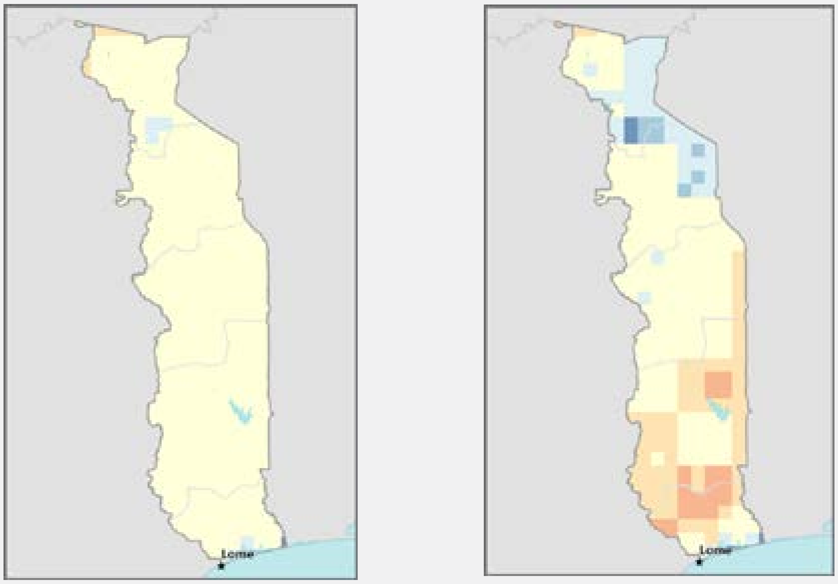
d. Climate-friendly (SSP4 and RCP2.6)



Note: Calculations based on changes in population counts per square kilometer.

Figure 7.104, panels a–d, displays the percentage differences between the climate and no climate scenarios. For all, percentage changes in and around Lomé are quite small for the size of the population. For the rest of the country, only the pessimistic scenario presents larger positive percentage changes in the south- and east-central areas, while negative percentage changes appear in the northeast. This is probably associated with the effect of some decline in crop productivity under RCP8.5.

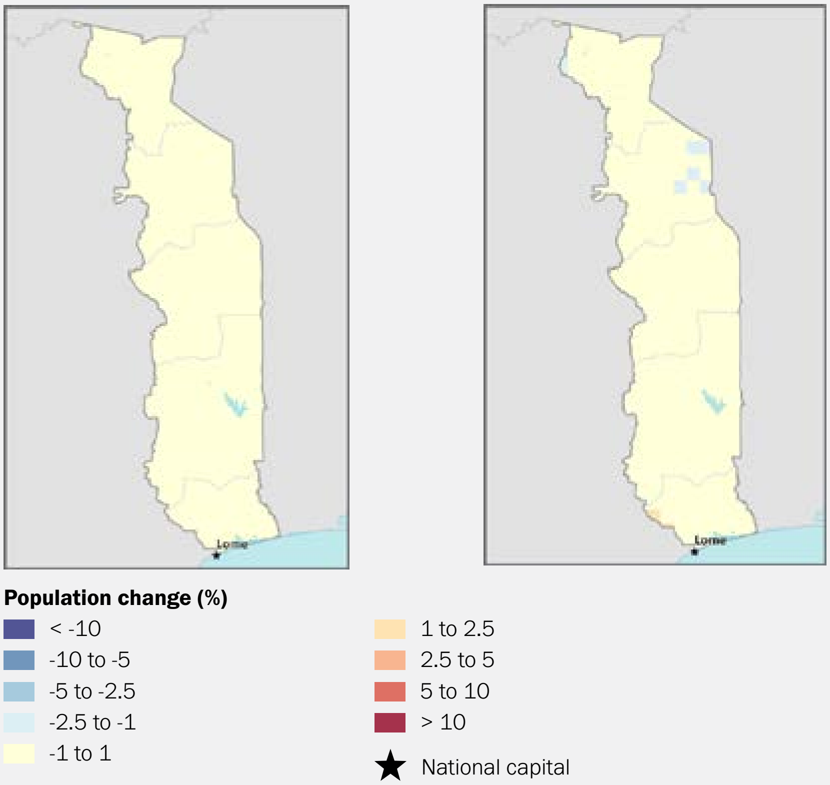
Figure 7.104 Projected Percentage of Differences between Climate Impact Scenarios and the Respective No Climate Impact (SSP-Only) Scenario, Togo, 2050



a. Inclusive development (SSP2 and RCP8.5) b. Pessimistic (reference) (SSP4 and RCP8.5)

c. Optimistic (SSP2 and RCP2.6)

d. Climate-friendly (SSP4 and RCP2.6)



Internal Climate Migration by Zone: Coastal Areas, Livelihood Zones, and Provinces

Climate Migration in Coastal Areas

Because of the small area represented by the 5-kilometer coastal zone, we processed coastal climate migration with the 1-kilometer resolution modeling outputs, not the results aggregated to 15 kilometers. This means that numbers of coastal climate migrants are not directly comparable to the numbers of climate migrants reported at the country level, nor are these numbers embedded in the migration numbers reported at the country level.

For Togo, modeling results for the four scenarios (figure 7.106, panels a–d) indicate a negative impact of climate change in the coastal zone, with differences in magnitude. There is a steady progression from the optimistic scenario (below 10,000) to the more climate-friendly, the more inclusive development, and finally the pessimistic scenario, which displays the largest negative balance (above 30,000). These results agree with sea level rise projections being larger for the RCP8.5 scenario, and larger population growth under SSP4. Figure 7.106 indicates that most of the coastal area is an area of negative climate net migration, likely with sea level rise impacts as the main drivers.

Figure 7.105 Projected Coastal Climate Migrants, Togo, 2015–50

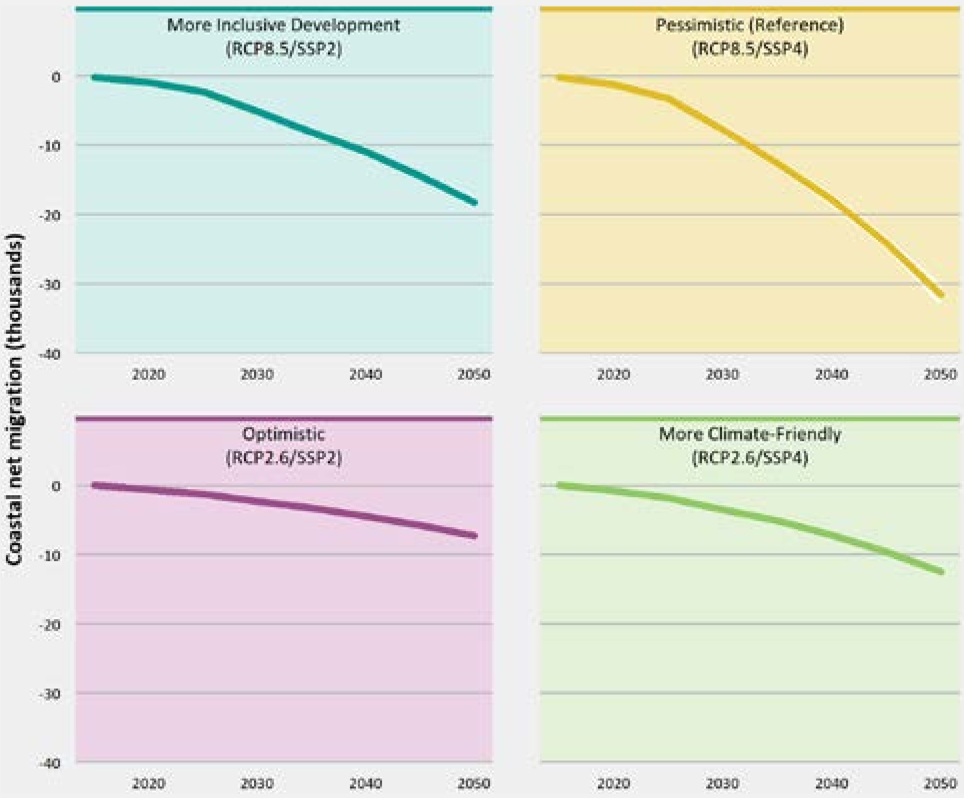
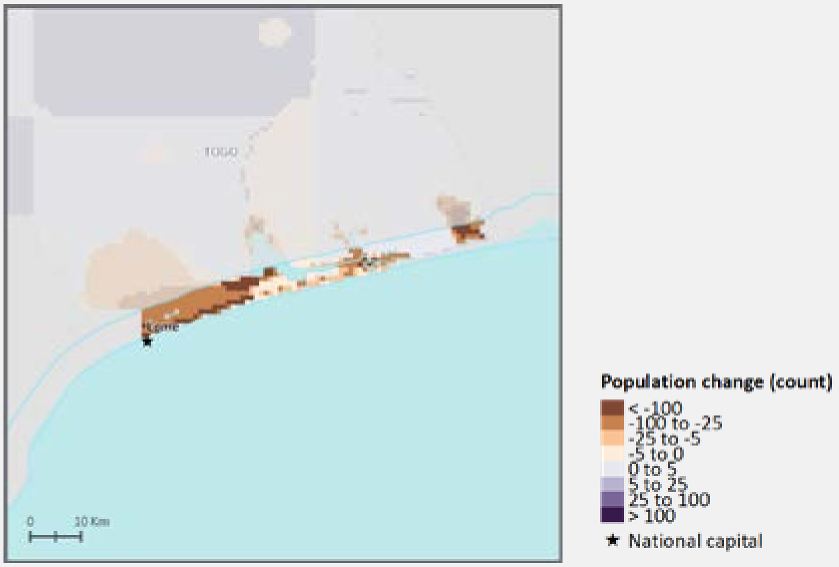


Figure 7.106 Projected Population Change Because of Climate Migration for Coastal Zone of City of Lomé, Togo, 2050



Note: Calculations based on per square kilometer under the pessimistic scenario.

Climate Migration by Livelihood Zone

Rainfed agriculture covers practically the whole country, with some small continuous areas of seminatural and woodlands, and patches of pastoral and rangelands, and dense settlements (figure 7.108). Table 7.22 presents the net climate migration results by scenario and decade for each livelihood zone. Dense settlements consistently show negative net climate migration, which could reflect the location of the main urban area (Lomé) in the coastal zone (figure 7.107). The rest of the livelihood zones display positive net climate migration, but some numbers are quite small.

Figure 7.107 Livelihood Zones, Togo, 2050

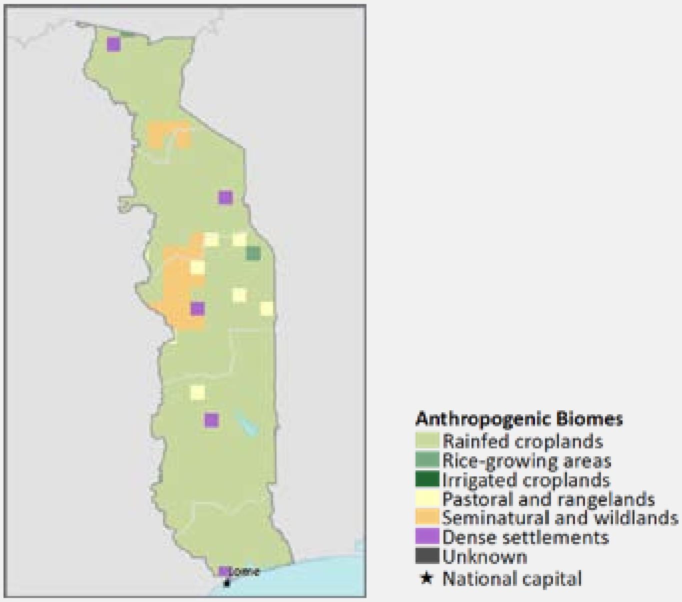


Table 7.22 Projected Net Climate Migration by Scenario, Livelihood Zone, and Decade, Togo, 2030, 2040, and 2050 (number of people)

Year and livelihood zone	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
2030				
Dense settlements	–1,385	–1,497	-690	–2,846
Pastoral and rangelands	125	187	80	195
Rainfed croplands	1,600	1,709	580	3,600
Rice-growing areas	–131	247	21	354
Seminatural and wildlands	68	-254	184	-682
Unknown	-277	-392	–175	-621
2040				
Dense settlements	–1,696	–2,417	-787	–5,038
Pastoral and rangelands	205	339	127	423
Rainfed croplands	2,177	2,459	752	6,416
Rice-growing areas	–171	502	56	460
Seminatural and wildlands	115	–138	228	–1,021
Unknown	-629	-745	-376	–1,241
2050				
Dense settlements	–2,231	–3,356	–1,024	–7,084
Pastoral and rangelands	302	432	189	317
Rainfed croplands	3,162	3,684	1,143	9,999
Rice-growing areas	–178	598	81	454
Seminatural and wildlands	65	-300	242	–1,836
Unknown	–1,121	–1,058	-630	–1,851

Climate Migration by Province

Figure 7.108 presents net climate migration by province (administrative units) by 2050. The commune of Lomé and the Maritime Province display negative balances for all the scenarios, largely due to sea level rise and water availability declines. These results are offset slightly by higher median age, which tends to act as an attractor to the coastal zone. Meanwhile, Centrale and Plateaux are net winners with positive balances across the board. Kara and Savanes (the two northernmost provinces) show mixed results: while the more inclusive development and optimistic scenarios project a positive balance, the pessimistic and more climate-friendly ones indicate a negative outcome (but with large confidence intervals).

Figure 7.108 Projected Net Climate Migration by Province and Scenario for Togo, 2050

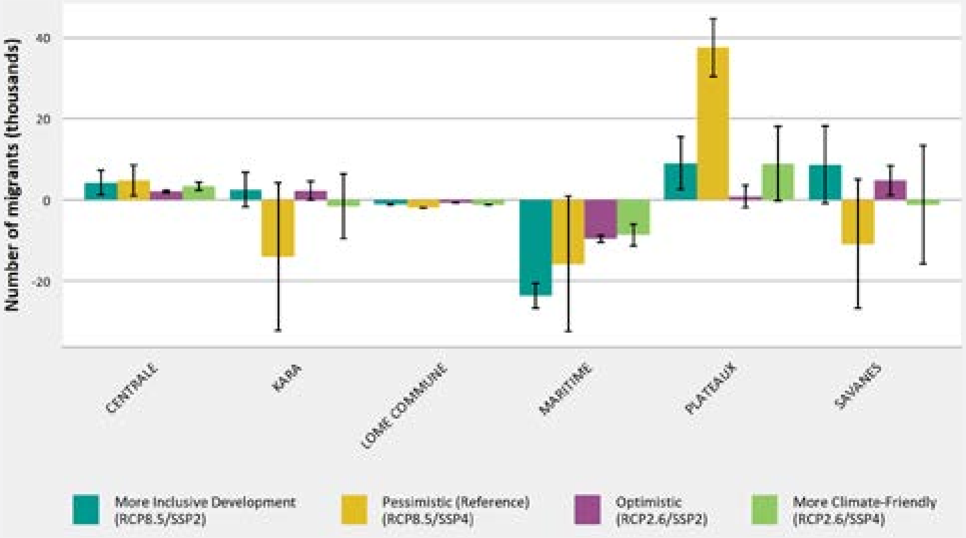


Table 7.23 Projected Net climate Migration by Scenario and Province, Togo, 2050

Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Centrale	3,385	4,304	2,090	4,827
Kara	–1,485	2,545	2,308	–13,945
Lomé Commune	–1,121	–1,058	–630	–1,851
Maritime	–8,562	–23,573	–9,513	–15,755
Plateaux	8,924	9,072	894	37,559
Savanes	–1,142	8,710	4,851	–10,835

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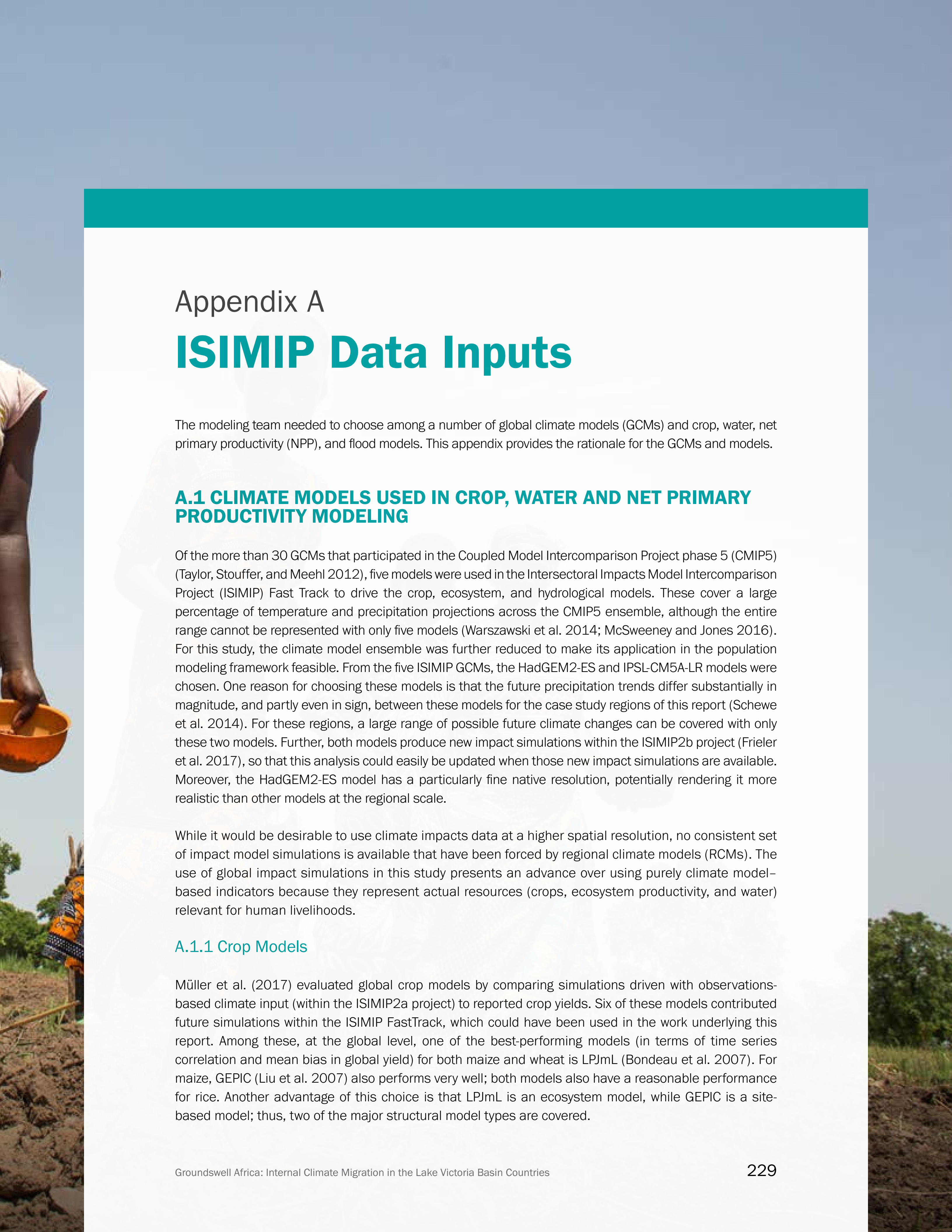

Appendix A

ISIMIP Data Inputs

The modeling team needed to choose among a number of global climate models (GCMs) and crop, water, net primary productivity (NPP), and flood models. This appendix provides the rationale for the GCMs and models.

A.1 CLIMATE MODELS USED IN CROP, WATER AND NET PRIMARY PRODUCTIVITY MODELING

Of the more than 30 GCMs that participated in the Coupled Model Intercomparison Project phase 5 (CMIP5) (Taylor, Stouffer, and Meehl 2012), five models were used in the Intersectoral Impacts Model Intercomparison Project (ISIMIP) Fast Track to drive the crop, ecosystem, and hydrological models. These cover a large percentage of temperature and precipitation projections across the CMIP5 ensemble, although the entire range cannot be represented with only five models (Warszawski et al. 2014; McSweeney and Jones 2016). For this study, the climate model ensemble was further reduced to make its application in the population modeling framework feasible. From the five ISIMIP GCMs, the HadGEM2-ES and IPSL-CM5A-LR models were chosen. One reason for choosing these models is that the future precipitation trends differ substantially in magnitude, and partly even in sign, between these models for the case study regions of this report (Schewe et al. 2014). For these regions, a large range of possible future climate changes can be covered with only these two models. Further, both models produce new impact simulations within the ISIMIP2b project (Frieler et al. 2017), so that this analysis could easily be updated when those new impact simulations are available. Moreover, the HadGEM2-ES model has a particularly fine native resolution, potentially rendering it more realistic than other models at the regional scale.

While it would be desirable to use climate impacts data at a higher spatial resolution, no consistent set of impact model simulations is available that have been forced by regional climate models (RCMs). The use of global impact simulations in this study presents an advance over using purely climate model–based indicators because they represent actual resources (crops, ecosystem productivity, and water) relevant for human livelihoods.

A.1.1 Crop Models

Müller et al. (2017) evaluated global crop models by comparing simulations driven with observations-based climate input (within the ISIMIP2a project) to reported crop yields. Six of these models contributed future simulations within the ISIMIP FastTrack, which could have been used in the work underlying this report. Among these, at the global level, one of the best-performing models (in terms of time series correlation and mean bias in global yield) for both maize and wheat is LPJmL (Bondeau et al. 2007). For maize, GEPIC (Liu et al. 2007) also performs very well; both models also have a reasonable performance for rice. Another advantage of this choice is that LPJmL is an ecosystem model, while GEPIC is a site-based model; thus, two of the major structural model types are covered.

For some crop-country combinations, very few models show a good performance at the national scale in terms of time series correlation and mean bias (Müller et al. 2017), which is, however, not to say that they cannot capture longer-term trends. To reflect overall agricultural productivity, the four major crops (maize, wheat, rice, and soybean) were combined into a total production index. Depending on the country, other crops are also important, but are not simulated by most of the global crop models.

A.1.2 Water Models

The ISIMIP hydrological models have so far been evaluated (Gosling et al. 2017; Hattermann et al. 2017) mainly for 11 large river basins, of which only the Ganges (Bangladesh) and Blue Nile (Ethiopia) are relevant for the present set of case study countries. Moreover, in these studies, the models have been anonymized, that is, individual models cannot be identified. One criterion that narrows the choice is that only a few models can provide simulations, including human water abstraction, dams, and reservoirs, which are major nonclimatic human influences on the water cycle. These simulations are normally closer to observed discharge. Of the models that participated in both ISIMIP2a and the ISIMIP FastTrack, these are available from H08, WaterGAP, PCR-GLOBWB, MPI-HM, or LPJmL. From these, LPJmL and WaterGAP (Döll, Kaspar, and Lehner 2003; Flörke et al. 2013) were selected. LPJmL integrates crop yields, water resources, and ecosystems in a single model. WaterGAP can be calibrated separately for each basin and therefore matches observed river discharge better than other global models in many river basins. None of the ISIMIP global models include glacier dynamics. Work is ongoing to include glacier dynamics both in PIK's regional hydrological model SWIM and in WaterGAP.

A.1.3 Net Primary Productivity Models

The choice of net primary productivity or ecosystem models follows similar considerations as that of crop and water models. Out of four global ecosystem models (also called biome models) that participated in both the ISIMIP Fast Track and ISIMIP2a, three provided future simulations with both HadGEM2-ES and IPSL-CM5A-LR climate model forcing: LPJmL, VISIT, and JULES. LPJmL is among the best-performing global ecosystem models according to recent studies evaluating models' interannual variability and extreme events (Ito et al. 2017; Schewe et al. 2019), and was therefore chosen for this report. In addition, VISIT serves as an alternative model to gauge the potential influence of modeling uncertainty on the final estimates. We note however that the VISIT historical (ISIMIP2a) simulations do not account for historical changes in human land use.

A.2 CLIMATE MODELS USED IN FLOOD MODELING

Of the more than 30 GCMs that participated in CMIP5, four models (IPSL-CM5A-LR, GFDL-ESM2M, MIROC5, and HadGEM2-ES) were used in the ISIMIP2b to drive the hydrological models. These cover a large fraction of the range of temperature and precipitation projections across the whole CMIP5 ensemble, although the entire range cannot be represented with only four models (McSweeney and Jones 2016; Warszawski et al. 2014). One reason for choosing these models in ISIMIP2b is the availability of variables and time span that satisfies the requirement of all impact model sectors within ISIMIP. Priority orders were defined for the four GCMs, such that the hydrological models with limited computational resources will complete all experiments for IPSL-CM5A-LR first, followed by GFDL-ESM2M, MIROC5, and HadGEM2-ES. All the GCMs provide forcing data for the two Representative Concentration Pathways (RCPs) investigated in the ISIMIP2b project: RCP2.6 (low level of global warming under strong climate mitigation) and RCP6.0 (business as usual).

A.2.1 Flood Models

Six global hydrological models (GHMs): H08, LPJmL, MPI-HM, PCR-GLOBWB, ORCHIDEE, and WaterGAP2, uploaded results for all required experiments at the start of this investigation. They vary in representation of hydrological processes on land, and their performance has been evaluated for river basins worldwide, including the Blue Nile Basin (Ethiopia) (Hattermann et al. 2017). Of the six models, MPI-HM is forced only by the first three GCMs (not HadGEM2-ES), and ORCHIDE is forced only by IPSL-CM5A-LR and GFDL-ESM2M. The other four GHMs are forced by all four GCMs, making a total of 21 GCM-GHM combinations that generate daily runoff at 0.5 by 0.5 degrees (about 50- by 50-kilometer) resolution for the globe.

Global Flood Model

Global flood models represent the hydrodynamic process that route the gridded runoff along river networks and compute the flood inundation patterns as potential results of the routing. The GHMs often include river routing schemes. However, none of the six GHMs used here provide flood inundation depth. While other global flood models such as ISBA-TRIP (Decharme et al. 2012) and HyMAP (Getirana et al. 2012) exist, the CaMa-Flood is one of the first and only open source global river model available that can simulate floodplain dynamics and backwater effects by solving the diffusive wave equation (Yamazaki et al. 2011). CaMa-Flood generally improves the peak river discharge simulation compared to the native routing schemes employed in the GHMs (Zhao et al. 2017). CaMa-Flood has been widely used in global flood studies, and its performance has been shown in detail (Dottori et al. 2018; Hirabayashi et al. 2013). CaMa-Flood is forced by the projected daily runoff for the 2010–49 period from the GHMs, and daily discharge at 0.25 by 0.25 degree resolution is generated.

Definition of Flood Hazard Ratings

The annual maximum discharge results from CaMa-Flood forced by the 21 GCM-GHM combinations and the two RCPs (RCP2.6 and RCP6.0,[88] representing low and high emissions pathways) are extracted for West Africa and downscaled to 500-meter resolution annual maximum flood inundation depth (either flooded or not flooded at 500-meter resolution) based on topography information. Downscaling and mapping to observational-driven flood depth to avoid bias from the global climate models are described in the supplementary text of Hirabayashi et al. (2013), Wilner et al. (2018), and Dottori et al. (2018). The annual maximum flood inundation depth at 500-meter resolution considers flood defenses in West Africa, which are usually very low (can protect only against floods with return period of two to five years) according to Scussolini et al. (2016). Only those exceeding the protection return period, based on statistics from an accompanying preindustrial control run, are kept unchanged for the simulated flood depth, under the assumption of levee break (so it is as if flood protection does not exist). Floods below the protection return period threshold are set to 0 flood depth.

According to global flood depth damage functions compiled at the Joint Research Center of the European Commission, a 1-meter flood depth would lead to near 40 percent damage for residential buildings in sampled African countries (Huizinga, de Moel, and Szewczyk 2017). This is used as threshold to define damaging flood and convert the annual maximum flood inundation depth at 500 meters to 1/0 for above/below this threshold. For each decade (2010–19, 2020–29, 2030–39, 2040–49), the occurrence of damaging annual maximum flood events is then aggregated for each model combination and serve as a base for the flood hazard rating, which is defined as below:

- Very high (3): at least 70 percent models agreeing on at least five years of damaging flood in the decade.
- High (2): at least 70 percent models agreeing on at least two years of damaging flood in the decade, excluding areas with very high (3) rating.
- Medium (1): at least 50 percent models agreeing on at least one year of damaging flood in the decade, excluding areas with very high (3) or high (2) rating.
- Low (0): more than 50 percent models agreeing on no damaging flood in the decade.

These definitions consider absolute flood depth, flood defenses in West Africa, and model agreement for each decade, although the thresholds chosen could be changed to define a smaller or larger area for each category. The relative areas of flood hazard ratings are expected to change between the decades not only from global warming trends but also from large interannual and decadal climate variations.

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[88] At the time of this modeling work, flood modeling had not yet been performed for RCP8.5, so RCP6.0 serves as a stand in for the high emissions pathway represented by RCP8.5.

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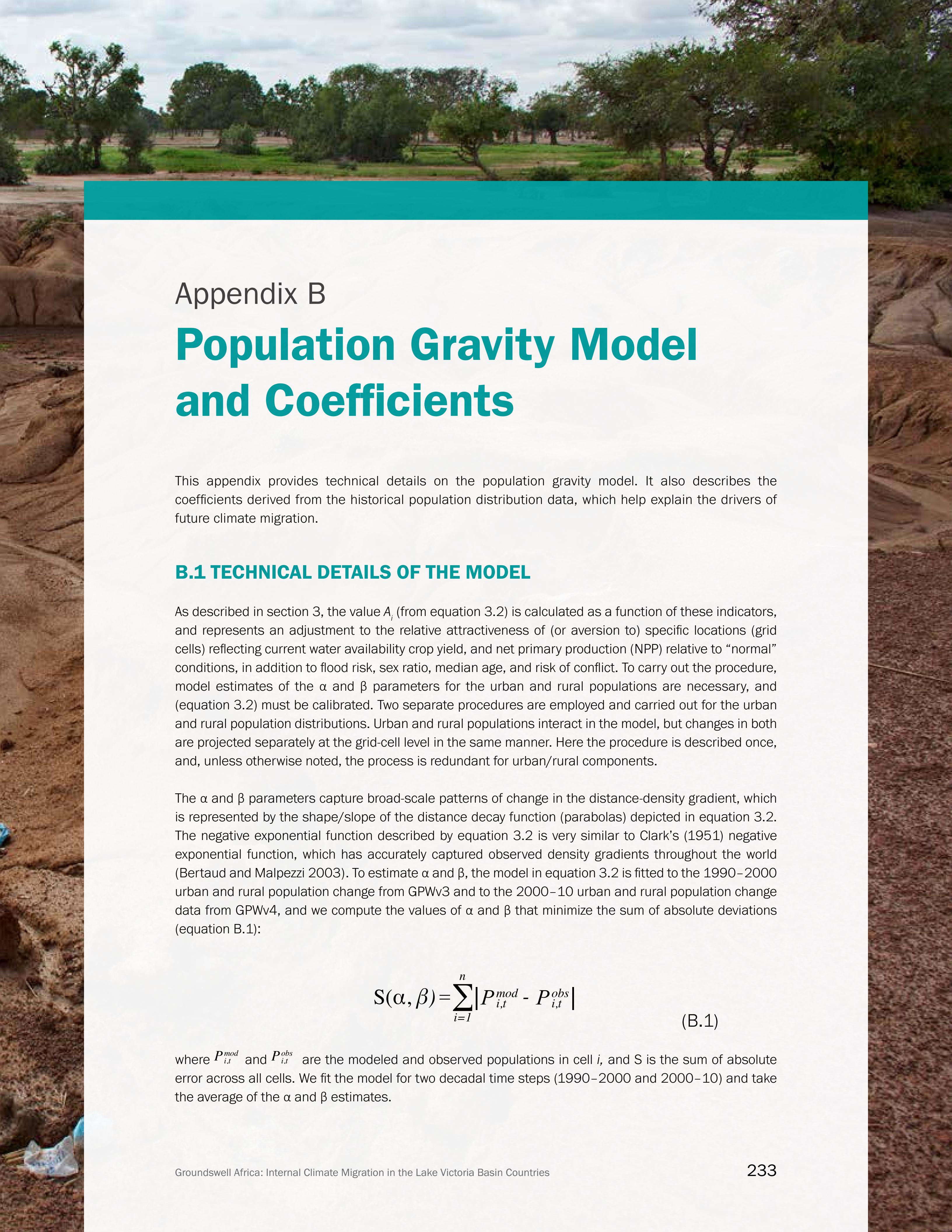


Appendix B

Population Gravity Model and Coefficients

This appendix provides technical details on the population gravity model. It also describes the coefficients derived from the historical population distribution data, which help explain the drivers of future climate migration.

B.1 TECHNICAL DETAILS OF THE MODEL

As described in section 3, the value A_i (from equation 3.2) is calculated as a function of these indicators, and represents an adjustment to the relative attractiveness of (or aversion to) specific locations (grid cells) reflecting current water availability crop yield, and net primary production (NPP) relative to "normal" conditions, in addition to flood risk, sex ratio, median age, and risk of conflict. To carry out the procedure, model estimates of the α and β parameters for the urban and rural populations are necessary, and (equation 3.2) must be calibrated. Two separate procedures are employed and carried out for the urban and rural population distributions. Urban and rural populations interact in the model, but changes in both are projected separately at the grid-cell level in the same manner. Here the procedure is described once, and, unless otherwise noted, the process is redundant for urban/rural components.

The α and β parameters capture broad-scale patterns of change in the distance-density gradient, which is represented by the shape/slope of the distance decay function (parabolas) depicted in equation 3.2. The negative exponential function described by equation 3.2 is very similar to Clark's (1951) negative exponential function, which has accurately captured observed density gradients throughout the world (Bertaud and Malpezzi 2003). To estimate α and β, the model in equation 3.2 is fitted to the 1990–2000 urban and rural population change from GPWv3 and to the 2000–10 urban and rural population change data from GPWv4, and we compute the values of α and β that minimize the sum of absolute deviations (equation B.1):

$$S(\alpha, \beta) = \sum_{i=1}^{n} \left| P_{i,t}^{mod} - P_{i,t}^{obs} \right| \tag{B.1}$$

where $P_{i,t}^{mod}$ and $P_{i,t}^{obs}$ are the modeled and observed populations in cell *i,* and S is the sum of absolute error across all cells. We fit the model for two decadal time steps (1990–2000 and 2000–10) and take the average of the α and β estimates.

In this modified version of the population potential model, the index A_i is a cell-specific metric that weights the relative attractiveness of a location (population potential) as a function of environmental or socioeconomic conditions. The modeling approach requires that the relationship between A_i and the sectoral impact, flood risk, demographic, and conflict indicators is estimated, which are hypothesized to affect population change. When α and β are estimated from historical data (for example, observed change between 2000 and 2010), a predicted population surface is produced that reflects optimized values of α and β, such that absolute error is minimized. Figure B.1 includes a cross-section (one-dimension) of grid cells illustrating observed and predicted population for 10 cells. Each cell contains an error term that reflects the error in the population change projected for each cell over a 10-year time step. It is hypothesized that this error can at least partially be explained by a set of omitted variables, including environmental/sectoral impacts. To incorporate these effects, we first calculate the value of such as to eliminate (from figure B.1) for each individual cell (which is labeled observed) (equation B.2):

$$\Delta P^{obs}_{i,t} = A_i * \Delta P^{mod}_{i,t} \tag{B.2}$$

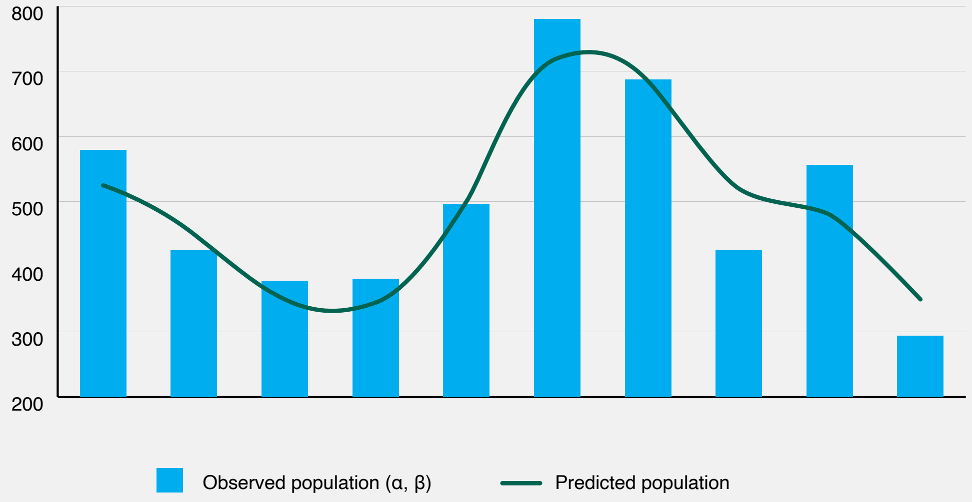
where $P^{obs}_{i,t}$ and $P^{mod}_{i,t}$ are the observed and modeled population change for each cell i and A_i is the factor necessary to equate the two.

The second step is to estimate the relationship between observed index and the different potential drivers of spatial population metrics by fitting a spatial lag model (equation B.3):

$$A_{i,t} = pW A_{i,t} + \beta_1 C_{i,t} + \beta_2 H_{i,t} + \beta_3 N_{i,t} + \beta_4 F_{i,t} + \beta_5 M_{i,t} + \beta_6 S_{i,t} + \beta_7 K_{i,t} + \varepsilon_{i,t} \tag{B.3}$$

where *C, H,* and *N* are the five-year deviations from the historic baseline on crop yield, water availability, and NPP, respectively, *F* is the flood risk metric, M is median age, S is sex ratio expressed as (male/female), and K is the conflict-related fatalities metric. These seven variables and their respective coefficients constitute the set of explanatory variables that produce index A_i For any grid cell in which *C* (crop yield) is a nonzero value, the value of *N* (NPP) is automatically set to zero, so that only one of the two variables is contributing to the index A_i Finally, is the spatial autocorrelation coefficient and *W* is a spatial weight matrix. From this procedure, a set of cell-specific α values is estimated for urban and rural population change.

Figure B.1 Cross-Section of Grid Cells Illustrating Observed and Projected Population Distributions



Note: The error term is used to calibrate the index A(i).

For future projections (for urban and rural populations), projected values are used of $C_{i,t}$, $H_{i,t}$, $N_{i,t}$, and $F_{i,t}$, and current values of $M_{i,t}$, $S_{i,t}$, and , $K_{i,t}$ are used along with their respective coefficient estimates from equation B.3 to estimate spatially and temporally explicit values of A_i Finally, to produce a spatially explicit population projection, estimates of α and β are adjusted to reflect the Shared Socioeconomic Pathways (SSPs) (for example, the SSP4 storyline implies a more concentrated pattern of development than SSP5; see Jones and O'Neill [2016]) to produce estimates of the agglomeration effect, to which the spatio-temporally variant estimates of A_i for the RCPs described above are applied. Finally, exogenous projections of national urban and rural population change are incorporated and the model applied as in equation 3.2.

Because of testing, cells meeting certain criteria are excluded from the calibration procedure. First, cells that are 100 percent restricted from future population growth by the spatial mask (*l,* equation 3.2) are excluded, because the value of v_i in these cells (0), renders the observed value of A_i inconsequential.

Second, the rural and urban distributions of observed A_i include significant outliers that skewed coefficient estimates in equation B.3. In most cases, these values correspond with very lightly populated cells where a small over- or underprediction of the population in absolute terms (for example, 100 persons) is quite large relative to total population within the cell (large percentage error). The value of A_i (the weight on potential), necessary to eliminate these errors, is often proportional to the size of the error in percentage terms, and thus can be quite large even though a very small portion of the total population is affected. Including these large values in equation B.3 would have a substantial impact on coefficient estimates. To combat this problem, the most extreme 2.5 percent of observations are eliminated on either end of the distribution.

Third, because the model is calibrated to urban and rural change separately, cells in which rural population was reclassified as 100 percent urban over the decade (2000–10) were excluded because the effect would be misleading. In the rural distribution of change it would appear an entire cell was depopulated, while in the urban change distribution the same cell would appear to grow rapidly. It would be incorrect to attribute these changes to sectoral impacts when they are the result of a definitional change. In most cases these exclusions eliminate 5 percent to 10 percent of grid cells.

B.2 DRIVERS OF MIGRATION

Table B.1 provides coefficient estimates derived from fitting the spatial autoregressive model to historic population distribution change data for the periods 1990–00 and 2000–10 for each potential driver of spatial population change. The coefficients are derived from an equation that includes each of the potential drivers of migration described in section 3: the index for each decade of water availability, crop production, and ecosystem NPP compared to the historical baseline, as well as the median age and sex ratio of the population in each grid cell, conflict-related fatalities, and flood risk. Because urban and rural populations evolve in fundamentally different ways, we fit the model to observed change in each component of the population separately.

The coefficients should be interpreted as the influence on the *observed deviation between observed population change and predicted population change given only the agglomeration effect*. The values represent the contribution of each driver to the weight on potential (A_i) necessary to eliminate prediction error, which indicates the relative attractiveness of each location. The coefficients are unstandardized. Therefore, they cannot be directly compared (except for the ISIMIP crop, water, and NPP values), because their value can be understood only in relation to the ranges in the values of each data layer. For the ISIMIP values (apart from flood risk) the range is 0–2, whereas the range for median age is roughly 11–26, and for sex ratio the range is 62–250. This means the coefficients for the demographic variables, particularly median age, which is already high, will have a disproportionate impact on future population distribution compared to the climate impact variables. Table B.2 provides the descriptive statistics for each nonclimate variables plus flood risk.

The coefficients in table B.1 represent the average of the coefficients across the two decades, and across three countries used for regional calibration: Mauritania, Guinea, and Sierra Leone. Only these three countries had matching population and population growth rates at the same administrative level across the three time steps from 1990 to 2010.[89] Sea level rise is not considered a driver of migration, but rather is inserted as a spatial mask in the modeling work to move populations out of inundated areas.

Table B.1 Coefficient Values Derived from Calibration for Mauritania, Guinea, and Sierra Leone

Indicator (driver)	(Parameter) coefficient		Units
	Urban cells	Rural cells	
Crop production	n.a.	0.400	5-year deviation from historic baseline
Water availability	1.696	1.071	5-year deviation from historic baseline
Net primary productivity[a]	n.a.	0.380	5-year deviation from historic baseline
Median age	0.617	0.078	Median age of the population in years
Sex ratio	0.024	0.006	(Males/females) ratio
Conflict-related fatalities	−0.025	−0.003	Number of recorded fatalities
Flood risk	0.147	0.020	5-year likelihood of flood event

Note: n.a. = not applicable.

a. Net primary productivity, which is intended to reflect impacts on pastoral populations, is included in the model only where crop production is not present.

The coefficients are unstandardized, and therefore cannot be directly compared (except for the ISIMIP crop, water, and NPP values), since their value can only be understood in relation to the ranges in the values of each data layer. So for the ISIMIP values (apart from flood risk) the range is 0–2, whereas the range for median age is roughly 11–26, and for sex ratio the range is 62–250. This means the coefficients for the demographic variables will have a higher impact on future population distribution than the coefficient values might otherwise suggest. Table B.2 provides the descriptive statistics for each of the non-climate variables plus flood risk, while Table B.3 provides examples of the multiplication of the minimum and maximum values times the rural coefficients.[90] While water availability still has the biggest absolute range in values (3.213) followed by crop production (1.200), median age and sex ratio[91] still have ranges in values of more than 1, which rival the values for crop production and net primary productivity. The impact of the conflict and flood risk variables is, by comparison, very small.

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[89] Were calibration to be applied in countries without matching population and population growth rates at the same level, results would be spurious because changes in population could be due to the changing administrative units used to construct the population grids in each time period.

[90] For example, for median age, the minimum value of 11, when multiplied by the rural coefficient of 0.078, yields a value of 0.858, while the maximum value of 26, when multiplied by the same coefficient yields a value of 2.028.

[91] Sex ratios are read as males per 100 females. The negative coefficient suggests that the higher the sex ratio in an area, the stronger the population decrease, meaning areas with many more males than females typically will see higher declines in population. Compared to the climate variables, the effects are still quite small, but they are higher than for the other non-climate impact variables.

Table B.2 Descriptive Statistics for West Africa for Data Layers

	Min.	Max.	Mean	SD
Median Age	11.0	26.0	17.8	2.3
Sex Ratio	61.5	250.0	105.6	19.9
Conflict-related fatalities	1.0	259.0	5.1	3.9
Flood Risk	0.0	4.0	0.2	0.6

Note: The minimum and maximum values for the ISIMIP values (crop production, water availability, and net primary productivity) are 0 and 2, respectively. SD = Standard deviation.

Table B.3 Results of minimum and maximum values times sample rural coefficients

	Min.	Max.	Coefficients (rural)	Min. x Coefficient	Max. x Coefficient	Absolute Range
Crop production	-1	2	0.4	-0.400	0.800	1.200
Water availability	-1	2	1.071	-1.071	2.142	3.213
Net primary productivity	-1	2	0.38	-0.380	0.760	1.140
Median Age	11	26	0.078	0.858	2.028	1.170
Sex Ratio	61.5	250	0.006	0.369	1.500	1.131
Conflict-related fatalities	1	259	-0.003	-0.003	-0.777	0.774
Flood Risk	0	4	0.02	0.000	0.080	0.080

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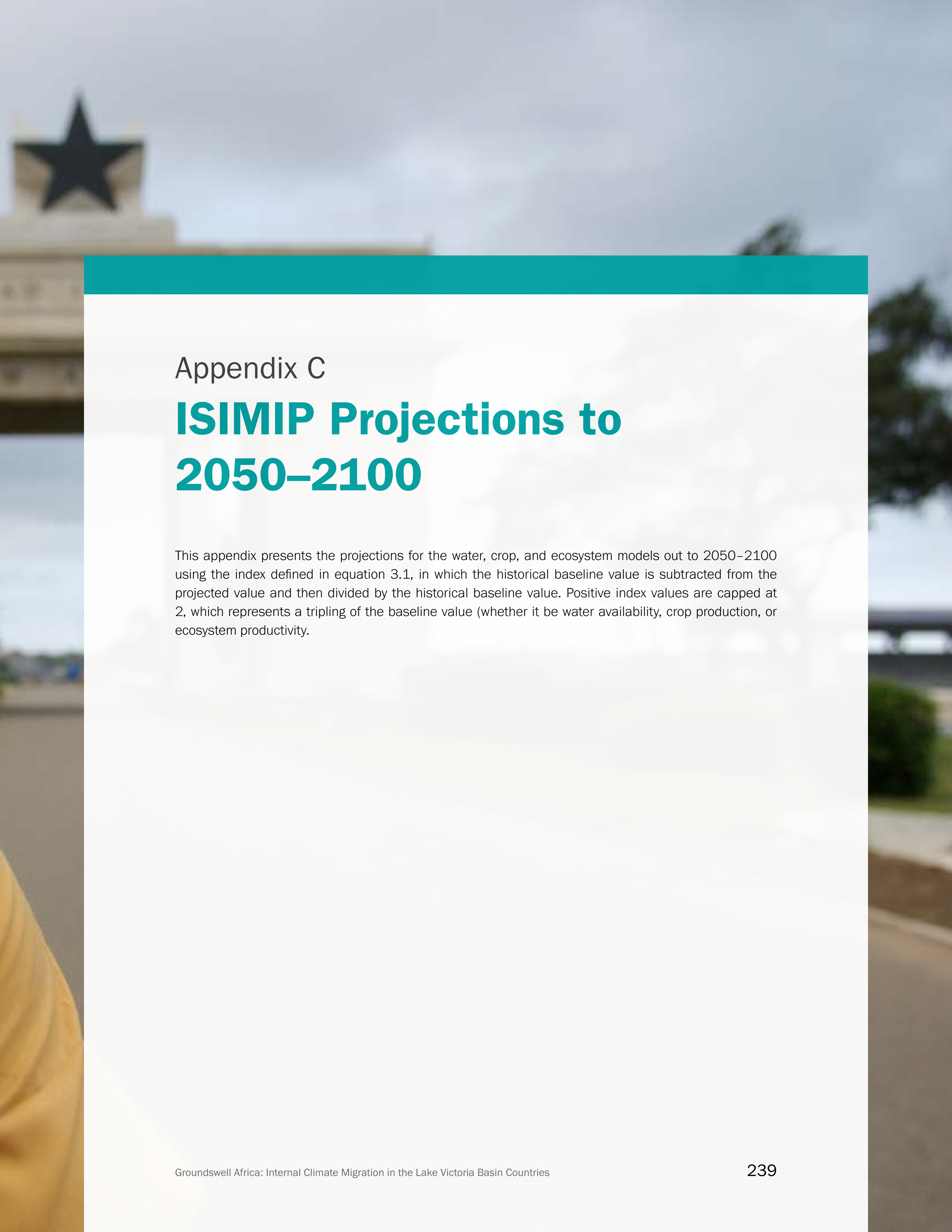
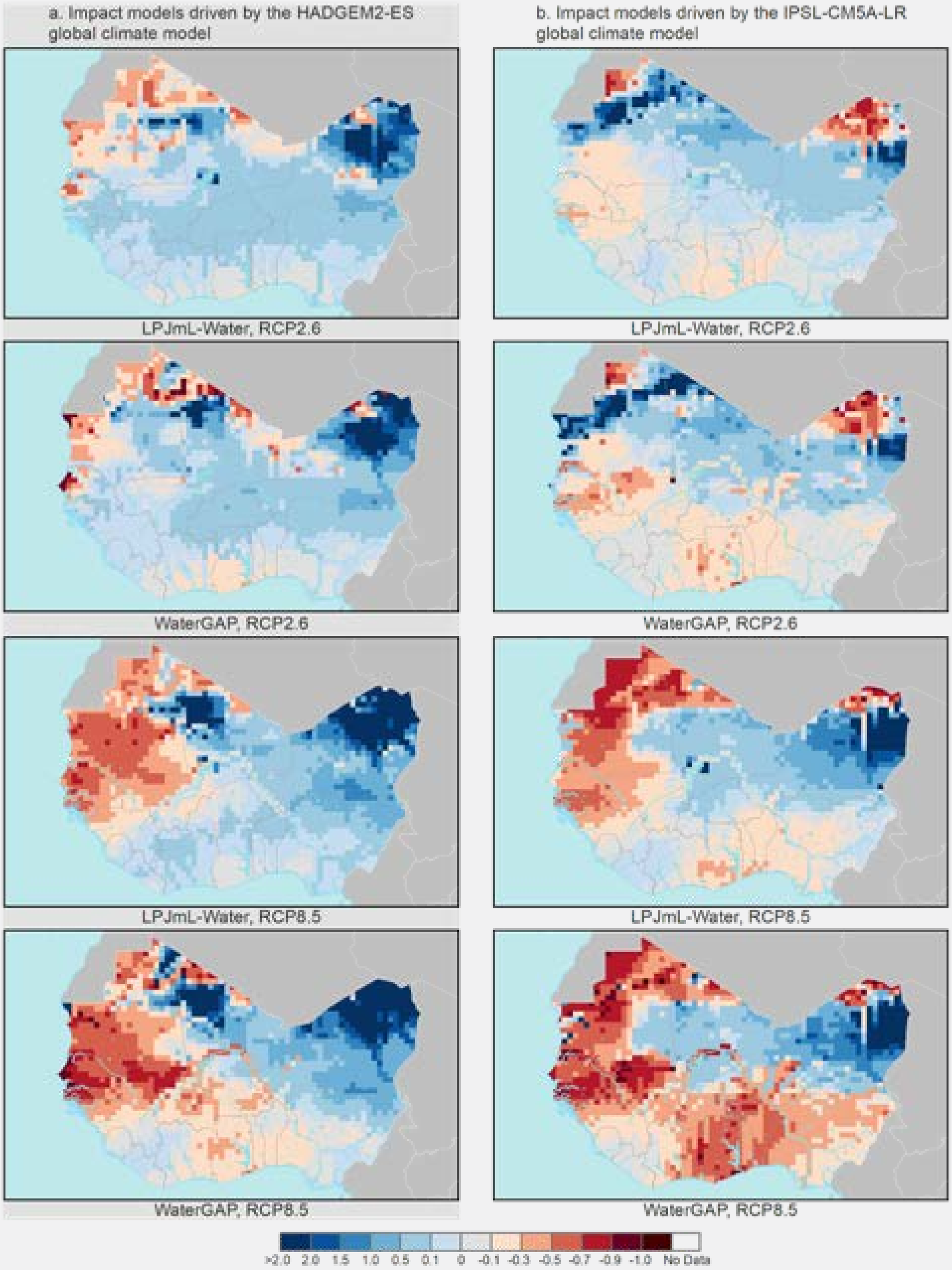


Appendix C

ISIMIP Projections to 2050–2100

This appendix presents the projections for the water, crop, and ecosystem models out to 2050–2100 using the index defined in equation 3.1, in which the historical baseline value is subtracted from the projected value and then divided by the historical baseline value. Positive index values are capped at 2, which represents a tripling of the baseline value (whether it be water availability, crop production, or ecosystem productivity.

Figure C.1 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, West Africa, 2050–2100

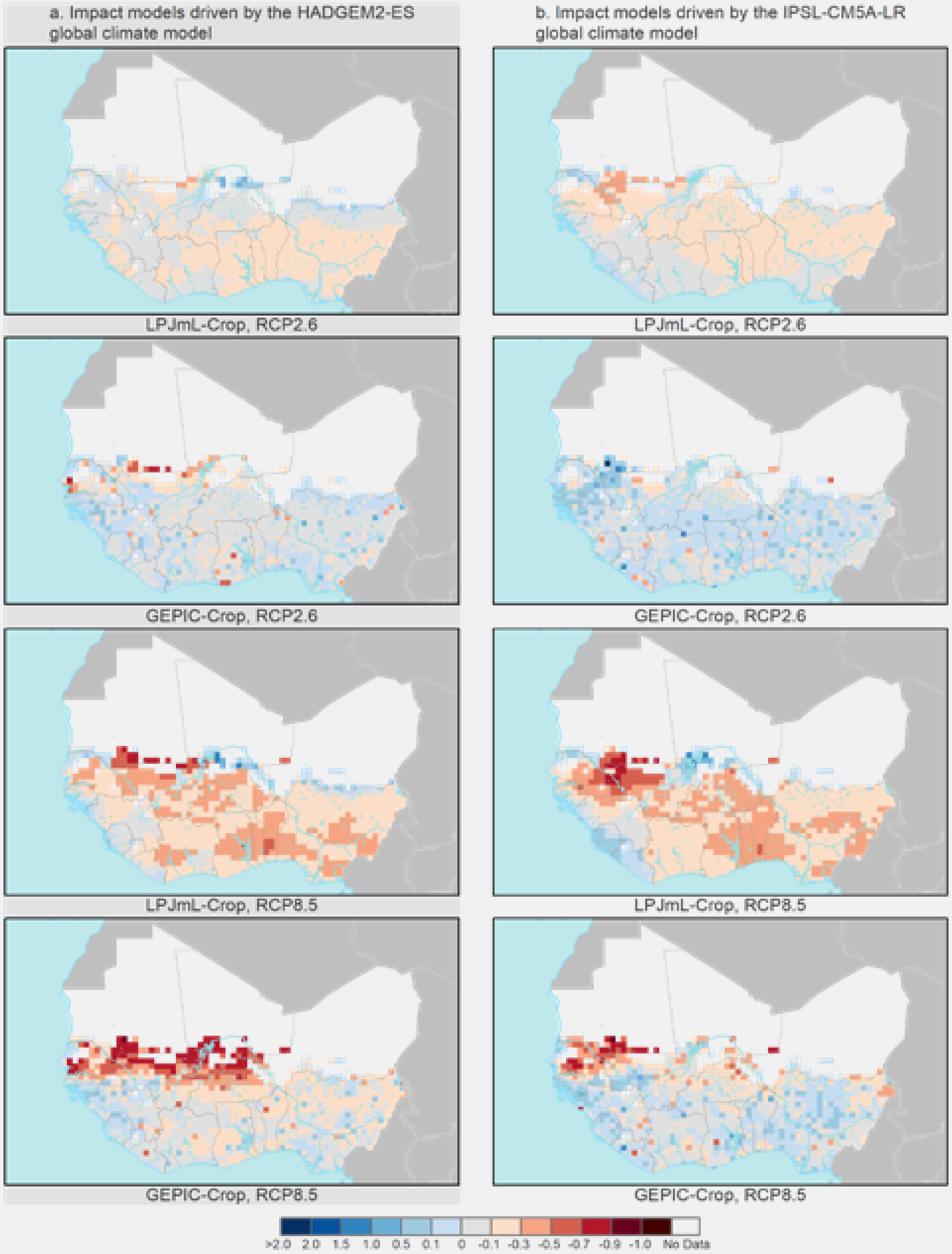


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A-LR global climate model

Note: Data compiled from LPJmL/water (panel a) and WaterGAP (panel b), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline, and gray and tan areas indicate drying.

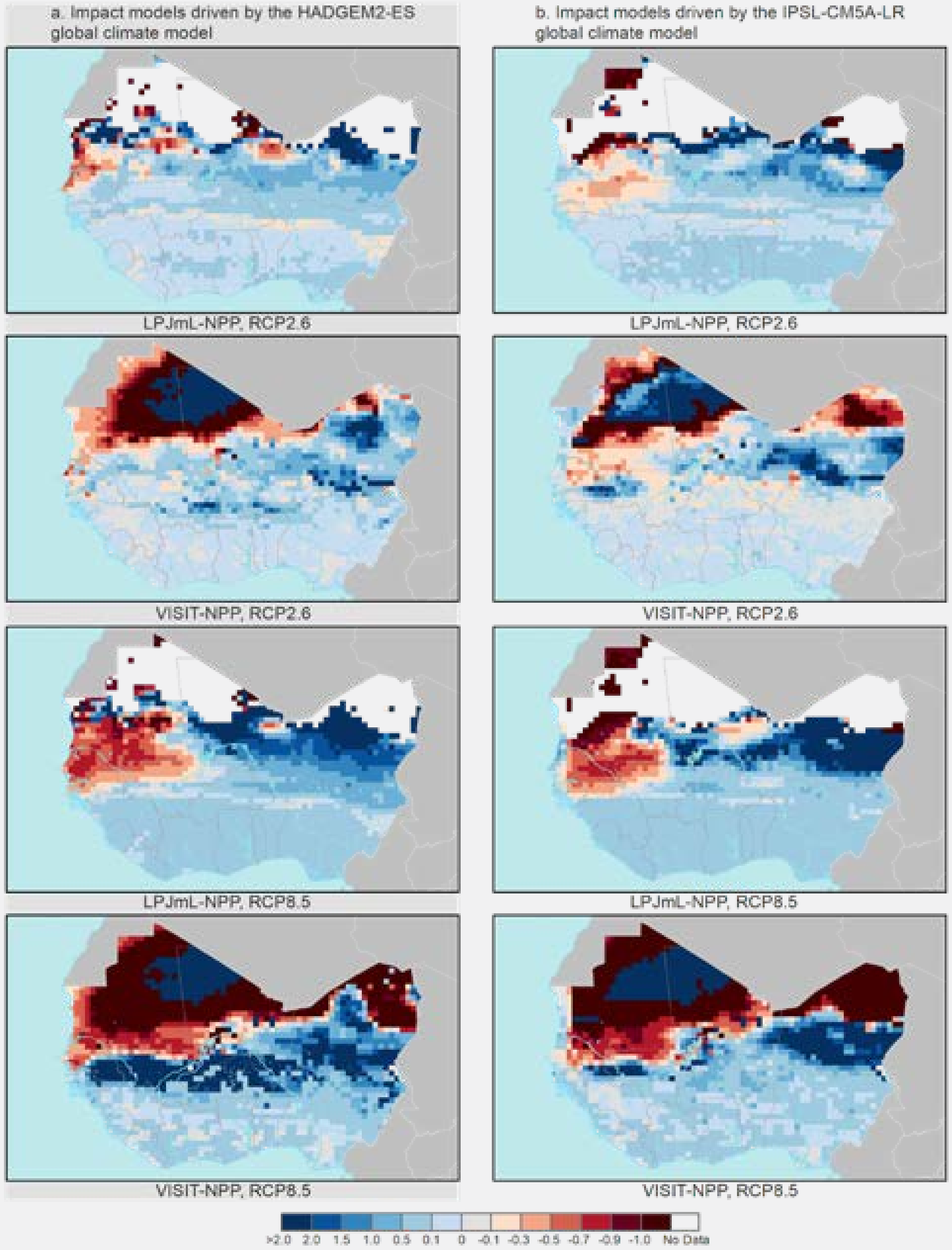
Figure C.2 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, West Africa, 2050–2100


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A-LR global climate model

Note: Data compiled from LPJmL/crop (panel a) and GEPIC (panel b), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline, and tan to red areas indicate drying. White areas do not grow the four major crops.

Figure C.3 ISIMIP Average Index Values against 1970–2010 Baseline for Ecosystem NPP, West Africa, 2050–2100



Note: Data compiled from LPJmL (panel a) and VISIT (panel b), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5. Blue areas indicate higher NPP relative to the historical baseline, and tan to red areas indicate lower NPP. NPP = net primary productivity.

Appendix D

Comparison Between Groundswell and West Africa Results

Comparing the estimated number of internal climate migrants in the original Groundswell report (see table 4.2 in Rigaud et al. [2018]) with the results of this report (denoted as Groundswell Africa) reveals commonalities and differences for three out of four scenarios (there was no optimistic scenario in the original Groundswell report). Similar to the Groundswell model, trajectories of climate migration are highest under the high emission pessimistic (reference) scenario followed by the high emission inclusive development scenario, and lowest under the climate-friendly scenario. The spatial patterns of in- and out-migration hotspots are also broadly similar. Yet overall, estimates for the original Groundswell model are higher than estimates for the Groundswell Africa model. This section provides explanations for these differences before comparing results.

D.1 EXPLANATIONS

A summary list of differences between the two models is found in table 3.1, with additional details found in section 3. Differences between the model outputs come down to two primary factors: the Groundswell Africa model includes more data layers (for example, biome, rapid onsets) that influence the population potential (relative attractiveness) of grid cells during each time step, and the modeling was carried out at a higher resolution.

Additional Data Layers

The Groundswell Africa model includes several additional spatial layers that influence the population potential at each time step. In addition to the effect of climate impacts on crop production, water availability, and sea level rise on future population distributions included in the original Groundswell model, the new model includes spatial data layers representing climate impacts on net primary productivity (NPP) and flood risk, differences in age and sex composition, and conflict-related fatalities. Each of these layers exerts an influence on the relative attractiveness of each grid cell at each time step. This is a function of the magnitude of the value for each variable (for example, strongly positive or negative NPP relative to baseline conditions), the coefficient values obtained from the calibration based on historical climate impacts, and the change in population distribution (from 1990 to 2000 and 2000 to 2010). The coefficient values for the original Groundswell report are in table D.1, and the coefficient values for the new model are in table D.2. Higher coefficient values (positive or negative) equate to higher impacts on the attractiveness of grid cells for any given increment of change for each additional data layer.

The expanded set of covariates and the resolution at which they are applied can lead to lower estimates of the number of internal climate migrants. First, because the Groundswell Africa model is fit to higher-resolution (1-kilometer) data, the coefficients on each covariate are going to vary because of the additional information in the higher resolution spatial data (both the population data used to measure migration and the potential drivers of migration). Tables D.1 and D.2 indicate variability in the crop and water coefficients between the two models. For example, the signal on crop yields on rural population change is noticeably stronger in the version 1 application, while the signal on water stress is very similar (and is the largest explanatory factor). Rural populations are quite large across the region. Therefore, the smaller signal on crop yields would suggest a dampened response to changes in agricultural productivity in the Groundswell Africa model relative to the original Groundswell model.

Finally, the coefficient on median age was high in this region (especially in urban areas), meaning that higher median age distributions were associated with greater attractiveness. This makes sense because urban areas have older age distributions. However, the strong signal on a nonclimate-related parameter in Groundswell Africa may have contributed to the lower number of estimated climate migrants relative to the original Groundswell work. The map of median age distribution (figure 4.6) shows higher median ages coincide with many areas where projected water availability will decline significantly. Water is the climate variable with the strongest effect on future population distribution across urban and rural areas. The result is that while the median age draws migrants to urban areas (particularly along the coasts of Senegal and the Bight of Benin region from Côte d'Ivoire to Nigeria), declines in water availability repel migrants, thereby offsetting each other.[92] Because urban areas are the engines of regional growth and are attractive to migrants, declining water availability dampens their influence. When demographic effects are working against climate impacts, there are fewer migrants. In addition, the short period over which we calibrated (1990 to 2010) may be a further factor, because the uncertainty is large around the coefficients.

Table D.1 Coefficient Values for West African Countries from Groundswell I

Indicator (driver)	(Parameter) coefficient		Units
	Urban cells	Rural cells	
Crop production	0.599	1.077	10-year deviation from historic baseline
Water availability	0.712	1.111	10-year deviation from historic baseline

Source: Rigaud et al. 2018.

Table D.2 Coefficient Values for West African Countries from Groundswell Africa

Indicator (Driver)	(Parameter) coefficient		Units
	Urban cells	Rural cells	
Crop production	n.a.	0.400	5-year deviation from historic baseline
Water availability	1.696	1.071	5-year deviation from historic baseline
Net primary productivity[a]	n.a.	0.380	5-year deviation from historic baseline
Median age	0.617	0.078	Median age of the population in years
Sex ratio	0.024	0.006	(Males/females) ratio
Conflict-related fatalities	−0.025	−0.003	Number of recorded fatalities
Flood risk	0.147	0.020	5-year likelihood of flood event

Note: Data represent an average of the calibrations using historical data for Mauritania, Guinea and Sierra Leone. N.a.= not applicable.

a. Net primary productivity, which is intended to reflect impacts on pastoral populations, is included in the model when crop production is not present.

Finally, because the Groundswell Africa modeling work included the nonclimate layers in both the climate impact and the no climate impact (SSP-only) model runs, their inclusion could serve to dampen (reduce) the difference between the climate and no climate model runs for each scenario. In other words, because the Groundswell Africa model includes a substantially larger number of drivers, there is an increased chance that, at any given location, two or more drivers are essentially compensating for one another (or canceling

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[92] For example, consider an urban location that is experiencing a particularly dry period, but that is also demographically characterized by an older, male-dominated population. While the drying trend would act to push people out of the region (a positive coefficient on water stress means that as water availability declines the attractiveness of a grid cell will also decline), the demographic profile of the city would have a dampening effect on that push, as shown by the positive coefficients on median age and sex ratios (table D.2).

each other out). While the increased number of covariates increases the likelihood of this phenomenon, it also reflects a more realistic representation of the wide range of factors that affect migration trends. In short, the potential for climate to drive migration is not lower. The relative level of the climate parameters has not changed much from the Groundswell modeling work, but the portion of migration the model attributes to them is changing because of the addition of the demographic data layers.

An example specific to Groundswell Africa relates to including NPP. Changes in crop productivity have an influence only where crop production is actually practiced. But large areas of the region do not have arable land because of climatic or other constraints. In such areas, the migration trends predicted by the original Groundswell model were based only on projected water availability (because there is no crop production). It is very likely that in the Groundswell Africa model, changes in NPP had a significant dampening effect on the influence of water across parts of the Sahel and southern Sahara where, in the Groundswell model, movement was projected solely on the basis of changes in water availability.

Including projected changes in NPP in the model will moderate the impact of projected changes in water availability. This interaction is likely the primary cause of the increase in estimated migration in eastern Niger in the Groundswell Africa model (relative to the original version). Instead of moderating the impact of water availability, NPP exacerbates the impact because both NPP and water availability are strongly positive in this region (see figures C.1 and C.3). This hypothesis is borne out by the fact that the Groundswell Africa model produces higher climate migration estimates in Niger than for the original Groundswell model, which apart from the tiny island nation of São Tomé and Príncipe, is the only country in the region in which Groundswell Africa climate migration estimates are substantially higher.

Finally, the crop yield covariate was applied to both urban and rural areas under the original Groundswell model but not in the Groundswell Africa model. This decision is directly tied to the resolution of the models. At coarser resolution, urban areas are less precisely captured by the gridded distribution, which means that it is possible (and even likely) that there are meaningful agricultural effects and urban landscapes within the same approximately 14-square-kilometer grid cell. On the ground this is simply agricultural land existing close to an urban landscape, common throughout the region. However, at 1-square-kilometer resolution it is far less likely that a grid cell exhibits both urban and agricultural characteristics. Quantitatively, this was evident in the statistically significant coefficient on crop yields generated by the original Groundswell model, and the coefficient derived under the Groundswell Africa model was insignificant in urban grid cells (as it was for the NPP variable). It is likely this logical decision contributes to the observed variation in estimated migration across the two models.

Different Resolution and Spatial Definition of a Migrant

For both the original Groundswell and the Groundswell Africa model, we hold the spatial definition of a migrant constant. To be considered a migrant, a person must cross the boundary of a 7.5 arc-minute grid cell, which equates to a move of approximately 14 kilometers, depending on where that person is within the grid cell. This is a reasonable definition. Longer moves suggest more in the way of fundamental life changes (new jobs, livelihoods, educational opportunities, etc.) that we tend to associate with migrants. Shorter moves, here less than approximately 14 kilometers, are more likely associated with a move that reflects less fundamental life changes. Of course, these assumptions may not be applicable everywhere, but in general the definition here fits with those often used by major statistical and government agencies.

The differences between the original Groundswell and Groundswell Africa models may be explained by the concept of intervening opportunities. Under the original Groundswell model, if climate impacts result in changes in population distribution, those changes will be manifested at the resolution of the model, which is 7.5 arc-minutes. This can be interpreted as follows: if a person is compelled to move, then the mover will cross a 7.5 arc-minute grid cell boundary, since that is the smallest areal unit considered by the model. However, for the Groundswell Africa model, the gravity model is run at the resolution of 1 kilometer, and results at that resolution are summarized at the 14-kilometer resolution (to conform to the spatially defined concept of migration). Thus, changes in population distribution that occur at the 1-kilometer resolution are averaged over the 7.5 arc-minute grid cell so that the population change may be attenuated. When interpreted in terms of migration, potential movers are offered destinations (intervening opportunities) that, if selected, would not qualify them as migrants because the distance is too small. For example, if a person leaves a 1-kilometer grid cell for another grid cell 5 kilometers away, but that does not cross a 7.5 arc-minute grid cell boundary, that person does not count as a migrant.

Conceptually, this approach is probably more realistic; however, compared to the original model, when conditions varied between 7.5 arc-minute cells such that a place became less attractive, movers either had to migrate or not migrate; short distance moves were not an option. Thus, if the same population were hypothetically exposed to the same risk of migrating but offered a different set of destinations that vary by resolution, it is likely that the model offering shorter-distance options will produce an estimate of total migrants lower than that of the model that does not, because the former has intervening opportunities that do not meet the definition of migration here.

In the Groundswell Africa model, coastal migration numbers are calculated at the 1-kilometer resolution using the outputs of the gravity modeling but are summarized in the 5-kilometer coastal band for the entire country. This means that the definition of a climate migrant is changed in this special case, because it is likely that many people will simply move back from the coastline a sufficient distance to avoid the effects of sea level rise and storm surge.

D.2 COMPARISON OF RESULTS

Estimates for the original Groundswell model are higher than those for the West Africa model, except in the cases of Niger and São Tomé and Príncipe. Table D.3 compares the projected number of internal climate migrants in West African countries in the original Groundswell and Groundswell Africa (West Africa).

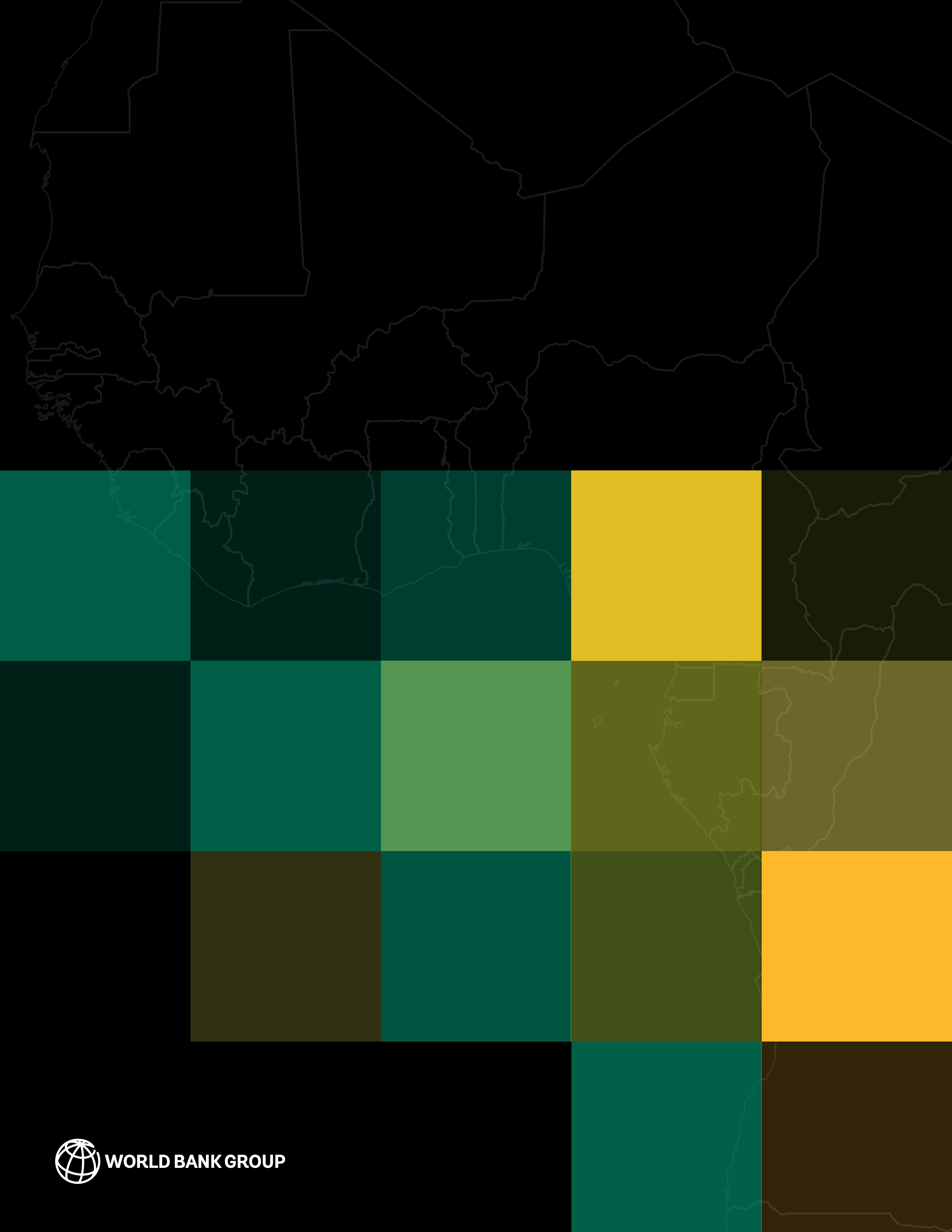
Table D.3 Comparison of Model Results for West Africa

The optimistic scenario was only conducted for the Groundswell Africa study.

Country	Scenario	Projected total population in the original Groundswell report	Projected number of internal climate migrants in the original Groundswell	Projected internal climate migrants in the original Groundswell (SD)	Total population in Groundswell Africa (West Africa)	Projected internal climate migrants in Groundswell Africa (West Africa)	Projected iternal climate migrants in Groundswell Africa (West Africa) (SD)	Difference in projected number of internal climate migrants between Groundswell Africa (West Africa) and the original Groundswell (Groundswell Africa (West Africa) - orignal Groundswell)
Benin	Optimistic	-	-	-	19,213,739.01	99,084.09	2,157.71	-
Benin	More climate-friendly	23,690,197	339,795	48,726	21,014,523.41	161,630	2,132	**-178,165**
Benin	More inclusive development	21,546,150	631,161	86,824	19213739.01	225,898	3,088	**-405,263**
Benin	Pessimistic (reference)	23,552,010	818,855	128,077	21,014,523.45	339,838	2,652	**-479,017**
Burkina Faso	Optimistic	-	-	-	38,601,849.38	113,189.54	97,036.42	-
Burkina Faso	More climate-friendly	48,672,201	741,885	229,997	45,887,153.94	107,031	111,706	**-634,854**
Burkina Faso	More inclusive development	41,066,593	1,563,352	938,872	38601849.38	358,588	261,094	**-1,204,764**
Burkina Faso	Pessimistic (reference)	48,676,466	2,206,195	1,330,056	45,887,153.94	298,256	209,469	**-1,907,939**
Cabo Verde	Optimistic	-	-	-	573,207.66	2,472.33	829.69	-
Cabo Verde	More climate-friendly	487,981	12,426	3,640	520,584.31	3,046	1,003	**-9,380**
Cabo Verde	More inclusive development	498,743	22,341	5,543	573207.4857	15,963	16,478	**-6,379**
Cabo Verde	Pessimistic (reference)	510,642	27,701	7,659	520,584.16	16,141	15,498	**-11,561**
Côte d'Ivoire	Optimistic	-	-	-	30,619,321.34	23,418.84	4,733.74	-
Côte d'Ivoire	More climate-friendly	39,261,854	502,102	81,083	37,294,515.05	49,276	10,641	**-452,826**
Côte d'Ivoire	More inclusive development	32,427,837	564,843	149,425	30619321.02	52,510	13,911	**-512,332**
Côte d'Ivoire	Pessimistic (reference)	39,262,499	1,093,126	271,184	37,294,514.66	116,840	37,782	**-976,286**
Gambia, The	Optimistic	-	-	-	3,273,075.62	3,023.24	956.56	-
Gambia, The	More climate-friendly	4,621,775	81,737	28,389	3,729,752.27	4,649	1,165	**-77,089**
Gambia, The	More inclusive development	4,089,157	255,068	87,322	3273075.706	13,772	5,298	**-241,296**
Gambia, The	Pessimistic (reference)	4,770,421	376,336	138,869	3,729,752.36	56,997	47,074	**-319,340**
Ghana	Optimistic	-	-	-	46,376,231.38	102,408.07	32,289.44	-
Ghana	More climate-friendly	57,830,154	811,651	164,890	54,060,789.33	147,152	52,109	**-664,498**
Ghana	More inclusive development	49,665,186	1,387,923	409,590	46376231.41	228,468	66,042	**-1,159,455**
Ghana	Pessimistic (reference)	57,818,067	2,194,162	669,726	54,060,789.35	327,176	133,298	**-1,866,986**
Guinea	Optimistic	-	-	-	15,479,772.10	7,229.48	823.72	-
Guinea	More climate-friendly	19,615,661	159,311	57,112	17,599,029.31	11,991	866	**-147,319**
Guinea	More inclusive development	17,394,016	353,586	35,072	15479771.72	26,137	1,159	**-327,449**

Country	Scenario	Projected total population in the original Groundswell report	Projected number of internal climate migrants in the original Groundswell	Projected internal climate migrants in the original Groundswell (SD)	Total population in Groundswell Africa (West Africa)	Projected internal climate migrants in Groundswell Africa (West Africa)	Projected iternal climate migrants in Groundswell Africa (West Africa) (SD)	Difference in projected number of internal climate migrants between Groundswell Africa (West Africa) and the original Groundswell (Groundswell Africa (West Africa) - orignal Groundswell)
Guinea	Pessimistic (reference)	19,704,317	538,605	56,900	17,599,028.97	46,053	1,161	**-492,552**
Guinea-Bissau	Optimistic	-	-	-	2,488,421.53	1,366.86	628.77	-
Guinea-Bissau	More climate-friendly	3,460,118	47,589	9,942	2,733,208.83	2,722	1,190	**-44,868**
Guinea-Bissau	More inclusive development	3,211,673	178,064	43,954	2488421.413	7,286	3,457	**-170,778**
Guinea-Bissau	Pessimistic (reference)	3,670,554	266,687	116,586	2,733,209.27	13,941	4,855	**-252,746**
Liberia	Optimistic	-	-	-	11,093,543.89	10,806.39	4,239.72	-
Liberia	More climate-friendly	13,720,318	101,855	51,791	12,453,786.00	11,446	2,938	**-90,410**
Liberia	More inclusive development	12,204,987	217,205	121,937	11093544.16	26,967	8,253	**-190,238**
Liberia	Pessimistic (reference)	13,734,446	270,708	154,550	12,453,786.28	27,532	6,957	**-243,176**
Mali	Optimistic	-	-	-	35,910,201.17	164,338.31	7,391.14	-
Mali	More climate-friendly	42,911,212	955,099	331,551	41,045,328.86	91,357	22,546	**-863,743**
Mali	More inclusive development	37,661,103	2,372,533	520,502	35910201.17	526,066	204,132	**-1,846,467**
Mali	Pessimistic (reference)	43,042,918	3,057,370	776,613	41,045,328.86	340,006	119,458	**-2,717,364**
Mauritania	Optimistic	-	-	-	6,271,098.33	28,511.51	5,074.08	-
Mauritania	More climate-friendly	8,319,214	275,667	16,960	7,151,487.41	34,435	10,898	**-241,231**
Mauritania	More inclusive development	7,587,610	888,538	221,987	6,271,098	100,231	53,163	**-788,307**
Mauritania	Pessimistic (reference)	8,826,114	1,143,404	269,442	7,151,487.41	91,085	24,102	**-1,052,318**
Niger	Optimistic	-	-	-	50,943,358.67	5,581,698.29	8,786,035.91	-
Niger	More climate-friendly	68,877,181	3,171,600	1,114,904	63,203,161.20	6,222,214	9,633,910	**3,050,615**
Niger	More inclusive development	56,712,462	5,630,935	1,246,286	50943358.67	7,506,778	10,068,496	**1,875,843**
Niger	Pessimistic (reference)	70,010,615	7,602,129	1,896,305	63,203,161.20	8,499,456	10,842,256	**897,327**
Nigeria	Optimistic	-	-	-	371,695,000.02	1,119,370.37	704,792.12	-
Nigeria	More climate-friendly	437,216,780	10,417,671	6,462,415	431,132,379.65	3,919,560	2,019,869	**-6,498,111**
Nigeria	More inclusive development	376,852,304	22,850,623	5,029,929	371695000	5,140,615	1,536,759	**-17,710,008**
Nigeria	Pessimistic (reference)	437,470,422	31,766,020	7,277,850	431,132,379.65	8,321,962	1,089,574	**-23,444,058**
Sao Tome and Principe	Optimistic	-	-	-	211,017.25	65.62	19.78	-
São Tomé and Príncipe	More climate-friendly	239,697	48	14	239,633.93	52	44	**4**
São Tomé and Príncipe	**More inclusive development**	**211,232**	**90**	**38**	**211166.3132**	**163**	**46**	**73**

Country	Scenario	Projected total population in the original Groundswell report	Projected number of internal climate migrants in the original Groundswell	Projected internal climate migrants in the original Groundswell (SD)	Total population in Groundswell Africa (West Africa)	Projected internal climate migrants in Groundswell Africa (West Africa)	Projected iternal climate migrants in Groundswell Africa (West Africa) (SD)	Difference in projected number of internal climate migrants between Groundswell Africa (West Africa) and the original Groundswell (Groundswell Africa (West Africa) - orignal Groundswell)
São Tomé and Príncipe	Pessimistic (reference)	239,697	121	44	239,632.99	177	41	57
Senegal	Optimistic	-	-	-	24,251,961.22	91,573.64	32,147.64	-
Senegal	More climate-friendly	32,865,674	1,062,589	161,503	30,505,192.30	133,769	64,786	-928,820
Senegal	More inclusive development	26,337,344	3,344,603	976,437	24,251,961.21	382,214	232,987	-2,962,389
Senegal	Pessimistic (reference)	32,843,285	5,551,508	2,114,996	30,505,192.14	602,646	421,798	-4,948,862
Sierra Leone	Optimistic	-	-	-	11,279,031.12	28,186.16	6,562.01	-
Sierra Leone	More climate-friendly	12,885,479	57,827	20,632	12,220,808.41	30,074	4,511	-27,753
Sierra Leone	More inclusive development	11,885,089	122,232	12,027	11279030.82	114,696	23,864	-7,536
Sierra Leone	Pessimistic (reference)	12,883,912	156,826	21,659	12,220,808.08	125,253	20,713	-31,573
Togo	Optimistic	-	-	-	10,349,349.25	13,723.88	3,440.52	-
Togo	More climate-friendly	14,259,033	162,146	53,847	11,059,249.99	29,394	10,976	-132,751
Togo	More inclusive development	13,227,650	254,902	68,059	10349348.87	31,040	4,237	-223,862
Togo	Pessimistic (reference)	14,313,135	409,220	107,192	11,059,249.56	74,583	24,230	-334,637
West Africa	Optimistic	-	-	-	676,141,757.40	7,389,099.75	8,814,921.11	-
West Africa	More climate-friendly	791,594,251	17,940,358	6,978,888	789117375.4	10,959,798	9,844,409	-6,980,560
West Africa	More inclusive development	678,347,510	38,464,857	6,640,606	676141905.3	14,757,392	10,193,563	-23,707,465
West Africa	Pessimistic (reference)	791,594,251	54,401,044	9,785,078	789117373.1	19,297,942	10,908,761	-35,103,102



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