

# GROUNDSWELL AFRICA

## INTERNAL CLIMATE MIGRATION IN THE LAKE VICTORIA BASIN COUNTRIES

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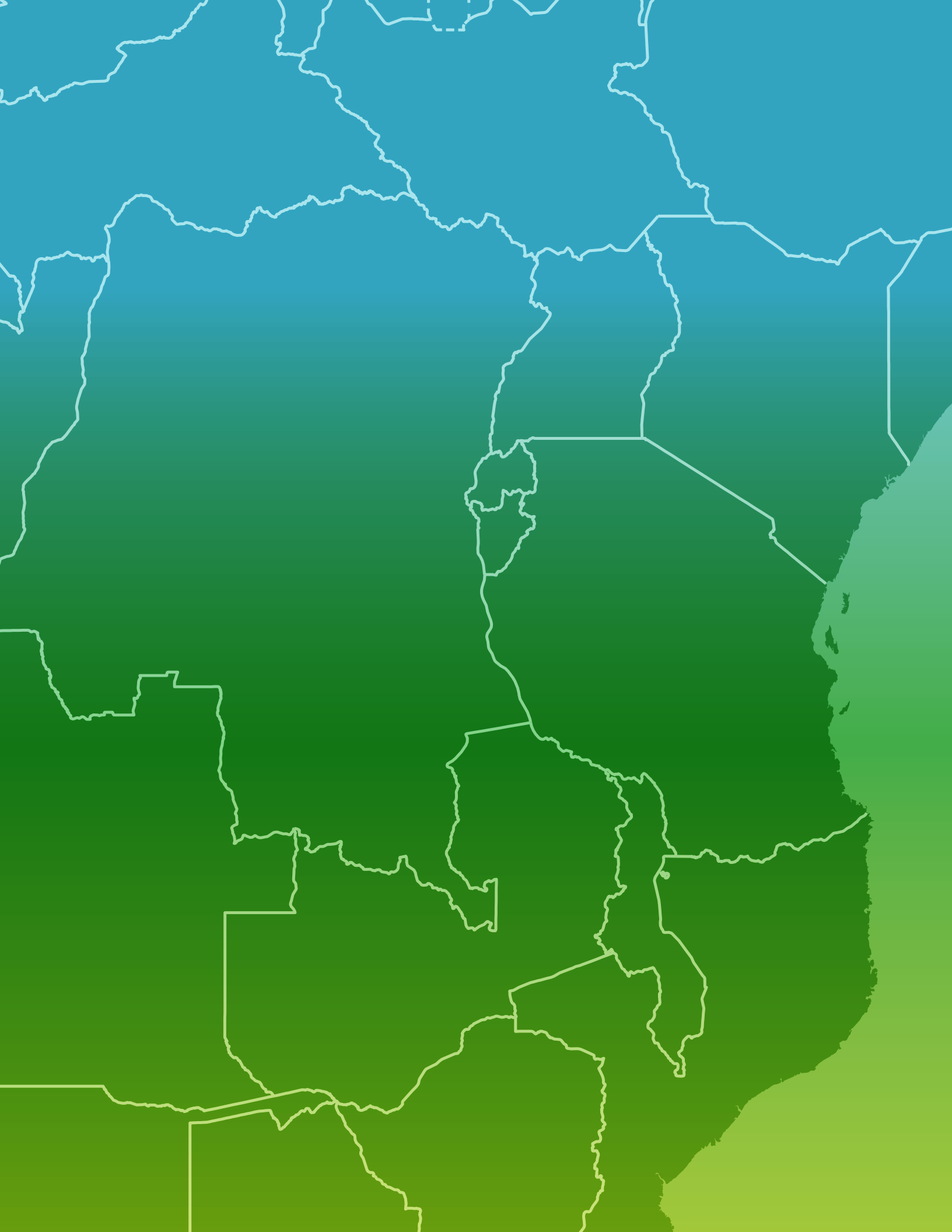
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# Glossary

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

**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.

**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 a number of 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 as a result 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 nonclimate 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 into account climate impacts 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 into account climate impacts 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.

**Country Partnership Framework (CPF):** Strategic document that guides the World Bank’s 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 analyse 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 as a result 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 not moving away from a place of risk due to choice.

**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 or cross-border 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:** An approach 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 i.e., adapt in place, enable mobility, and 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 estimates 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 as a result of 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 as a result of 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. 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 (SCD):** Tool used by the World Bank 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.

**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.

**Transformation:** The strategies and actions that reduce the root cause of vulnerability or fundamentally alter the state that results in climate induced migration.

**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

<b>ACLED</b>	Armed Conflict Location & Event Data Project
<b>CCDR</b>	Country Climate Development Report
<b>CIESIN</b>	Center for International Earth Science Information Network
<b>CMIP5</b>	Coupled Model Intercomparison Project phase 5
<b>CPF</b>	Country Partnership Framework
<b>DRDIP</b>	Development Response to Displacement Impacts Project
<b>EAC</b>	East African Community
<b>ENSO</b>	El Niño–Southern Oscillation
<b>FYDP</b>	Five-Year Development Plan
<b>GCM</b>	global climate model
<b>GDP</b>	gross domestic product
<b>GHG</b>	greenhouse gas
<b>GHM</b>	global hydrological model
<b>GoK</b>	Government of Kenya
<b>GPW</b>	Gridded Population of the World
<b>GRID</b>	Global Report on Internal Displacement
<b>ICT</b>	Information and Communications Technology
<b>IDP</b>	Internally displaced person
<b>IGAD</b>	Intergovernmental Authority on Development
<b>IOM</b>	International Organization for Migration
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>ISIMIP</b>	Intersectoral Impacts Model Intercomparison Project
<b>ITCZ</b>	Inter-Tropical Convergence Zone
<b>LECZ</b>	Low Elevation Coastal Zone
<b>LIC</b>	low-income country
<b>LMIC</b>	lower-middle-income country
<b>LVB</b>	Lake Victoria Basin
<b>MACS</b>	Migration and Climate-informed Solutions
<b>MIC</b>	middle-income country
<b>NAPA</b>	National Adaptation Programme of Action
<b>NCAR-CIDR</b>	National Center for Atmospheric Research-CUNY Institute for Demographic Research
<b>NCPD</b>	National Council on Population and Development
<b>NETIP</b>	Northeastern Transport Improvement Project
<b>NPP</b>	Net primary productivity
<b>OHCHR</b>	Office of the United Nations High Commissioner for Human Rights
<b>PDD</b>	Platform on Disaster Displacement
<b>RCM</b>	regional climate model
<b>RCP</b>	Representative Concentration Pathway
<b>SCD</b>	Systematic Country Diagnostic
<b>SDG</b>	Sustainable Development Goal
<b>SSP</b>	Shared Socioeconomic Pathway
<b>SST</b>	sea surface temperature
<b>UNHCR</b>	United Nations High Commissioner for Refugees
<b>WACA</b>	West Africa Coastal Areas

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The report benefited from a virtual consultation in February 2021 with stakeholders from civil society, government institutions, and academia, as well as regional and international organizations and donors. Participants included representatives from Burundi, Kenya, Tanzania, as well as the African Union, GIZ, the Intergovernmental Authority on Development (IGAD), the Internal Displacement Monitoring Centre (IDMC), the International Crisis Group, the International Organization for Migration (IOM), United Cities and Local Governments of Africa (UCLG Africa), the United Nations Development Programme (UNDP), the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), and UN-Habitat.

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Sarah Farhat / World Bank

# GROUNDSWELL AFRICA

## LAKE VICTORIA BASIN COUNTRIES

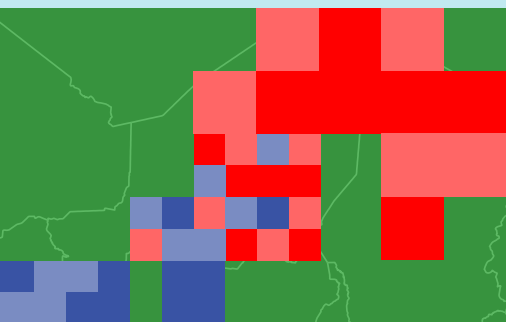


**16.6 - 38.5 million**

internal climate migrants in the Lake Victoria Basin countries by 2050.

**30% reduction**

in internal climate migrants across the Basin countries by 2050 with concrete climate and development action.



**Climate migration hotspots could emerge as early as 2030**

and continue to intensify and expand to 2050

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

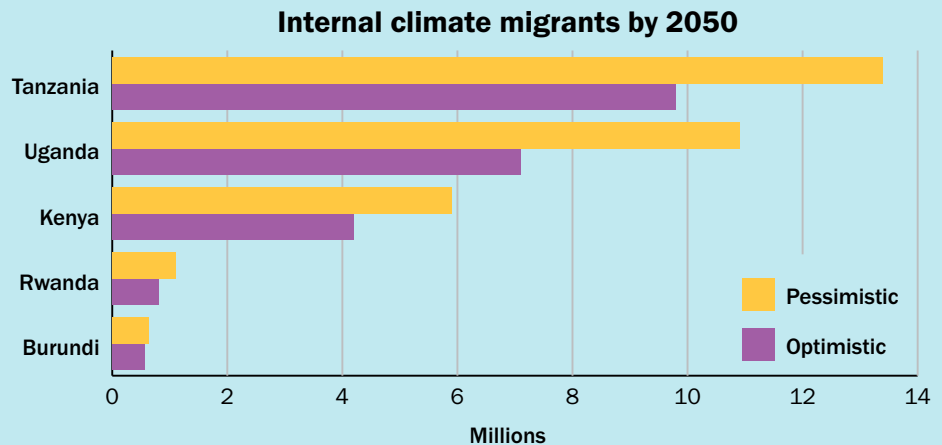


Median age

# Locality and context matter

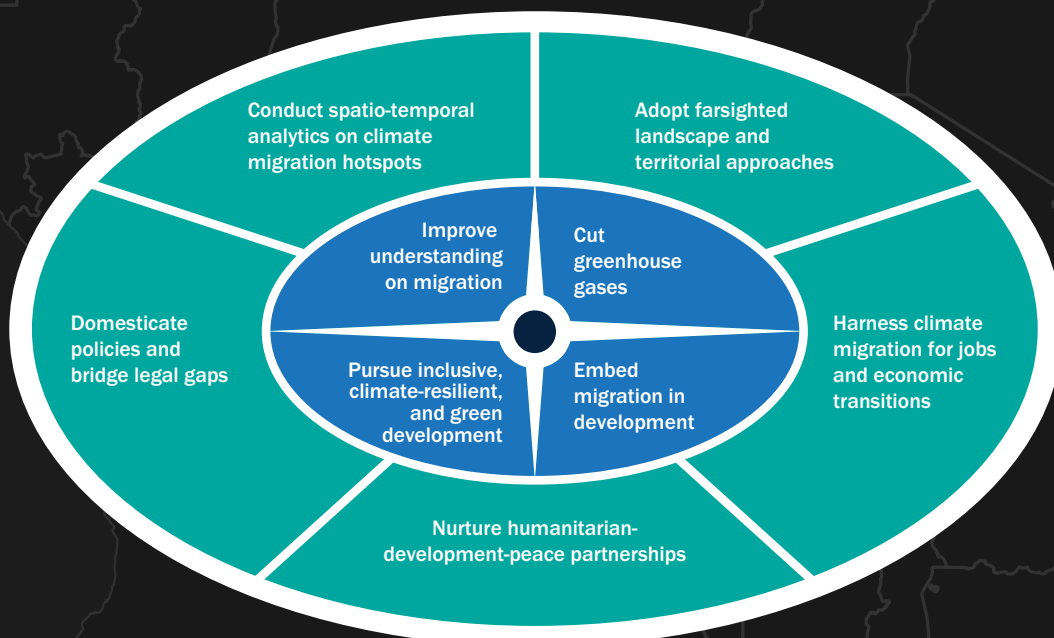
**Internal climate migration is not uniform across countries. Some areas will be more adversely impacted by climate change than others.**

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



## TAKING RESULTS TO ACTION

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





# Foreword

Amid a drought, a young family in Burundi must decide whether they will be better off staying at their home to farm the family plot or if they take the risk to search for better opportunities elsewhere. Another farmer in Tanzania knows he must leave but is deciding whether to look for other farmland or move to the city in search of new work. In Uganda, a mother that lacks safe drinking water also lacks the money to move and will stay put despite the health risks. In Rwanda, engineers are redesigning city streets to make them less prone to flooding and overcrowding amid an influx of newcomers. These are some of the decisions facing people in the Lake Victoria Basin as climate change impacts communities—decisions that are becoming increasingly common and increasingly critical to get right.



**Hafez Ghanem**  
World Bank Vice President  
Africa East and Southern Region

Without broad, urgent action in the Lake Victoria Basin, which extends into five countries—Kenya, Tanzania, Uganda, Burundi, and Rwanda—as many as 38.5 million people could be internally displaced as a consequence of climate change by 2050.

This report builds on the landmark 2018 *Groundswell* report, providing an update on climate migration trends in Lake Victoria Basin and expanding the analysis to provide more detailed information that can better inform policy makers and planners.

The report identifies hotspots where climate migration is expected to be felt most acutely. Communities that struggle to get by will see people leave for greener pastures, cleaner or more abundant water, or less risky settings while communities that fare relatively well will see people arrive, putting pressure on limited resources and job opportunities. And amid these seismic shifts, those in living in poverty or in fragile or conflict-prone settings are most vulnerable.

Still, the scenarios for climate migration presented in this report are not foregone conclusions—but local, national, and global action is urgently needed to drastically cut greenhouse gas emissions on the one hand and invest in adaptation and resilience on the other hand.

Together, these dual objectives can unlock new opportunities for low-carbon, resilient development that protects communities from the worst effects of climate change and stimulates opportunities for growth and job creation.

The World Bank Group's new Climate Change Action Plan, which complements the Next Generation Africa Climate Business Plan, commits that over the next 5 years, 35 percent of World Bank Group financing will directly contribute to climate action. This commitment will support the countries of the Lake Victoria Basin as they work to address climate change and pursue low-carbon, resilient development pathways.

Together, we can help families make safer, less risky decisions about their future, we can help communities get the services and resources they need to stay healthy, and we can help countries pursue resilient, long-term development—all of which allows people to truly thrive, unlocking new opportunities for innovation and promoting greater equity in development outcomes.

A handwritten signature in black ink, appearing to read 'Hafez Ghanem'.



Sarah Farhat / World Bank



# Executive Summary

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## MESSAGE 1:

**The scale of internal climate migration across all five Lake Victoria Basin countries is projected to increase significantly by 2050, unless we pursue urgent and concrete climate and development focused action.**

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**The Lake Victoria Basin (LVB) is one of the most mobile regions in the world, with a long history of trade, nomadic pastoralism, and dry season migration for livelihood diversification.** Migration (or mobility, more broadly) in the five Basin countries—Burundi, Kenya, Rwanda, Tanzania, and Uganda—is intrinsically linked to the history, traditions, and social fabric. These are embedded in 20th-century colonial legacies and post-independence strategies, which are entrenched in broader geographical and climate characteristics. The Basin contains the largest tropical freshwater lake in the world and has relatively moderate temperatures throughout the year. Climate change stressors, such as change in rainfall patterns, endanger ecological resilience, and affect migration patterns because populations have increased demand for land, food, and hydrological resources.

**Migration in the Lake Victoria Basin is driven by various economic, social, religious, political, environmental, and increasing, climate “push and pull” factors.** In Rwanda, migration is primarily practiced by the working age group (16 years old and older) and includes both long-term and temporary or circular migration. Urban centers in Tanzania, such as Dar es Salaam, Mwanza, and Arusha, attract migrants because of economic opportunities, availability of land for settlement, and rich natural resources. Uganda, with 1.5 million refugees, is the third biggest refugee-housing country in the world and the largest in Africa. Burundi has a history of conflict displacement, including both refugee flows and internal displacement. Kenya has witnessed rural to urban flows to large and medium cities and nomadism of pastoral groups in the northern regions. Nomadic pastoralists in the Basin depend on favorable climate, and severe droughts have aggravated recurring tensions between farmers and pastoralists. Environmental shocks and climate variability have affected agricultural productivity, which coupled with population pressures, have amplified rural to urban and rural to rural migration patterns across the Basin.

**This Lake Victoria Basin 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).

**Without concrete climate and development action, the five Lake Victoria Basin countries could see as many as 38.5 million internal climate migrants (10.48 percent of the population) by 2050 as a consequence of slow onset climate impacts (Figure ES.1).** This number could be reduced by around 30 percent under the optimistic scenario, which combines low emissions and moderate pathways. 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. No country in the Lake Victoria Basin is immune to internal climate migration, but there are differences among countries depending on their demographic, economic, and climate trends (Figure ES.2). Tanzania and Uganda are projected to have the highest numbers of internal climate migrants by 2050, reaching a high of 16.6 million and 12.0 million, respectively, under the pessimistic scenario (which combines high emissions with unequal development pathways). This will be followed by Kenya (7.6 million), Rwanda (1.2 million), and Burundi (1.0 million). A similar pattern emerges when we consider the share of internal climate migrants to total population. Tanzania exhibits the highest percentage under the high end of the pessimistic scenario (13.97 percent), followed by Uganda (10.72 percent) and Kenya (8.29 percent).



Simone D. McCourtie / World Bank

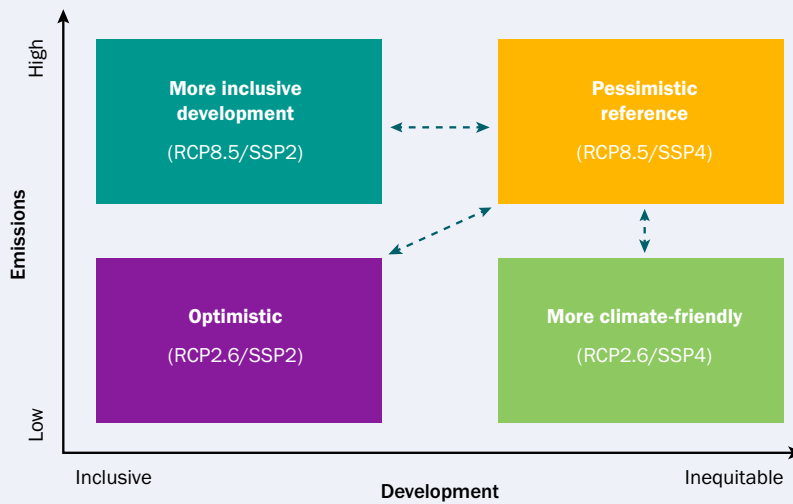
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### Box ES.1: An Enhanced Groundswell Model

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



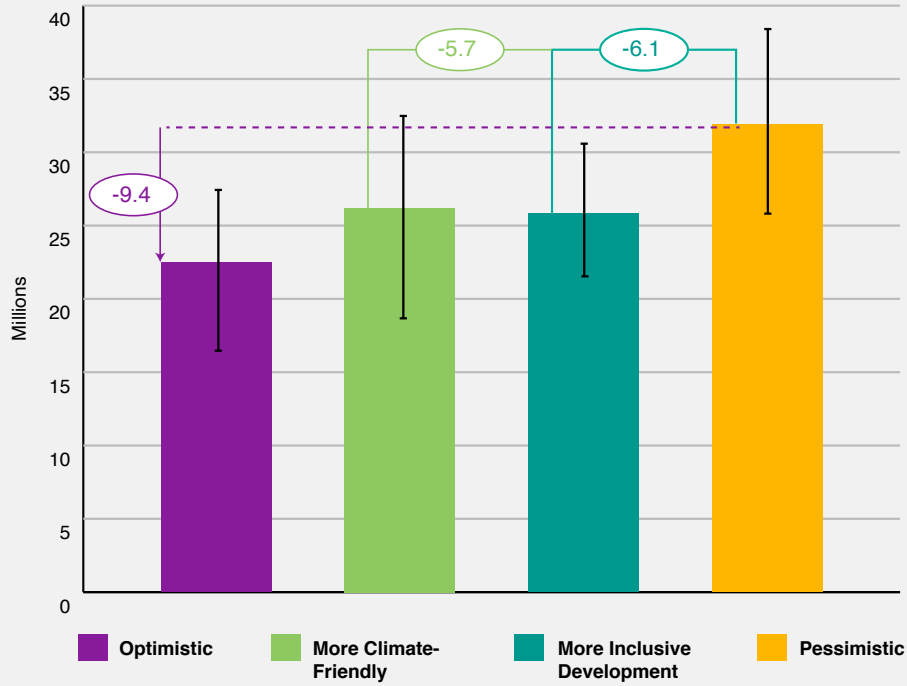
Note:

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

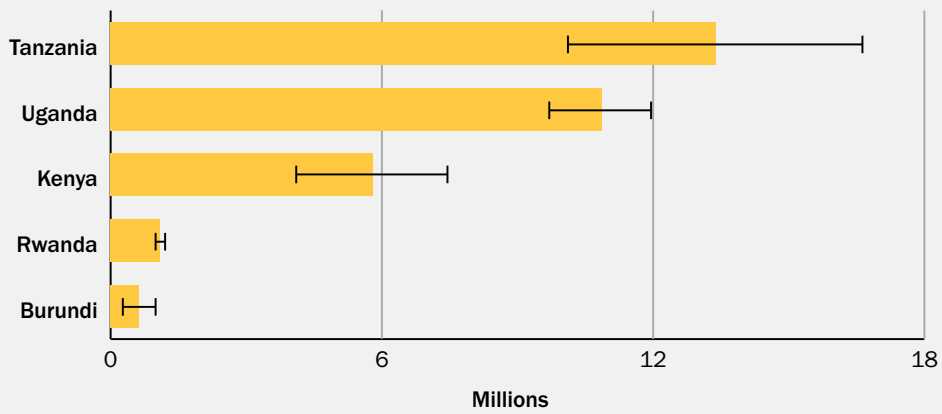
The expanded model provides a more granular analysis better placed to inform policy dialogue and action. To estimate the scale of internal climate migrants a population gravity model was used to isolate the portion of future changes in population distribution that can be attributed to climate change 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. Nonclimate 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, Lake Victoria Basin, 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 Lake Victoria Basin Countries under the Pessimistic Scenario by 2050**



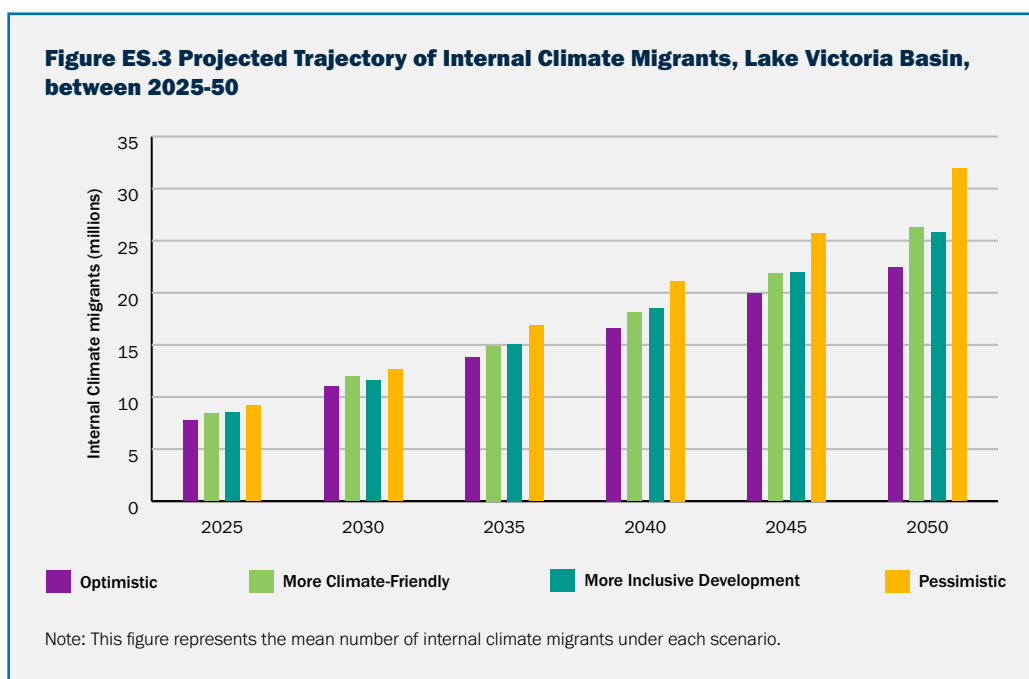
Note: The whiskers represent the lowest and the highest number of internal climate migrants in the pessimistic scenario.

## MESSAGE 2:

**The trajectory of internal climate migration is not uniform within countries in the Basin, but in all cases, early action can abate the worst impacts.**

Internal climate migration in the Basin could increase between 2025 and 2050, but with some variation between scenarios and countries (figure ES.3). There is a consistent upward trend across the scenarios, but the pessimistic scenario shows an acceleration in the rate from 2045-50. The number of internal climate migrants in the Basin could see anywhere from a 2.9-fold increase (under the optimistic scenario) to a 3.5-fold increase (under the pessimistic scenario) between 2025 and 2050. This pessimistic scenario reflects the plausible outcome under continued high emissions and unequal development pathways. Alternative scenarios, which emphasize more inclusive and more climate-friendly pathways, could reduce the scale of internal climate migration.

Similar to the Basin, the trajectory of internal climate migration in Tanzania and Rwanda will be consistently upward trend in all scenarios across decades. In Uganda, the trajectory is more gradual up to 2030 and then increases more rapidly to 2050. In Kenya and Burundi, there is an accelerated upward trend in the last decade of the range, especially under the pessimistic scenario. These differences and the varying levels of certainties around these trajectories mean that internal climate migration will unfold differently in each country, and thus require contextualized responses. For example, Uganda exhibits higher level of confidence across the models for each scenario, compared to the other countries in the Basin.



**Climate-induced migration could emerge as an important type of internal migration in the Basin by 2050.** At the country level, climate migrants could outpace other internal migrants in Tanzania, Uganda, Kenya, and Burundi as early as 2030 in at least two scenarios, including the pessimistic. Even in Rwanda, climate migrants could constitute more than 75 percent of internal migrants. This underscores the point that climate-induced migration is not a distant policy challenge, but a reality set to increase in the Basin, and early action is key.

**Timely and concrete climate and development action taken early on 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 (IPCC 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. For example, the number of climate migrants in Tanzania might reach up to 16.6 million by 2050 under the pessimistic scenario, but the optimistic scenario, with low emissions and inclusive development, could see a reduction of internal climate migrants of at least 27 percent (or 3.6 million). These projections underscore the need for both inclusive development and low emissions for modulating the scale of climate migration, and the need to pursue highly resilient policies and shifts toward less climate sensitive sectors at scale.

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### **MESSAGE 3:**

**The emergence of internal climate in- and out-migration hotspots in the Lake Victoria Basin countries as early as 2030—and their convergence with impoverished areas and centers of economic growth—calls for holistic and farsighted approaches to ensure sustainable and durable outcomes.**

---

**Climate in- and out-migration hotspots could emerge as early as 2030 and continue to intensify and spread by 2050 (Figure ES.4).** These plausible hotspots represent areas where population movements are considered of high certainty across the scenarios modelled. These shifts are a response to the changing viability of ecosystems and landscapes to support livelihoods due to water stress, drops in crop productivity and ecosystem productivity.

**Lake Victoria is projected to be a major climate in-migration hotspot as early as 2030.** The lake will become more attractive under climate change because of its higher elevation and more stable and plentiful rainfall, compared to semi-arid regions of Uganda, Kenya, and Tanzania. The Ugandan locality of Mbale, Ntungamo, and the capital Kampala, and the northern Tanzanian cities of Mwanza, Magu, and Geita could become high-certainty climate in-migration hotspots near the lake. Kenya could see out-migration immediately surrounding the lake, but in-migration in the area around Eldoret, just to the north of the lake but still within the Lake Victoria Basin. Given these countries' high reliance on fisheries and natural resources of the lake, proactive and collaborative management of its resources across the three countries is essential. Some of the climate in-migration hotspots (e.g. Mwanza in Tanzania) coincide with areas of high poverty. Coupled with increasing population density, these already vulnerable areas have poor infrastructure and basic social services and demand inclusive and participatory climate resilient development and planning.

**Other major climate in-migration hotspots could emerge throughout the Basin.** The central region of Rwanda close to the capital, Kigali, and in the north by the borders with Uganda and Tanzania, is projected to see climate in-migration by 2050. In Burundi, a high-certainty in-migration hotspot could emerge in the center, including the new capital, Gitega, by 2040. Given that the capitals of these countries are already facing high population growth and rapid urbanization, effective planning and management efforts will be indispensable to preserve growth and development.

**Coastal areas could face out-migration due to sea-level rise amplified by storm surge.** In Tanzania, coastal urban centers such as Dar es Salaam, and the Kenyan city of Mombasa are projected to see climate out-migration as early as 2030. Climate out-migration does not necessarily imply that populations will decline in these areas, rather that there will be a dampening of the population growth due to climate impacts. Early action to fortify coastal assets through green and gray infrastructure must be optimized through adapt in place options—and policy makers should consider participatory planned relocation as part of longer-term solutions.

**Inland localities across the Basin could see climate out-migration by 2050 due to decreases in water availability and crop production.** Uganda will have climate out-migration hotspots in the north-west and west central areas around Lake Albert, and Tanzania could see these in the south, north, and east central regions. In Burundi, the former capital, Bujumbura, could see climate out-migration. Focusing on these hotspots and the spatial dimension of the challenge will be pivotal to build resilience and readiness across timescales. See figure ES.4 for projected hotspots for 2030 and 2050.



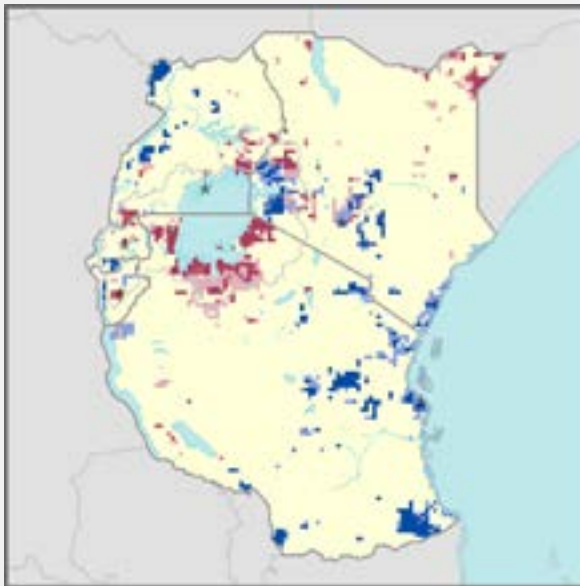
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**Figure ES.4: Projected Hotspots of Climate In- and Out-Migration, Lake Victoria Basin, by 2030 and 2050**

a. 2030



b. 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

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 Lake Victoria Basin 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 of these climate in-migration hotspots in the Basin are facing severe environmental challenges due to climate change, including landslides, flooding, drought, 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 Tanzania, particularly around Lake Victoria, in cities such as Mwanza, Magu, and Geita, coincide with areas where poverty incidence is the highest. In contrast, climate out-migration hotspots in the east and south include Dar es Salaam, Arusha, Korogwe, Dodoma, and Morogoro, which are centers of economic growth. These trends, in many cases, run counter to the historical development-induced migration. Better management of environmental and fisheries resources and the rural landscapes is an essential part of any strategy to avert the adverse consequences of migration and displacement.

**Water stress, crop and NPP losses, and sea level rise are key climate factors that will influence internal climate migration in the Basin countries over the next decades.** Generally, areas that see positive deviations in water and crop productivity experience more in-migration, as reflected through spatial population distribution shifts. The coefficient for water availability in rural areas is around 2.8 times higher than that of crop production and 4.7 times that of NPP. The climate impacts will continue to amplify beyond 2050, with some models indicating drying in the south of the Lake Victoria Basin region and a wetting in the north, while others showing mostly a wetting pattern across the region. A number of models show strong declines in crop productivity in northeastern Kenya and in western Tanzania and Uganda. Storm surge and sea level rise could lead to loss of habitable land across coastlines. For example, Tanzania's coastline in the east and south will witness sea-level rise compounded by storm surges, putting people and assets at risk.

**As applied to the Lake Victoria Basin countries, nonclimate factors, including median age, sex, and conflict, provide a more complete representation of how climate-induced migration trends could manifest.** Age and sex composition are not strong influencers of spatial population shifts in the region, and conflict-related fatalities are negatively correlated with population change showing stronger effect in urban areas.

**The climate migration hotspots in Lake Victoria Basin countries are not predestined, but the agreement across the scenarios on climate in- and out-migration underscores the need for farsighted and anticipatory approaches to avert, manage, and plan for the consequences of climate-induced migration.** 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 to enable and support mobility. Box ES.2 summarizes the results of a virtual consultation with stakeholders of the Lake Victoria Basin countries.

### 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 international bilateral and multilateral organizations (World Bank, unpublished). Several points of consensus aligned with the results of the modeling exercise, including agreement that climate change is an increasingly important driver of migration and displacement in the Lake Victoria Basin countries. Water availability was widely accepted as one of the driving factors of mobility in the region along with the ability of land to support livelihood. The group found the scenarios and climate in- and out-migration hotspots (developed in this study) to be plausible and stressed the importance of preparedness and resiliency. The areas of greater focus that emerged are population dynamics, pastoral communities, and the need to contextualize and localize results. In particular, the consultation pointed out the challenge of land degradation and poverty, which was emphasized in the study.

## MESSAGE 4:

### Global responsibility for swift action to cut greenhouse gas emissions is critical for significantly 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 finds that without immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C will be beyond reach (IPCC 2021). Beyond the threshold temperatures, extreme events will be on the rise and climate-related risks for natural and human systems are higher, with disproportionate impacts on the poorest and most vulnerable (IPCC 2021; UNEP 2020). Some impacts are already locked-in.

**Concerted action at the global level to reduce GHG emission is an imperative to reduce the climate pressures that drive people to migrate.** Without aggressive global emission reductions to meet the Paris targets—which are in line with the optimistic and climate-friendly scenarios modeled in this study—the chance to reduce the scale of internal climate migrants will be hard to achieve. The window of opportunity to meet the Paris target is fast closing. The responsibility for solving the challenges of internal climate migration cannot be delegated to the very communities that may have to move in response to increasing intensity and frequency of climate impacts.

**Strong, green, resilient, and inclusive 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. Major GHG emission countries must find direct and indirect ways to complement countries' efforts on climate-induced migration.

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## MESSAGE 5:

**Internal climate migration in the Lake Victoria Basin is a reality and can be nurtured into a positive force through a proactive and dedicated focus on a core set of policy areas informed by domains of action.**

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**Internal climate migration cannot be divorced from development and as the human face of climate change, it must be addressed in a holistic, end-to-end manner.** The Migration and Climate-informed Solutions (MACS) framework (figure ES.5 and box ES.3) brings together domains of action, buttressed by core policy areas, to reduce the scale of climate-induced migration, usher in social and economic transformations, and reduce vulnerabilities. This anticipatory approach will ensure that the economy of the Basin countries is braced not just for the challenges but also the opportunities of internal climate migration.

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

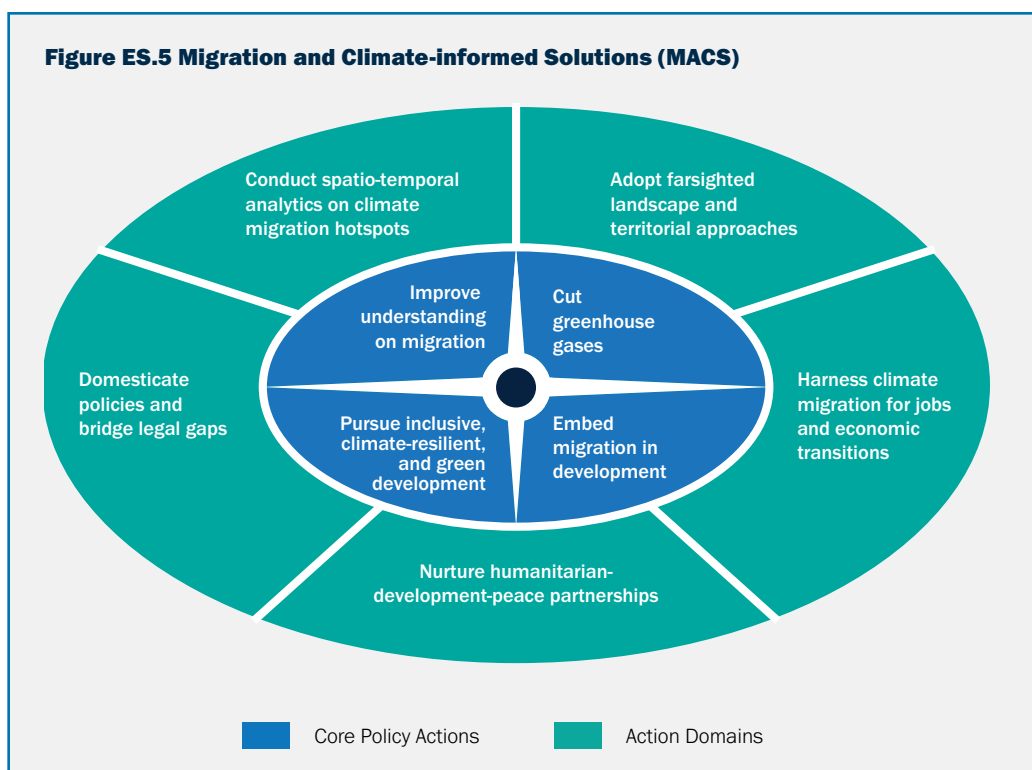
- Cut GHGs now.
- Pursue inclusive, climate-resilient, and green development.
- Embed migration in development planning.
- Invest in an improved understanding of migration.

**The diverse context of countries in the Lake Victoria Basin where internal climate migration will play out calls for focused attention and solidarity.** It can be guided by these five action 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.
- Domestic 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 support 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 viability of 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 subsequent deeper dives via 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 multi-stakeholder 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 policymakers 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.

### The scale, trajectory, and geographical spread of internal climate migration in Lake Victoria Basin calls for focused attention on their shared resources (table ES.1).

Lake Victoria is rapidly deteriorating due to environmental degradation, including over-harvest of fish stocks, resurgence of water hyacinth, and deteriorating water quality, and these impacts are amplified by climate change. Addressing long-standing environmental challenges is an imperative in the Basin, where lives, livelihoods, and the economy are integrally linked with climate sensitive livelihoods. Unattended, these adverse consequences will lead to climate-induced migration, deepen existing vulnerabilities and lead to 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 can help avert adverse outcomes while harnessing the opportunities of climate-induced migration.** The National Development Plan (NDP), Systematic Country Diagnostic (SCD), and Country Partnership Framework (CPF) include pivotal actions to prepare, plan, and respond to climate migration in the Lake Victoria Basin. These include job diversification, land management, landscape programming, climate change resilience, and resource and environmental risk management. 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 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 (Rigaud et al. 2021b) carried out a portfolio review 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 portfolio findings 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 enabling interventions (early warning systems and social safety nets) and address underlying causes of mobility. There is a need to step up such interventions with great vigor and urgency—acting in partnership and engagement of those directly affected.

**Several projects supported by the World Bank provide lessons and opportunities for scaled-up action and engagement.** An example of leveraging migration as an adaptation strategy is the Regional Pastoral Livelihoods Resilience Project (P129408) in Uganda and Kenya. It enhances mobility by building local platforms for conflict resolution and enables access to water through project infrastructure rehabilitation. The Development Response to Displacement Impacts Project in the Horn of Africa (DRDIP)—a partnership between the World Bank, the United Nations High Commissioner for Refugees (UNHCR), and the Government of Kenya (GOK)—protects the poor and those displaced by fragility and violence through investments in basic social service infrastructure, integrated natural resources management and alternative livelihoods like value-addition to agriculture products and fish farming. Both projects leverage migration as an adaptation strategy and seek to strengthen social risk management while also working towards poverty reduction.

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## **MESSAGE 6:**

### **Climate migration, as a cross-cutting issue, has to be addressed through policy-informed actions that are farsighted in their approach and execution.**

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**The domains of action set out in the MACS framework provide a pragmatic and farsighted approach to addressing internal climate migration—delaying action will raise the stakes considerably.** 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.



**Conduct spatio-temporal analytics to gauge the emergence of climate migration hotspots in poverty pockets and growth centers—for challenges and opportunities—with a focus on cities, the periphery of Lake Victoria, and coastal areas.** 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 broader global trends. Water availability—a major driver of migration in the model—is projected to remain stable or to increase in the Lake Victoria Basin, but to decrease (under one of the water

models) in much of Tanzania to the southeast of the lake. Some of those areas (mostly larger towns such as Dar es Salaam, Dodoma, and Arusha) are characterized by out-migration hotspots. 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 for climate in- and out-migration hotspots.** Site-based and locally driven practices for forest and water management, integrated community programs, and land use plans can be leveraged in emerging climate in- and out-hotspots, especially in Lake Victoria. Areas around the lake are projected to become out-migration hotspots because of decreased water availability and crop production. The emergence of the lake and its surroundings as a climate in-migration hotspot suggests the urgent need for approaches that enhance its conservation and management. 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. An example of managing the Lake Resources within and across countries is the Lake Victoria Environmental Management Project (World Bank 2018), which fostered a collaborative management of the natural resources among partners and governments in the Basin.



**Harness climate-induced migration for jobs and economic transitions to leverage green growth and development opportunities based on countries' structural transformational needs and investment on human capital (including with regard to youth bulge).** For instance, Tanzania's highly productive areas in the southern and northern highlands are increasingly affected by declining rainfall, frequent droughts, and significant increases in spatial and temporal variability of rainfall. In this context, the focus on building resilience and adopting adaptive strategies must include farsighted planning not just for agriculture, but alongside economic transitions toward less climate-sensitive jobs and livelihood opportunities. 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 their 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. The high levels of temporary and circular migration in Rwanda, conflicts between pastoralists and farmers in Tanzania, and climate pressures forcing the Karamoja pastoralists in Uganda to migrate longer and farther away are some of the factors that call for the integration of humanitarian-development-peace efforts.



**Domesticate 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 environment and management of natural resources. 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 (IDPs). The Intergovernmental Authority on Development (IGAD) Free Movement Protocol contains provisions for access to territory of the host country, conditions of stay, and protection of people moving due to climate

impacts. World Bank financing instruments offer support climate change and mobility, and there is potential for further support that might focus on development opportunities and policies for the safe movement of people and provide viable options for *in situ* adaptation.

**Climate-induced migration will occur in Lake Victoria Basin countries, 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 needs to 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 World Bank report on climate migration in the Lake Victoria Basin 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 the Lake Victoria Basin, Africa, and the global community.

**Table ES.1 Summary of Results Aggregated for the Lake Victoria Basin Countries**

Factor	Regional Results
Populations in 2025 and 2050	Increases from 201.0 million to 313.3 million (in SSP2); 210.3 million to 367.2 million (in SSP4).
Total population at baseline (2010)	140 million
Primary drivers	Water availability, followed by crop productivity and changes in NPP.
Number of internal climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 31.9 million (8.69% of projected population) and a high end of 38.5 million climate migrants (10.48%).
Trajectory to 2050	Gradual increase in the number of climate migrants, from 3.5 million from 2025–30, 8.5 million from 2030–40, and 10.8 million from 2040–50 under the pessimistic scenario. There is also a gradual increase under all scenarios, suggesting a growing momentum.
Internal climate in-migration hotspots	<ul style="list-style-type: none"> <li>The shores of Lake Victoria are highly attractive for climate in-migration in Tanzania and Uganda, and most highland areas.</li> <li>There is a small in-migration hotspot in northeastern Kenya because of projected increases in water availability. A large, high-certainty in-migration hotspot is in the center of Burundi, including the new capital, Gitega.</li> </ul>
Internal climate out-migration hotspots	<ul style="list-style-type: none"> <li>The primary climate out-migration hotspots are in southern parts of Tanzania because of declining water availability.</li> <li>In Kenya and Tanzania, coastal areas see significant climate out-migration because of sea level rise. Three major high-certainty out-migration hotspots in Uganda are mainly in the northwest and west central around Lake Albert. A long, narrow out-migration spot is located in the west, close to Lake Tanganyika and including part of Bujumbura Marie in Burundi.</li> </ul>
Climate migrants vs. other migrants by 2050	The projected number of internal climate migrants by 2050 (31.9 million) could surpass that of other internal migrants (28.0 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.

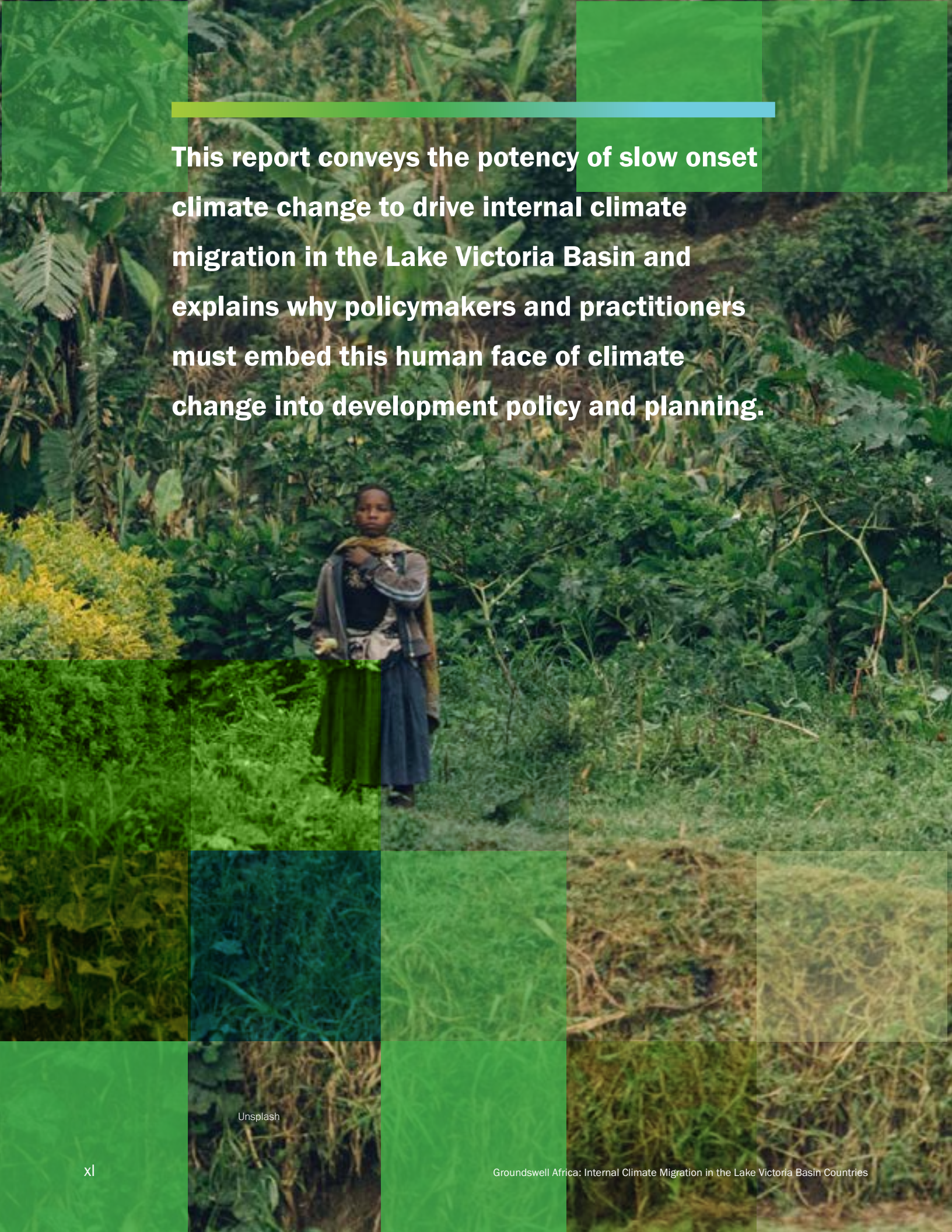
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A Melody Lee / World Bank



**This report conveys the potency of slow onset climate change to drive internal climate migration in the Lake Victoria Basin and explains why policymakers and practitioners must embed this human face of climate change into development policy and planning.**

Unsplash



## Chapter 1

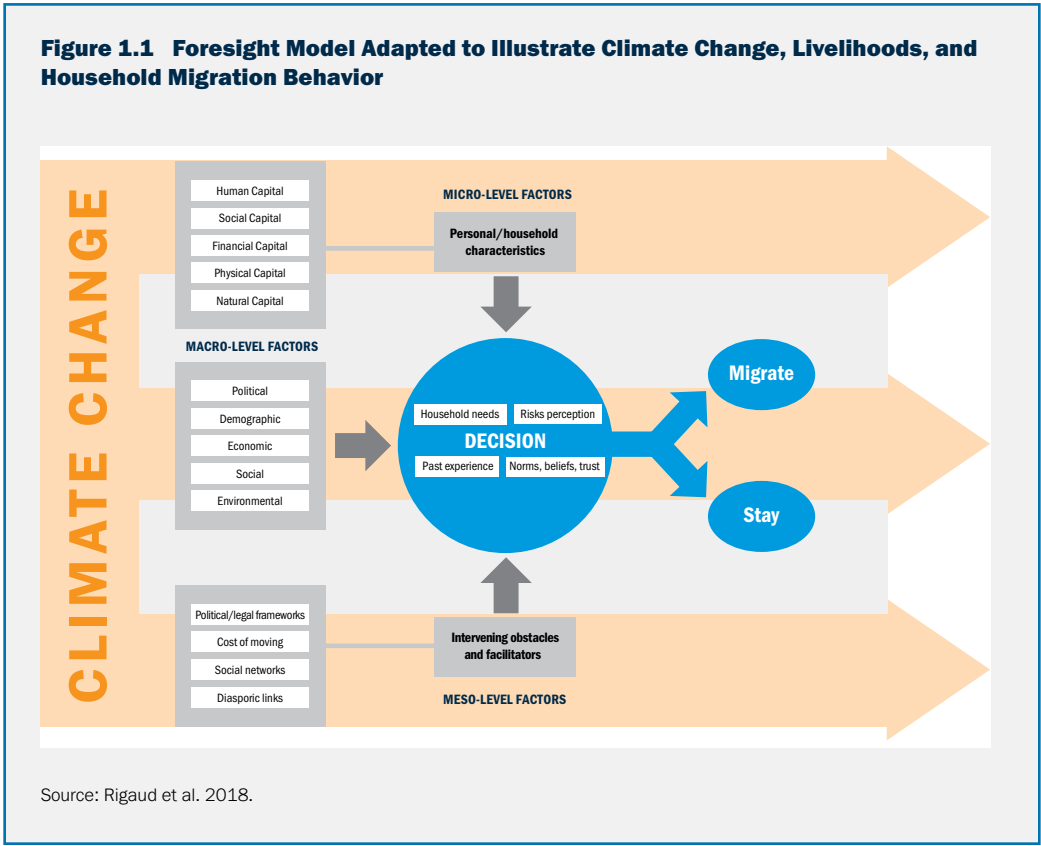
# Introduction

**There is growing concern 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 (UNDP 2009).<sup>1</sup> Although there is no consensus on the current number of climate-induced migrants, most research recognizes that the rate of climate-induced migration is growing 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 IPCC report (IPCC 2021) finds that the global average temperature is likely to increase beyond 1.5°C by the end of the decade unless there is a deep reduction in greenhouse gas (GHG) emissions in the upcoming decades.

**As climate change affects precipitation and temperature in East Africa, this has consequences on livelihoods, particularly where these are climate sensitive, including agriculture, pastoral, and livestock sectors.** East Africa faces the possibility of 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.

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1. World Urbanization Prospects, 2015 (database), UNDESA, New York, <https://population.un.org/wup>.



The World Bank flagship report *Groundswell: Preparing for Internal Climate Migration* (Rigaud et. al 2018) notes that without concrete climate and development action, the number of internal climate migrants in Sub-Saharan Africa could reach a high of 86 million by 2050. In East Africa, rapid population growth has contributed not only to land fragmentation, which has spurred rural to urban migration, but also to rapid urbanization through natural increase, and movements from the highlands to lowlands. The region has a history of internal displacement and refugee flow because of conflict (IDMC 2021). The Groundswell report shows that the Lake Victoria Basin (Lake Victoria Basin) (Burundi, Kenya, Rwanda, Tanzania, and Uganda) is an emerging hotspot of climate in- and out-migration (Rigaud et. al. 2018).

**Natural hazards and disasters have led to significant internal displacements in Sub-Saharan Africa.** In 2020, around 4.3 million people were displaced within their countries due to disasters, 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). If unaddressed, poverty, vulnerability, conflict, and climate change could put more people at risk in the region, especially in the face of high population growth and increasing urbanization rates, which are predicted to augment dramatically in the coming decades. The steady increase in conflicts that spill over borders and the intensifying impacts of climate extremes aggravate this situation. The growing number of people on the move is straining current systems and will have long-term impacts on host countries. Influxes of migrants could undermine and reverse much of the development progress that has been achieved in the past two decades.



Sarah Farhat / World Bank

**In the face of escalating climate impacts, climate-induced migration is emerging as a critical issue.**

To drive informed policy and planning, there is an urgent need to go beyond individual case studies and specific events to assess how the escalation of climate impacts could drive migration at scale in the coming decades. Concerted action on climate change mitigation and adaptation, together with inclusive development policies and embedding climate migration into policy and planning, could help to substantially reduce the number of internal climate migrants (Rigaud et al. 2018; Clement et al. 2021). Policy decisions made today will shape the extent to which the effects of climate change will be positive for migrants and their families. Inaction would mean missing a vital opportunity to reconfigure where, when, and how climate-resilient investments are made in support of robust economies.

**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 as mostly rural agriculturalists move from highly impacted areas toward regions with better conditions for the crops and livestock on which they depend. More important, in areas where development deficits and adapt-in-place opportunities persist, internal migration may accelerate as people move to secure livelihood options in more viable areas. In this context, concrete climate and development action can reduce the scale of internal climate migration (Rigaud et al. 2018; Clement et al. 2021) and must be pursued to achieve sustained development outcomes in the face of a changing climate.

**Understanding when, where, and how climate migration will unfold is critical so that countries and communities can pursue the right policies and targeted action.**

The focus of this report remains on internal migration (most migration takes place within a country's boundaries). The drivers of displacement in the region are a complex overlap of social, political, economic, and environmental factors, particularly slow-onset hazards such as drought, desertification, coastal erosion, and land degradation.

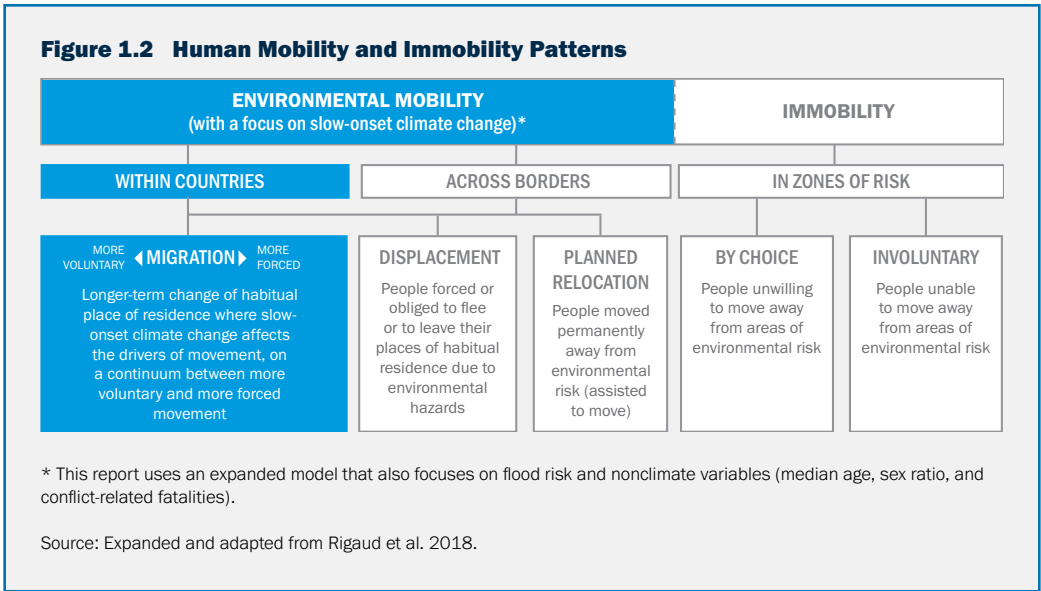
## 1.1 OBJECTIVE AND SCOPE

**The objective of this report is to examine the potency of climate-induced migration in the Lake Victoria Basin 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 uses a quantitative and qualitative understanding of plausible future climate migration scenarios and proposes core policy direction and domains for action to better anticipate and prepare for the issue.

**This report also provides strategic policy responses to guide countries in the Lake Victoria Basin to better anticipate and prepare for the scale and effects of internal climate migration.**

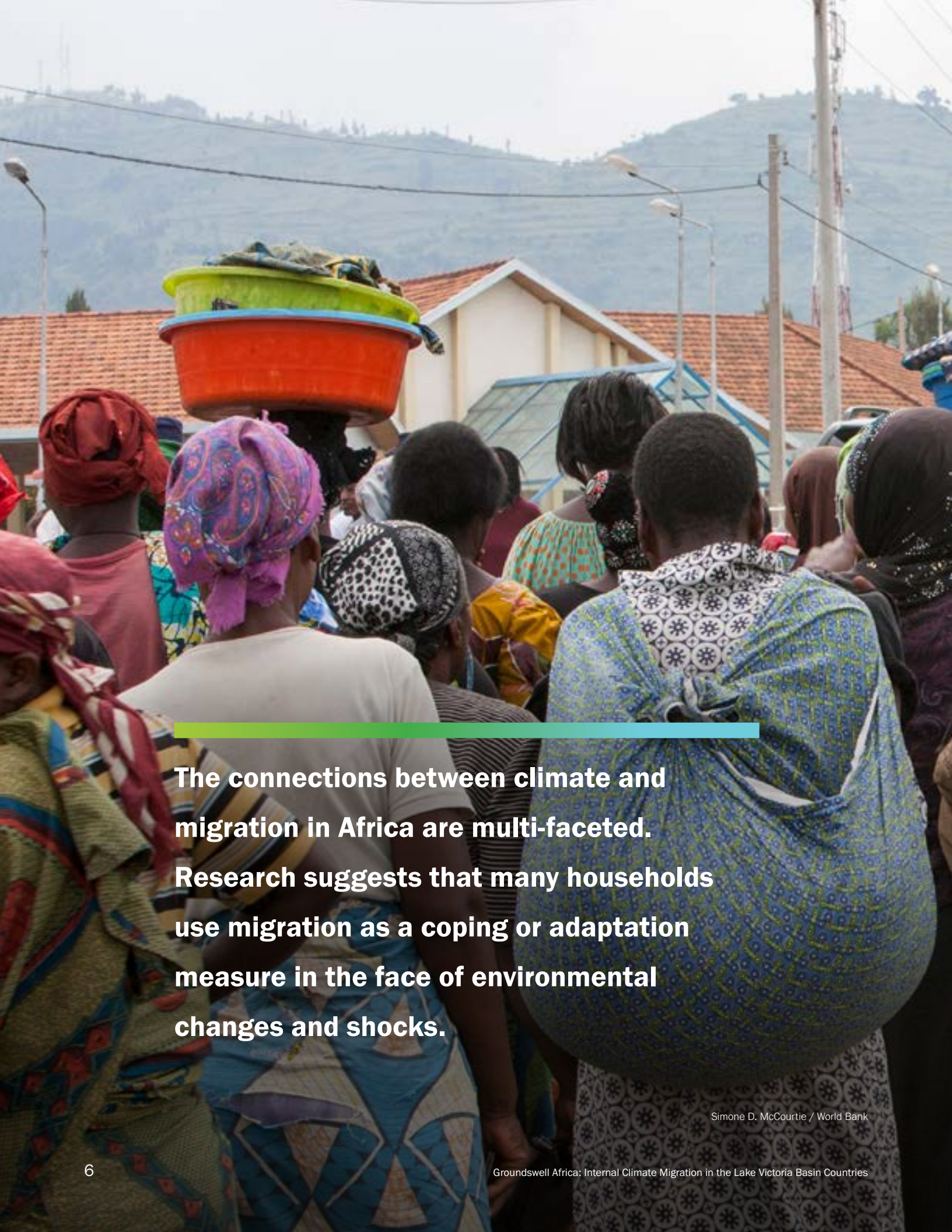
While there is no universally agreed upon terminology for human movement in the context of environmental change (Dun and Gemenne 2008), the focus of this report is on internal climate migration (within countries) and uses the terms depicted in figure 1.2. Overarching policies must embed climate risks 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.



## 1.2 TARGET AUDIENCE AND OUTLINE OF REPORT

The analysis and recommendations of this report speak to both high-level decision-makers and practitioners, including local actors on the front line of climate-induced migration. The need to work 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.

The report is organized as follows. Chapter 2 sets out the development and demographic context and addresses the past, present, and future climate of the Lake Victoria Basin 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 that have been applied in this study. Chapter 4 presents the climate impact modeling results, and chapter 5, the modeled results on plausible future climate migration scenarios from 2025–50 with a focus on the climate migration trends and patterns for the Lake Victoria Basin region and countries of focus. Chapter 6 presents and discusses core policy directions and a set of key domains of action that can be leveraged to foster concrete climate and development action to mainstream climate migration into development planning. Chapter 7 provides country snapshots and analysis of modeling results and qualitative assessments for the Lake Victoria Basin focus countries. Additional details on modeling inputs and methods are found in appendix 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.**

Simone D. McCourtie / World Bank



## Chapter 2

# Understanding the Climate-Migration-Development Nexus in the Lake Victoria Basin

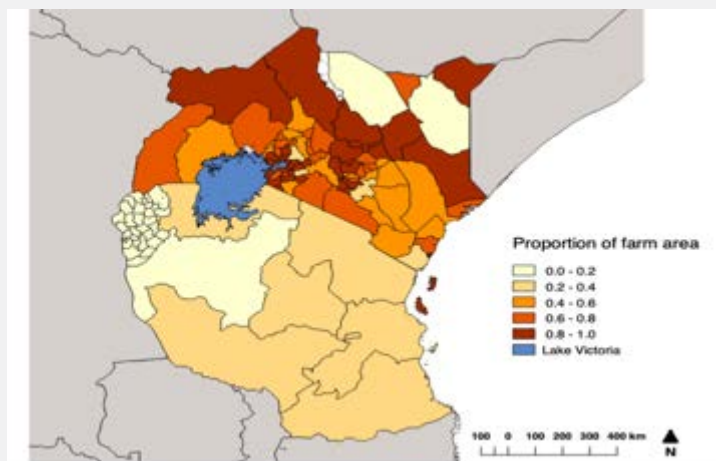
### 2.1 DEVELOPMENT CONTEXT

Two of the five Lake Victoria Basin (Lake Victoria Basin) countries—Tanzania and Kenya—are in the lower-middle-income country (LMIC) category; Rwanda, Uganda, and Burundi are low-income countries (LICs).<sup>2</sup> Poverty is widespread, along with high dependence on natural resources (World Bank 2018a). Approximately 80 percent of the rural population of East Africa gains their livelihood from agriculture (Lake Victoria BasinC 2018). Fertile soils and a humid tropical climate with a long growing season have attracted immigration to the areas surrounding the Lake Victoria Basin. Spanning 180,950 square kilometers, the Lake Victoria Basin has seen population growth from 1 million in 1960 to over 30 million in 2013 (Gabrielsson, Brogaard, and Jerneck 2013). Many have moved to the area for access to farmland, and these increased demands have diminished the average size of farms and contributed to declining crop productivity and land degradation.

**The Lake Victoria Basin has vital economic and ecological significance.** Large rural population are dependent on the degraded lands in the upper basin, especially in the Burundi, Rwanda, and Kenya highlands (World Bank 2018a). Agriculture has precipitated changes in and around the basin, leading to soil erosion, nutrient runoff, and increased atmospheric pollution. Certain activities are more destructive than others: perennial horticulture is typically more manageable than the growth of annual cash crops such as maize, bananas, and coffee (LVBC 2016). Annual cash crops have been linked to higher rates of soil erosion, and bananas and coffee to the lowest (Majaliwa et al. 2005). As demand for land increases, with 2.2 percent more land under cultivation annually, demand on land for grazing and irrigation has outpaced ecological capacity. Figure 2.1 shows the proportion of the households whose landholding is between 0 and 2 hectares, which could represent 1 metric of pressure on land or inadequate land resources by farming households.

2. See World Bank Data, Country and Lending Groups at <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519>.

**Figure 2.1 Share of Total Area of Small Farms, Lake Victoria Basin**



Source: Elaborated with data from Azzarri and Signorelli 2020 and Ricciardi et al. 2018.

Note: Farms are from 0 to 2 hectares.

**While the climate has historically been conducive to farming and grazing, heavy rains and prolonged dry periods can render certain periods more difficult for small producers.** Throughout the Lake Victoria Basin, populations experience a fairly consistent period of hardship from January through March, correlated with higher temperatures and reduced rainfall, higher prevalence of disease, and diminished access to food and work (Gabrielsson, Brogaard, and Jerneck 2013). The rainy season from May through August is characterized by cropping, abundant supply of fish, lush lands for grazing, and a more temperate climate. As regional climate patterns grow more extreme, resulting in a higher frequency of droughts and floods, livelihood stress is increasingly common throughout the year. Many farmers have thus begun to depend on imported products for basic sustenance.

**While the focus of this report is on climate impacts on subsistence agriculture and to a lesser degree pastoralism along the shores of Lake Victoria, fisheries are important to local livelihoods.** Fisheries are in decline, much of the production is exported elsewhere, but fish are still an important part of local diets. According to Njiru et al. (2018), Lake Victoria changed from a multispecies subsistence fishery into a commercial fishery consisting mainly of Nile perch, Nile tilapia, and cyprinid. Past studies have indicated the lake fisheries declined because of major challenges such as overfishing, invasive species, loss of biodiversity, ecological alterations, climate change, and inadequate data. With reestablishment of the East African Community (EAC) in the mid-1990s, riparian states initiated an ecosystem approach to sustainably manage the fishery. According to Njiru et al. (2018), interventions have not yet had much success in reducing degradation of the lake water quality and the decline in fish catches. Despite the importance of fish locally, Nunan (2010) reports that around 90 percent of fisherfolk (boat owners and crew) are involved in farming in Kenya, compared with 70 percent in Tanzania and around 50 percent in Uganda. This is mostly subsistence farming or subsistence with sale of surplus to local markets.

## 2.2 LAKE VICTORIA BASIN CLIMATE

**Spanning 68,000 square kilometers, Lake Victoria is the largest tropical freshwater lake in the world (Beverly et al. 2020).** Located in an equatorial zone with diverse ecological habitats and at elevations around 1,500 meters, the Basin sees relatively moderate temperatures throughout the year (Kienberger and Hagenlocher 2014). Highland areas typically see temperatures averaging around 20°C (with lows of 15°C and highs of 25°C), which contrasts with lowland and coastal tropical areas of Kenya and Tanzania, where average monthly temperatures range from 25°C to 30°C. The region sees the coolest temperatures in July and the warmest between October and February (LVBC 2016).

**East African rain patterns are shaped not only by the El Niño–Southern Oscillation (ENSO) phenomenon (which brings wetter conditions) but also by the intertropical convergence zone, large-scale African monsoonal winds, the quasi-biennial oscillation, meso-scale circulations, and extratropical weather systems (Gabrielsson, Brogaard, and Jerneck 2013).** The region’s bimodal rainfall pattern is characterized by a long rainy season between March and May followed by a dry season and a short rainy season from October through mid-December (Gabrielsson, Brogaard, and Jerneck 2013). In the highlands (Great Lakes) region, temperatures tend to be more moderate with limited seasonal variation, and the rainfall has a bimodal distribution with peaks in March through May and October through December, with a humid to subhumid climate. The coastal region has the same bimodal distribution: March to May is characterized by higher rainfall, and October to December, by lower rainfall. In terms of average annual rainfall, coastal Eastern Africa is semiarid due to the cool waters offshore that limit precipitation (Yang et al. 2015a).

**Around the lake, annual precipitation ranges from approximately 1,400 millimeters to 1,800 millimeters per year (Beverly et al. 2019).** Rainfall is particularly heavy in the west and northwest corners (LVBC 2016). Precipitation is significantly lower in the southeast, such as in Musoma, Tanzania. The highest rainfall is at the center of the lake, where the small Nabuyonge Island sees over 3,000 millimeters of rain per year. The average annual evaporation is around 1,460 millimeters per year, nearly equal to mean precipitation. Local precipitation largely draws from the lake, which means that the lake’s levels closely mirror rainfall patterns.

**Anthropogenic climate change has contributed to warming temperatures, changing seasonal patterns, and increasing extremes.** In the Lake Victoria Basin, climate change and local stressors, such as increased demand for land, food, and hydrological resources, threaten ecological resilience. Current changes in rainfall show a trend toward increasingly extreme precipitation events, particularly during the shorter rainy season (Gabrielsson, Brogaard, and Jerneck 2013). This can have a serious impact on agricultural production, as occurred in 2011 with major flooding on the Kenyan side of the lake, which resulted in loss of crops and livestock (Warner et al. 2012). While rainfall events are likely to grow more severe, the region can also expect to see more frequent drought and reduced precipitation between rainy seasons (Beverly et al. 2020).

**Given the variables affecting rainfall in a given site and year, average annual precipitation trends are contested.** For East Africa as a whole, climate models predict an increase in precipitation despite more severe droughts (Funk 2012). This phenomenon is known as the East African climate paradox (Beverly et al. 2020) because recent trends show a decline. For example, studies of the Lake Victoria Basin over the past few decades show a decline in overall precipitation (López-Carr et al. 2014). Over the past 30 years, rainfall has declined in the March through June rainy season (Williams and Funk 2011), with longer and more pronounced dry periods (LVBC 2018). Box 2.1 addresses some reasons for the “climate paradox.”

### **Box 2.1 Uncertainties in Climate Projections in the Lake Victoria Basin**

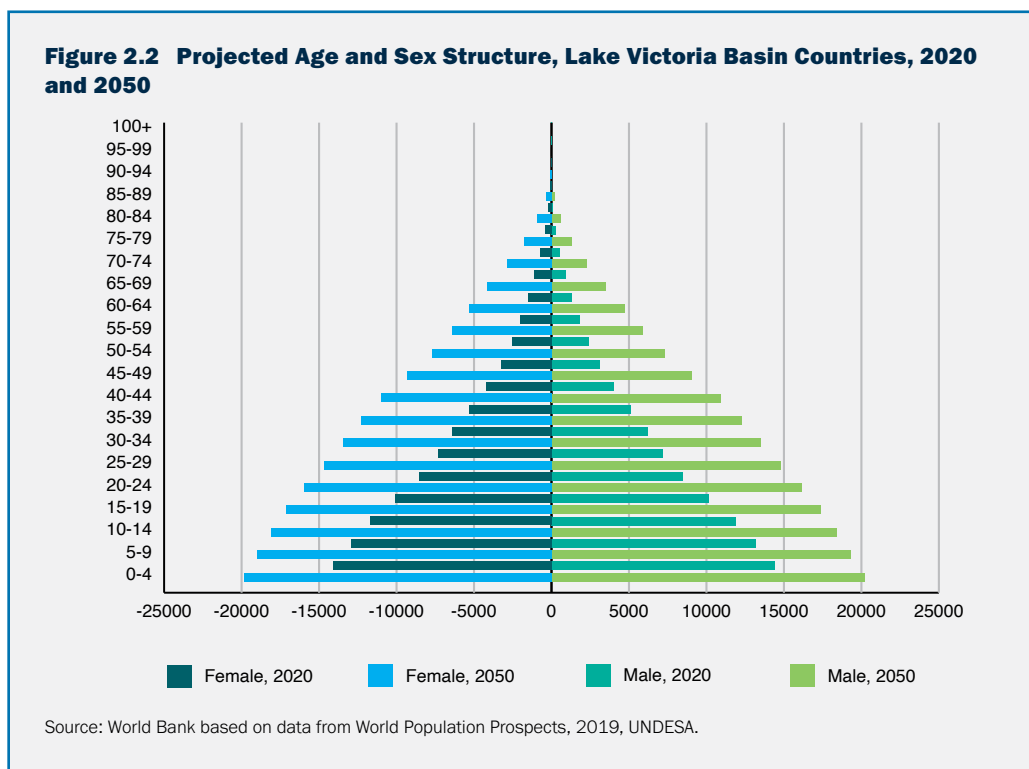
LVB countries have two rainy seasons that lie between the northern hemisphere summer and winter monsoons. The cool waters offshore make East Africa’s coast semiarid. (Yang et al. 2015a). Climate models tend to underestimate east-west sea surface temperature (SST) gradients and to weaken them further under greenhouse gas (GHG) forcing (Yang et al. 2015b). Hence, they predict coastal East Africa to get wetter. However, coastal East Africa has gotten drier over the past century (Williams and Funk 2011). This may partially be due to natural variability; however, it may also be that the Intergovernmental Panel on Climate Change (IPCC) climate models in the Coupled Model Intercomparison Project 5 (CMIP5) archive do not well-represent the role of ocean dynamics in influencing tropical SSTs. This inability means the models do not correctly represent the seasonal cycle of precipitation in coastal East Africa (Yang et al. 2015b). Further, it may be that the east-west SST gradients could actually increase, which would tend to result in drier conditions, not wetter.

The area is a hotspot for climate vulnerability with the dual stressors of reduced rainfall and 2.6 percent average annual population growth, further stretching increasingly limited resources (Kienberger and Hagenlocher 2014). Population growth coupled with climate change could exacerbate the spread of disease. Malaria is endemic to the region and the leading cause of mortality and morbidity in children and adults (Gabrielsson, Brogaard, and Jerneck 2013). Higher temperatures and extreme precipitation contribute to the spread of insect-borne diseases. The Lake Victoria Basin is expected to become warmer and wetter in the short and long rainy seasons, thus providing conducive environments for both vector-borne and diarrheal diseases (LVBC 2018). The Lake Victoria Basin is part of a network of freshwater systems for which it is both a catchment and source. Further from the lake the climate tends to be subhumid or semiarid. Clean, potable water is an increasingly strained resource (Awange et al. 2013). Cholera is also a critical challenge, with access to water an important contributor (Gabrielsson, Brogaard, and Jerneck 2013).

## 2.3 POPULATION DYNAMICS

**Lake Victoria Basin countries have large and growing populations.** Total population for the five countries was estimated at 184 million for 2020,<sup>3</sup> and projections to 2050 range between 313.3 million (SSP2) and 367.2 million (SSP4) (KC and Lutz 2017; Riahi et al. 2017). The population growth rate for 2015–20 was 2.9 percent per year on average, with the highest value in Uganda (3.6 percent) and the lowest in Kenya (2.3 percent). High population growth is linked to the declining but still high fertility rates, which went from an average of 5.9 children per woman of reproductive age (15–49) in 2000–05 to 4.6 children in 2015–20, with the highest rates in Burundi (6.9 and 5.45, respectively) and the lowest in Kenya (5 and 3.5, respectively).<sup>4</sup>

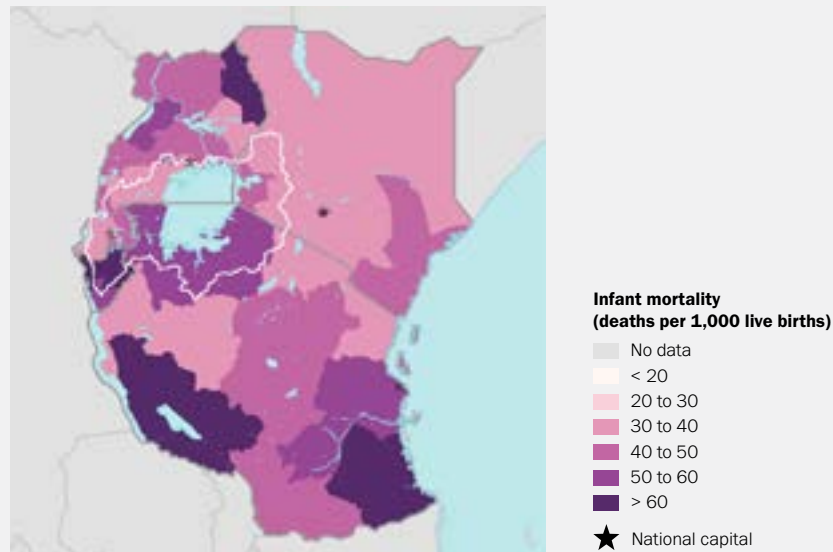
The population pyramid in 2020 displays the classical shape of a young population (average median age for 2020 was estimated at 18.4 years) with a wide base and a narrow end (figure 2.2). This structure is in line with the overall high fertility of the countries in the basin, combined with still high infant mortality rates, particularly in Burundi and some areas of Tanzania and Uganda (figure 2.3), with a mean life expectancy at birth estimated at 64.6 years for 2015–20.



3. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.

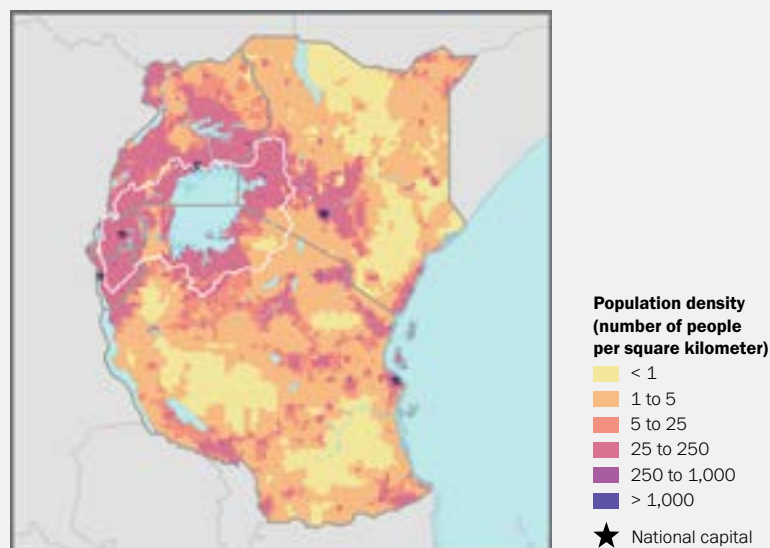
4. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.

**Figure 2.3 Infant Mortality Rate, Lake Victoria Basin, 2015**



Source: CIESIN database, 2019, <https://doi.org/10.7927/H4PN93JJ>.

**Figure 2.4 Population Density, Lake Victoria Basin, 2015**



Source: CIESIN database, 2018, <https://doi.org/10.7927/H4F47M65>.

By 2050, the population pyramid is transitioning to an older population structure (figure 2.2). The base narrows, and a small bulge shows in the young adult years, suggesting that smaller cohorts are entering the population. The fertility rate is projected to decline to 2.9 children per woman by 2045–50. Average life expectancy and median age are expected to reach 71.8 and 25 years, respectively, by 2050 (according to the medium variant).<sup>5</sup>

5. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.

**Population distribution is very heterogeneous across the region (figure 2.4).** Rwanda and Burundi display high population densities in almost all their territories. Tanzania and Kenya display higher densities along the coast and in the areas closer to Lake Victoria. Uganda presents high densities in the southern areas, including around Lake Victoria. These high population densities make the Basin a hotspot of vulnerability to climate change impacts because of high exposure to negative climate change impacts (as populations increase on lands with decreasing rainfall) (López-Carr et al. 2014).

**Urbanization is still low, but it is increasing.** The country average percentage of urban population was 23 percent in 2018,<sup>6</sup> and urbanization projections to 2050 range between 38.7 percent (SSP2) and 54.3 percent (SSP4) (country average) (Jiang and O’Neill 2017; Riahi et al. 2017). Most of the population live in rural areas, but some major cities are in the basin. These include Eldoret and Kisumu in Kenya; Kigali in Rwanda; Musoma and Mwanza in Tanzania; and Entebbe, Kampala, and Mbarara in Uganda (LVBC and GRID-Arendal 2017, 20).

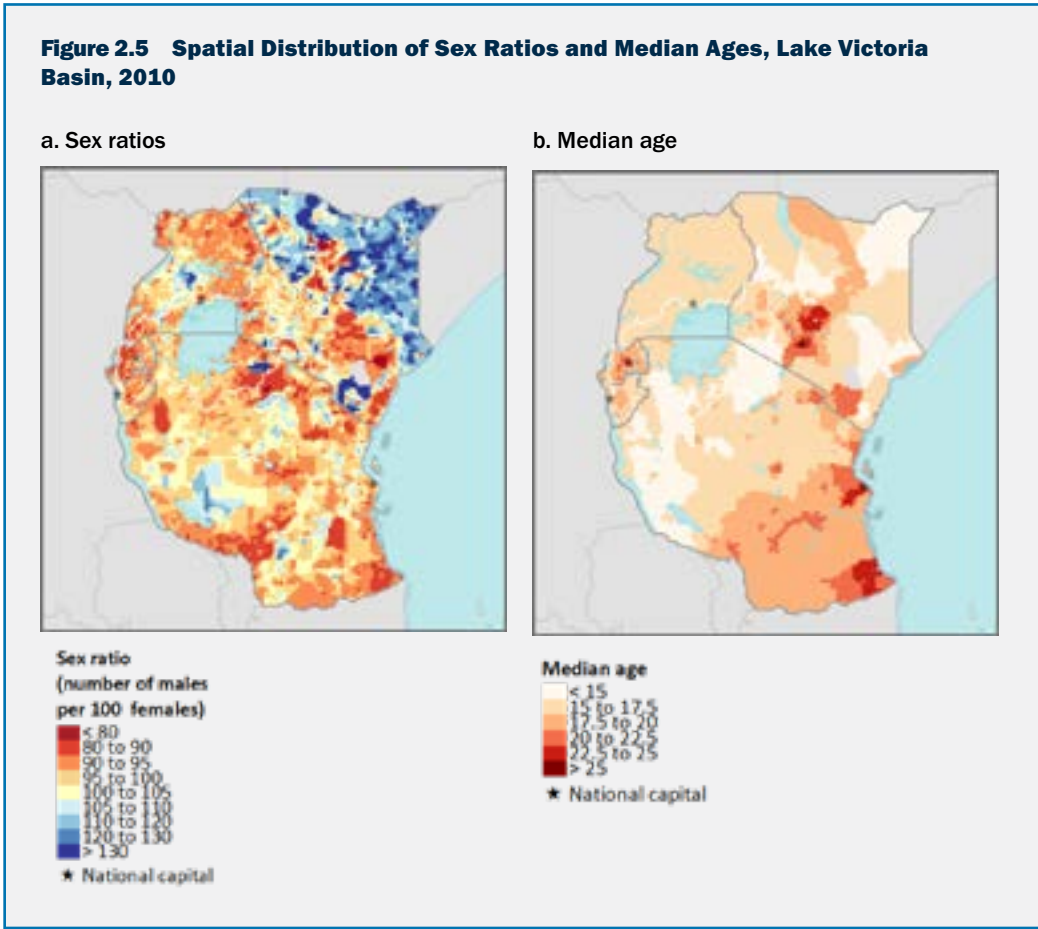
**Population structures have a marked spatial heterogeneity (figure 2.5, panels a and b).** Sex ratios are very high (considerably more men than women) in eastern and northern Kenya. Patches of very low sex ratios (more women than men) are visible in northern and southern Tanzania, northeast Uganda, Burundi, and Rwanda. In terms of median age, and within a regional context of very young populations, older median ages appear in central Rwanda, southern Tanzania (particularly along the coast closer to Dar es Salaam and Mtwara), and in central Kenya close to Nairobi.

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6. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.



Peter Kapuscinski / World Bank



## 2.4 MIGRATION TRENDS

The East African Community (EAC) has had a free movement agreement in place since 1999, and with Rwanda and Burundi joining the community in 2007, all Lake Victoria Basin countries are now included (box 2.2). Regional drivers of internal, regional, and international mobility include education, family links and reunification, the economy (looking for better income and improving living conditions), conflict, and insecurity (Bakewell and Bonfiglio 2013; Mercandelli and Losch 2017; RVI 2018c). The typical migrant is of rural origin, male, and young (below 34 years old). Overall, these migrants are more educated (i.e., more years of schooling) than nonmigrants in rural areas, but less educated than the general urban population.

**Education levels affect employment in migrants' destination (self-employed jobs or waged employment) (Mercandelli and Losch 2017).** Economic reasons act as both push (lack of jobs in origin areas) and pull factors (opportunities to improve livelihoods in destination areas) (IOM ROEHA 2019).

**International migration includes cross-border, intraregional, and other international destinations within and outside Africa.** Intraregional flows have been declining since the 1960s, while migration to other international destinations has increased (Flahaux and De Haas 2016). Nevertheless, intraregional destinations (including cross-border destinations such as the Democratic Republic of Congo, South Sudan, Somalia, and Ethiopia) still made up the largest proportion of total flows in 2010–15 (Abel and Cohen 2019). Other international destinations for that period include the United States, South Africa, the United Kingdom, and France. Main drivers of international migration (including seasonal and short-term movements) include economic reasons, conflict and violence, as well as environmental factors (IOM ROEHA 2019; Marchand, Reinold, and Dias e Silva 2017). Table 2.1 shows the flows among the Lake Victoria Basin countries from 2000 and 2015. Tanzania and Uganda are the largest sending countries, while Kenya, Burundi and Uganda are the largest receiving countries.

## Box 2.2 Migration in the East African Community

The EAC was born in 1967 following the signing of a Treaty of Cooperation between Tanzania, Kenya, and Uganda. The community disintegrated in 1977, but was reconstituted in 1999, with the signing of the Treaty for the Establishment of the East African Community. The three founding members were later joined by Rwanda and Burundi in 2007 to make the EAC, a five-member regional economic bloc. Under article 104, the partner states agreed to adopt measures to achieve free movement of persons, labor, and services and to ensure the enjoyment of the right of establishment and residence of their citizens within the community. To facilitate citizens' enjoyment of these rights and freedoms, the partner states concluded the Protocol for Establishment of the East African Community Common Market, which came into effect on July 1, 2010.

Migration in the context of the protocol may be reflected under several provisions. These include article 5, which calls for the implementation of the common market and strategies for realization of the rights and freedoms of citizens; ease of cross-border movement of persons and adaptation of integrated border management; removal of restrictions on movement of labor; and the right of establishment and residence.

For purpose of identifying the citizens of partner states, and pursuant to article 8 of the protocol, partner states agreed to establish a common standard system of issuing identification documents to their nationals. In accordance with article 9, citizens are expected to use a valid common standard travel document.

The freedom of movement of workers is catered for under article 10, where partner states have guaranteed free movement of workers who are citizens of other partner states within their territories. The article also provides for entitlement of workers regarding application for employment and free movement in partner states, concluding contracts of employment, and enjoying rights and freedoms of association.

Under article 11, partner states mutually recognize the academic and professional qualifications granted, experience obtained or requirements met, licenses or certifications granted in other partner states. They further agree to harmonize their educational curriculums, examinations, standards, certifications, and accreditation of education and training institutions. This article is intended to actualize free movement of labor.

Article 12 provides that partner states agree to harmonize labor policies, laws, and national laws and programs to enable free movement of labor within the community. In addition, national social security policies, laws, and systems of partner states are expected to be reviewed and harmonized.

The EAC is home to hundreds of thousands of refugees due to the region's proximity to centers of conflicts within the Great Lakes region and the Horn of Africa. Accordingly, article 124(5)(h) of the treaty partner states that partners agree to establish common mechanisms for management of refugees. In addition, article 7(8) of the protocol stipulates that the movement of refugees will be governed by relevant international conventions. In view of the foregoing treaty and protocol provisions on refugee management, the chiefs of refugee management are developing the EAC refugee management policy and action plan.

Source: The EAC "Immigration and Labour" web page, <https://www.eac.int/immigration>.



**Table 2.1 Bilateral Flows among Lake Victoria Basin Countries, 2000–15**

Origin, 2000	Destination, 2015					Total
	Burundi	Kenya	Rwanda	Tanzania	Uganda	
Burundi	0	2,759	57,915	133,563	30,264	224,501
Kenya	1,770	0	3,284	39,726	142,199	186,979
Rwanda	49,341	6,873	0	21,697	82,539	160,450
Tanzania	272,910	59,528	82,444	0	57,340	472,222
Uganda	8,718	294,293	100,390	15,459	0	418,860
Total	332,739	363,453	244,033	210,445	312,342	1,463,012

**As in other parts of Sub-Saharan Africa, internal mobility is prevalent in Lake Victoria Basin countries (Mercandalli and Losch 2017).** It includes rural to urban migration to both large and secondary cities (RVI 2018c ) as well as rural to rural migration. In some secondary cities (e.g., Gulu, Uganda; Eldoret, Kenya), rural migration has been an important driver of population growth. Most migrants are young people who move to the city looking for educational and labor opportunities not available in rural areas. Social networks (kinship, ethnicity, and friendship) are key to access urban labor markets and services and are the basis for the development of multilocality (“having a foot in the city”) as a strategy to face instability in origin and destination areas. Most rural migrants enter the informal urban economy, but a small number of highly skilled workers, related to information and communications technology (ICT), are emerging. Overall, rural residents see rural and urban migration as positive because of remittances and the access to urban markets, but some are concerned it could erode cultural values and depopulate rural areas. The large influx of migrants could strain the cities’ infrastructure and services, reduce incomes, increase rents and cost of living, and exacerbate conflicts between longer-term residents and newcomers (RVI 2018c).

**Internal migration includes rural-to-rural flows.** While these movements relieve demographic pressure in some densely populated rural areas, they often increase it in others and have been linked to forest clearing, overgrazing, and landscape burning (Mercandalli and Losch 2017; Salerno et al. 2017). Land abundance is one of the pull factors, as well as employment in commercial farms (e.g., tea and sugar cane plantations in Uganda (Boutin 2016).

### 2.4.1 Environmental Migration

**Poverty, conflict, and environmental factors influence the migration dynamics in the Basin (IOM ROEHA 2019).**<sup>7</sup> The relevance of environmental drivers (including those related to climate variability and change) depends in part on the type of livelihood (resource-based livelihoods are more sensitive); migration (internal or international), and environmental events. In addition, the driver mix is highly context dependent (Borderon et al. 2019).

**Climate stressors are affecting the livelihoods of Kenyan and Tanzanian farmers near Lake Victoria.** Migration is becoming a less convenient option because of evolving labor markets in destinations (usually cities) and limited ability to extend agriculture. In addition, migration intensification depends on inputs other than the household’s labor force pool (Gabrielsson, Brogaard, and Jerneck 2013). Ocello et al. (2015) find that droughts, floods, and crop diseases reduced interdistrict migration in Tanzania, but individual characteristics (e.g., education) modify this migratory response (those with no education were more likely to migrate in response to floods and droughts).

7. Migration data in Eastern Africa (database), Migration Data Portal, IOM, Berlin, accessed April 20, 2020, <https://migrationdataportal.org/regional-data-overview/eastern-africa>.

**Gray and Wise (2016) compare climate-induced rural and urban out-migration in five countries, including Kenya and Uganda.** They find no robust relationships between migration and rainfall variability, but fluctuations in temperature systematically affect migration patterns. The direction of the relationship and statistical significance varies by country. For example, in Uganda migration increases with temperature variability, while the opposite occurs in Kenya.

**Mueller et al. (2020) test the hypothesis that temporary migration (of less than one year) is sensitive to climate deviations (temperature or precipitation) in both rural and urban areas in Uganda and Tanzania.** Surprisingly, climate deviations did not have a statistically significant impact on short-term migration in rural areas, though they did have such an impact in urban areas. Acknowledging that research seems to support a relationship between climate variability and long-term migration, the authors conjecture that the discrepancy in the two patterns may reflect the type of labor markets that attract people into short-term versus longer-term migrant labor and the respective vulnerabilities of those markets to climate shocks.

**Another possible explanation for the lack of migratory response to climate in rural areas is the absence of employment opportunities in potential urban destinations, because urban labor force participation is the lowest at climate extremes.** If climate is correlated between rural areas and potential urban destinations, high urban unemployment may reduce incentives for rural out-migration during extreme events. In the first global meta-analysis of environmental migration, Hoffmann et al. (2020) use estimates of the environment-migration link based on a meta-regression model of 221 countries to identify potential hotspots of environmental migration worldwide. East Africa appears as a hotspot due to increased exposure to multiple environmental hazards and a sufficiently high level of income to finance migration, combined with a high level of agricultural dependency that increases the populations' vulnerability to environmental change.

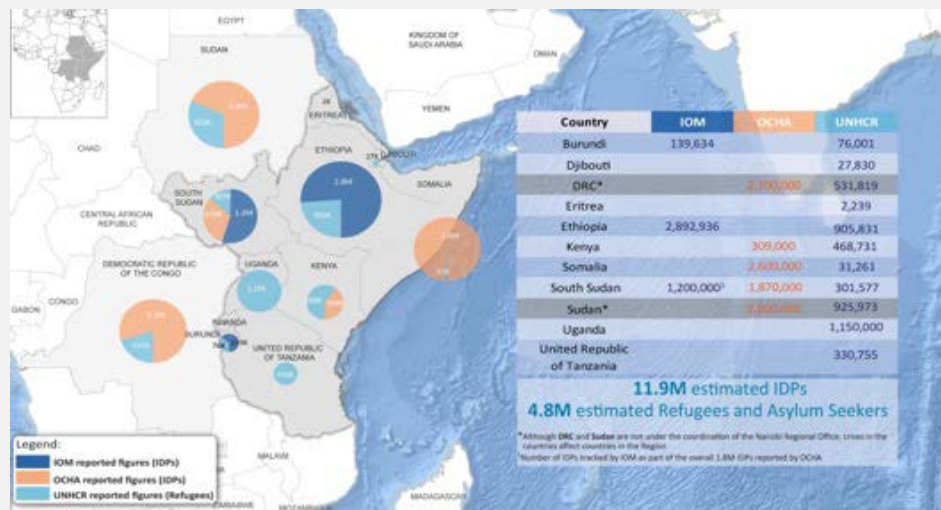
#### 2.4.2 Conflict Displacement and Migration

**Lake Victoria Basin countries have a history of internal and international conflict resulting in a significant number of internally displaced people (IDPs) and refugees (figure 2.6).** The region has received refugees from countries outside the basin, notable from the Democratic Republic of Congo and South Sudan (World Bank 2015). Uganda, with 1.5 million migrants as of September 2021, is the third largest refugee-housing country in the world and the first in Africa; and Kenya and Rwanda have about 520,000 and 130,000 refugees, respectively.<sup>8</sup> Figure 2.6 shows conflict areas in the region, which are concentrated in the drylands of northeastern Kenya, along the Uganda border with the Democratic Republic of Congo, and around Nairobi, Kenya. In addition to immediate impacts, conflict displacement could have long-term consequences and even lead to conflict in resettlement areas. A study on disputes over fisheries in the Uganda-Kenya border on Lake Victoria (Misingo Island) suggests that increasing fishing is coincident with the arrival of populations displaced by conflict in northern Uganda (Glaser et al. 2019).

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8. See UNHCR Operational Data Portal for Kenya, Rwanda, and Uganda at:  
<https://data2.unhcr.org/en/country/ken>  
<https://data2.unhcr.org/en/country/rwa>  
<https://data2.unhcr.org/en/country/uga>

**Figure 2.6 Displacement of IDPs, Refugees, and Asylum Seekers, East Africa and Horn of Africa, December 2018**



Source: IOM ROEHA 2019.

Note: IDP = internally displaced person.

The IPCC's Fifth Assessment Report concludes (with medium confidence) that climate change impacts have the potential of exacerbating known drivers of conflict in Africa (Niang et al. 2014).

A recent study for East Africa concludes that population and economic growth and political instability were the main contributors to regional conflict and population displacement between 1963 and 2014, while environmental factors (severe droughts) were significant only in the case of refugees (cross-border displacement) (Owain and Maslin 2018). Findings from Raleigh and Kniveton (2012), using rainfall variability as a marginal driver of the frequency of conflict, find that extreme wet and dry conditions exacerbated conflict by affecting natural and agricultural resources at the local level (disaggregated data at higher resolution).

## 2.5 LEGAL AND POLICY FRAMEWORK

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).<sup>9</sup> These human rights implications are often further exacerbated in

9. 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](https://undocs.org/en/A/HRC/41/L.24)

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 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,<sup>10</sup> 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 National Adaptation Programmes of Action (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 internal 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.<sup>11</sup>

10. 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/>

11. 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.



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.

**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.<sup>12</sup> 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.<sup>13</sup>

**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

12. Sendai Framework, in particular, paragraphs 27, 28, 30, 33, and 36.

13. 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, IGAD adopted the Drought Disaster Resilience and Sustainability Initiative (IDDRSI).

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). 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).

**The Intergovernmental Authority on Development (IGAD)<sup>14</sup> and the Southern African Development Community (SADC)<sup>15</sup> frameworks are also worth mentioning in the context of cross-border movement within the sub-region.** The IGAD recently endorsed the IGAD Free Movement Protocol, which also includes specific provisions for access to territory of the host country, conditions of stay, and protection of people moving due to climate impacts. It will be crucial to improve implementation and capacity-building to operationalize these provisions moving forward (PDD 2019). The SADC does not have any sub-regional free movement arrangement in place currently, however there are bilateral arrangements and less stringent visa requirements that facilitate entry for the citizens of the countries in the region (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.<sup>16</sup>

**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

14. The IGAD comprises of the countries of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda.

15. The SADC comprises of 16 Member States: Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe.

16. For a comprehensive analysis on the issue, see Burson et al. 2018.

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.*” 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.

**At the continental level, the “Kampala Convention”<sup>17</sup> 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.<sup>18</sup> 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 has been slow.


**Moreover, the 2006 Great Lakes Protocol on Protection and Assistance to Internally Displaced Persons (Great Lakes Protocol)<sup>19</sup> provides a legally binding instrument at the sub-regional level, incorporating the UN Guiding Principles on Internal Displacement.** Its Article 3(2) requires Member States to “*mitigate the consequences of displacement caused by natural disasters and natural causes*” to the extent possible. Under its Article 6, Member States are required to “*enact national legislation to domesticate the UN Guiding Principles fully and to provide a legal framework for their implementation within national legal systems*” and ensure effective participation of IDPs in the process. Domestication and effective implementation of these frameworks and principles can play a significant role in preventing and managing further displacement (Wood 2013).

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17. 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.

18. Art. 3(1)(d) and Art. 9(2).

19. Member States are: Angola, Burundi, Central African Republic, Democratic Republic of Congo, Republic of Congo, Kenya, Rwanda, Sudan, Tanzania, Uganda, and Zambia.

A woman wearing a white shirt and a colorful patterned skirt is standing in a shallow river, washing clothes. She is holding a piece of dark fabric. To her right, various items of laundry, including colorful towels and clothes, are hanging on a line or rack on the grassy bank. The background shows a lush, green landscape with trees and hills. The overall scene is a rural, outdoor setting.

**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.**

Sarah Farhat / World Bank



## Chapter 3

# Methods: Modeling Climate Migration

### 3.1 CLIMATE AND NONCLIMATE MODELING METHODS

**Climate change-induced migration (climate migration) is already 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. The modeling methods in this chapter provide a pioneering approach to answering these questions.

**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.**<sup>20</sup> The enhanced model and refined methods include shorter time steps, higher spatial resolution, more climate impact parameters, and nonclimate factors. Table 3.1 summarizes the main enhancements. The scenarios combine development scenarios and emissions pathways, in the context of a population gravity model, to estimate the potency of climate to drive internal migration. Box 3.1 summarizes the method. Appendix D includes a comparison of the estimated number of climate migrants reported in the original Groundswell report (Rigaud et al. 2018).

20. 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.

**Table 3.1 Comparison between Groundswell I and the Lake Victoria Basin 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 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: For the first time, the modeling used actual climate impact models for agriculture, water resources, and sea level rise compounded by storm surge, to understand how these would affect future population distributions.	Includes another slow-onset impact (ecosystem impacts) and rapid onset events (flood risk); 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 into the gravity model, and impacts 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 SSPs and 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.	Modeling is performed on population data at 1-km resolution (0.5 arc-minute), while the original Groundswell model was applied at a 15-km (7.5 arc-minute) resolution.
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 virtual multistakeholder consultation in February 2021 (World Bank, unpublished).

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

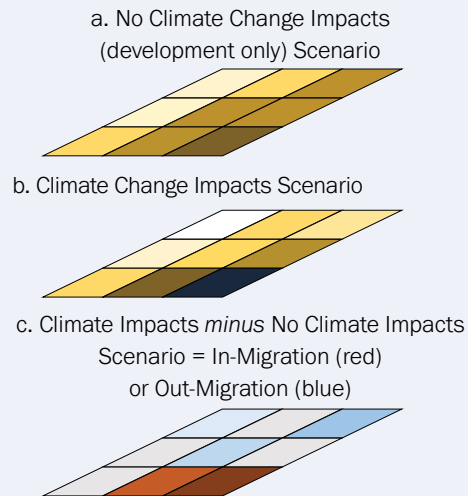
### Box 3.1 Modeling Approach in a Nutshell

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.

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. Figures a–c of 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).



#### 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 [GHG] emissions reductions) and societal adaptation to climate change.

The analysis uses SSPs as story lines to develop spatial population projections at 30 arc-second resolution (grid cells of about 1 square kilometer at the equator).<sup>21</sup> The five SSPs developed by O'Neill et al. (2014) span 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 and 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.<sup>22</sup>

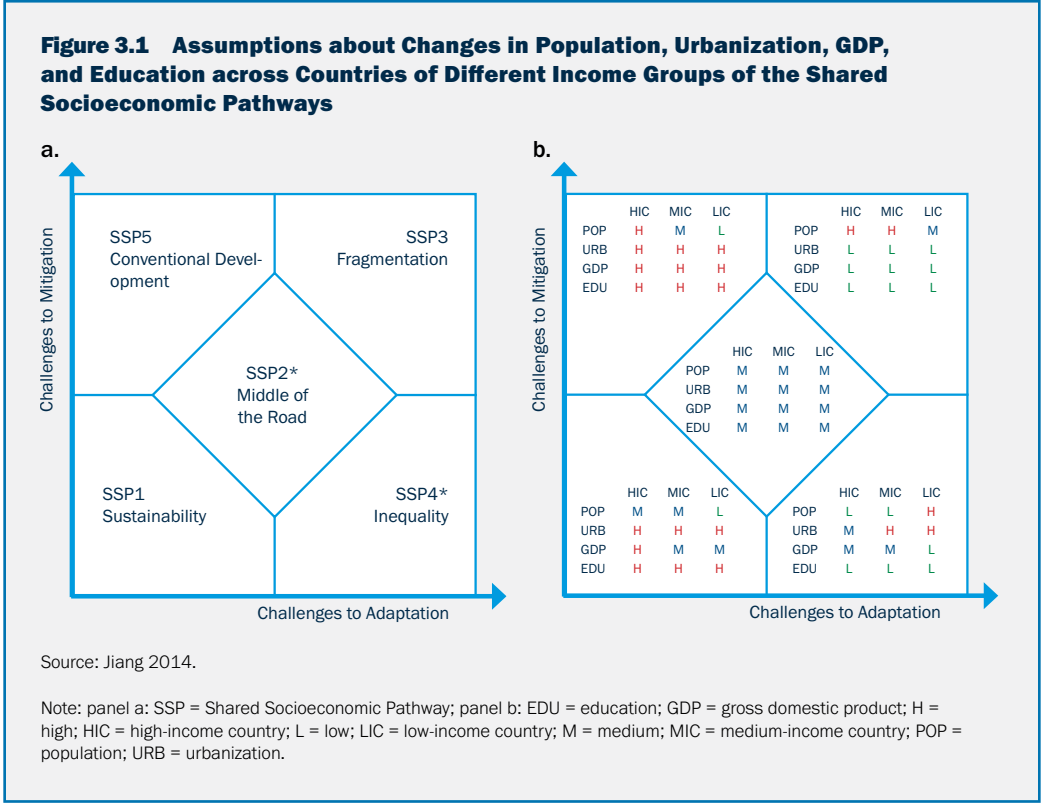
**Table 3.2 Shared Socioeconomic Pathway (SSP) Narratives**

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.

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

22. Shared Socioeconomic Pathways (SSP), (database), <https://tntcat.iiasa.ac.at/SspDb>.



**The model used 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 LMICs are characterized by moderate population growth, urbanization, income growth, and education; with a moderate challenge 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 the 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 is limited to assessing internal climate migration.** Because this study builds on the SSPs, it includes bilateral migration flows included in the national-level population projections that correspond to each SSP (KC and Lutz 2017). For both SSP2 and SSP4, these flows are in the middle of the range.<sup>23</sup> 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.**<sup>24</sup> The lower emissions scenario (RCP2.6) is a world in which temperatures peak at 0.25°C–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<sub>2</sub> and CH<sub>4</sub> 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<sub>2</sub> and CH<sub>4</sub> 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, the 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 is 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 are the ranges and plausibility of scenarios as the low and high end.

### 3.1.3 Scenario Combinations Used in the Model

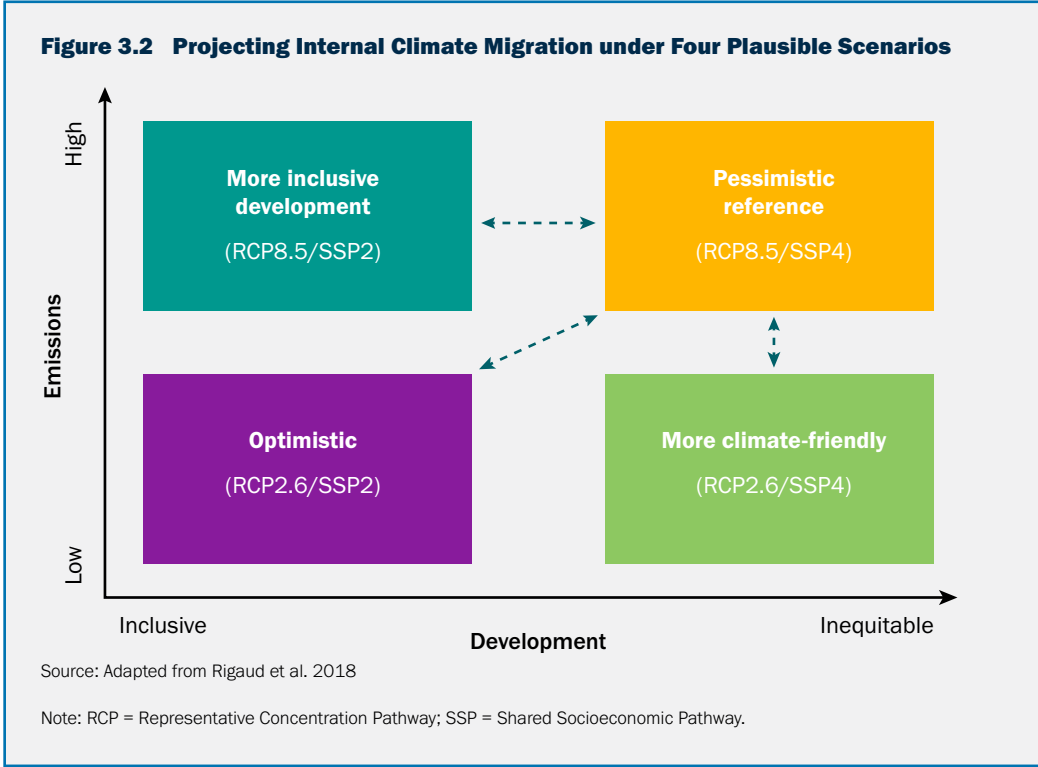
**Four plausible future internal climate migration scenario combinations are examined** (figure 3.2), and for each scenario, the estimate represents an ensemble of model runs using combinations of crop, water, ecosystem, and flood impact models from the Intersectoral Impacts Model Intercomparison Project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

- 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

23. 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.

24. The term emissions scenarios is technically not correct, in that the RCPs represent concentration levels of GHG and other pollutants that warm the earth’s surface. It is used here as shorthand, because emissions contribute directly to concentration levels.

- 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.



There are inherent uncertainties in the way climate impacts will play out in a given locale, and at higher resolutions these impacts 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 Model Intercomparison Project—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 (net primary production [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 aims at contributing to a quantitative and cross-sectoral synthesis of the differential impacts of climate change, including uncertainties. It 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).<sup>25</sup> 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 U.K. 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 supply, 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 also be important drivers of migration.<sup>26</sup> Finally, sea level rise is included as a spatial mask that does not permit people to live in areas likely to experience inundation. Each input layer 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 employed in this report does capture 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.<sup>27</sup> The data were converted to five-year average water availability and crop production (in tons) per grid cell.<sup>28</sup> 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):

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

where  $D_{avg}$  is the five-year average crop production/water availability and  $B_{avg}$  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.

25. See the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) at <https://www.isimip.org>.

26. Water availability is influenced by rainfall and rising temperatures. Crop production is a function of rainfall, temperature, CO2 concentrations, irrigation, and other management practices that are incorporated in the ISIMIP models.

27. The ISIMIP models seek to assess the risk that climate change will affect the potential for agriculture in a given location. For this purpose, the relative changes in average yield potential are useful.

28. 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 the location where crops are 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).



**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.<sup>29</sup> 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**

**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. At the time that the original Groundswell modeling (Rigaud et al. 2018) was done, the ISIMIP ecosystem productivity models were not available.

**The second reason was to fill gaps where crop production does not take place.** 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 with the ecosystem productivity data, which are areas more likely to encompass pastoral livelihoods. Even so, in this study, ecosystem productivity is applied only in the model to those areas lacking crop productivity, since there is high spatial co-linearity between the crop and ecosystem metrics.<sup>30</sup>

**Ecosystem productivity is measured in terms of NPP.** The ecosystem models simulate the natural growth of several plant functional types, including grasses. The NPP 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. 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).<sup>31</sup> The models were driven by the same GCMs using the same RCPs as in the original Groundswell report (Rigaud et al. 2018).<sup>32</sup>

29. 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.

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

31. More specifically, the ecosystem models are used to gap-fill the LPJmL and GEPIC crop models, respectively.

32. See chapter 3 and appendix A of Groundswell: Preparing for Internal Climate Migration (Rigaud et al. 2018).

### **Flood Models Used in the Gravity**

The original Groundswell modeling did not include flood risk. The flood hazard layer is based on projected flood depth simulated by a global flood model CaMa-Flood (Yamazaki et al. 2011) version 3.4.4. It primarily represents riparian (along rivers), not coastal flooding, although it does capture rivers emptying into the ocean. Potential coastal flooding is better captured by the sea level rise mask. 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 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 helped 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**

The analysis also considers sea level rise projections from the IPCC Fifth Assessment Report, augmented by an increment for storm surges. The figures in table 3.4 represent the lower-, middle-, and upper-bound sea level rise by 2030 and 2050, as reported by the IPCC (Church et al. 2013) but do not consider storm surge. 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. Nor were we able to find data on coastal erosion that cover enough of the coastline consistently.

**Table 3.4 Projected Sea Level Rise under Low and High RCPs, Lake Victoria Basin**

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.

We adapted two scenarios to represent changes in sea level by 2050 associated with RCP2.6 and RCP8.5 by adding an increment to account for storm surge on top of the estimates of sea level rise (table 3.3). 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. Both the 1- and 2-meter sea level rises are based on NASA Shuttle Radar Topography Mission data, as modified by the Low Elevation Coastal Zone (LECZ) ver. 2 dataset.<sup>33</sup> Processing coastal elevation over large areas is time consuming, and the fact that the global LECZ data were already available expedited this work. That said, there is strong scientific grounding for adding increments (Dasgupta et al. 2007; Hallegatte et al. 2011).

33. CIESIN, 2013 (database), Columbia University, New York, <https://sedac.ciesin.columbia.edu/data/set/lec2-urban-rural-population-land-area-estimates-v2>

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 SLR by progressively removing land from occupation, thereby reducing the population that will be accommodated in a coastal grid cell over time.

### 3.1.5 Population Data

The population baseline is the 2010 baseline in GPWv4.<sup>34</sup> The gravity model was calibrated twice, first based on population change estimates for 1990–2010 derived from GPWv3 (CIESIN et al. 2005), and second for 2000–10 from GPWv4. GPW versions 3 and 4 model the distribution of the population on a continuous global surface based on the highest spatial resolution census data available from the 2000 and 2010 rounds of censuses, respectively. In this work, population count grids were 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.

**Uncertainties in GPWv4 2010 population count grid generally relate to the timeliness and accuracy of the underlying census data and to the input resolution of the census units.** In East Africa, the census year ranges from 2008 in Burundi to 2014 in Uganda, and the mean size of the input units ranges from 78 square kilometers in Rwanda to more than 1,779 square kilometers in Tanzania (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. This affects the confidence in the decadal population change grids used for model calibration. The populations for 2000 were backcast at admin 1 (province level) for Kenya and Uganda and a mix of admin 1 and 2 for Burundi and Tanzania, and at admin 3 (district) level for Rwanda (table 3.5). Higher order matching of admin units across both versions of GPW provides higher levels of confidence in backcast population distributions. Because of corresponding admin 3 units over each census time step, the model was calibrated using historical ISIMIP index values with population data from Tanzania.

**Table 3.5 Population Data Inputs by Lake Victoria Basin Countries for GPWv4**

Country	Census year	Admin. level	Mean unit size (km <sup>2</sup> )	Growth rate: start	Growth rate: end	Growth rate: admin. level
Burundi	2008	2	265.12	1999	2008	1, 2
Kenya	2009	5	976.19	1999	2009	1
Rwanda	2012	3	78.08	2002	2012	3
Tanzania	2012	3	1,779.60	2002	2012	1, 2
Uganda	2014	3	452.45	2002	2014	1

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

34. CIESIN, 2016 (database), Columbia University, New York, <http://dx.doi.org/10.7927/H4X63JVC>.

Though the Lake Victoria Basin modeling was carried out at the original 1-kilometer spatial resolution of the GPWv4 data (30 arc-seconds), it was aggregated to approximately 15-kilometer grid cells (7.5 arc-minutes) because the data analysis and visualization methods are only appropriate at this coarser resolution. This is primarily because the resolution at which analysis is undertaken, by proxy, defines what qualifies as migration. It is assumed 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 these differences can feasibly be attributed to migration. 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 becomes important to balance spatial resolution with a realistic definition of the distance that constitutes migration. Here, although we run the model at higher 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 (owing to sea level rise and other climate impacts), the 1-kilometer resolution data are used.

### 3.1.6 Additional Nonclimate Data Factors

#### *Conflict*

**In the Lake Victoria Basin 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. Spatial data on conflict occurrence were obtained from the Armed Conflict Location & Event Data Project (ACLED) database<sup>35</sup> (Raleigh et al. 2010). 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. 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. 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 (see appendix B for details on the calibration results).

#### *Demographic Characteristics—Median Age and Sex*

**Spatial data on the age and sex distribution per grid cell was obtained from the GPWv4.10 Basic Demographic Characteristics.**<sup>36</sup> 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 (figure 2.5). In most regions, owing to the propensity of youth to migrate to urban areas, rural areas would typically have higher median age. 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.

**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 original 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 at higher resolution it becomes difficult to attribute observed differences in outcomes between the climate and no climate scenarios to climate-induced migration.

35. Armed Conflict Location & Event Data Project (ACLED) (database), accessed September 2018, Madison, WI, <http://www.acled.org>.

36. CIESIN, 2017 (database), Columbia University, New York, <https://doi.org/10.7927/H45H7D7F>.

The original Groundswell report did not assume or apply any maximum population density in rural areas before they reached carrying capacity or became urban in nature. However, research suggests such limits may exist. In Kenya, for example, densities beyond a threshold of 500 to 600 persons per square kilometer resulted in no further intensification or 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 et al. 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,<sup>37</sup> population densities were evaluated across all grid cells (Table 3.6).

**Table 3.6 Population Density of Rural and Urban**

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

Note: n.a. = not available SD = Standard Deviation.

Based on the above statistics, a threshold for maximum rural population densities of 1,000 persons per square kilometer were applied, and a 50,000 person per square kilometer threshold 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 per square kilometer for rural areas and 50,000 for urban areas.

### 3.1.7 Coefficients

The enhanced model includes model coefficients that show the influence of the variable on the observed deviation between observed population change and projected population change (spatial shifts) based on historical calibration of climate signal from 1990 to 2000 and 2000 to 2010. 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, since their populations are not directly dependent on cropping or animal husbandry.

The coefficients in table 3.7 represent the average of the coefficients across the two decades for Tanzania, the only country with matching population and population growth rates at the same administrative level across the three time steps from 1990 to 2010.<sup>38</sup> Note that sea level rise (in coastal Kenya and Tanzania) 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.

37. CIESIN, 2011 (database), Columbia University, New York, <https://data.amerigeoss.org/dataset/global-rural-urban-mapping-project-version-1-grumpv1-urban-extent-polygons-revision-01>

38. 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.

**Table 3.7 Model Coefficients for the Lake Victoria Basin**

Predictor	(Parameter) coefficient		Units
	Urban	Rural	
Crop production	n.a.	0.793548	5-year deviation from historic baseline
Water availability	1.303542	2.261628	5-year deviation from historic baseline
Net primary productivity <sup>a</sup>	n.a.	0.477869	5-year deviation from historic baseline
Median age	-0.00534	0.002636	Median age of the population in years
Sex ratio	0.001975	-0.00424	Males/females
Conflict-related fatalities	-0.00465	-0.00027	Number of recorded fatalities
Flood risk	0.218818	0.020851	5-year likelihood of flood event

Note: Calculations based on Tanzania 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.

**Water availability is a key climate factor that will influence migration over the next few decades.** The coefficient for water availability in rural areas is around 2.8 times higher than that of crop production and 4.7 times that of NPP. Critically, it is the only climate driver other than floods and sea level rise influencing future urban population distribution. Water availability is projected to have a far greater influence on future population distribution than most of the other climate variables. This means that greater water availability results in increasing attractiveness of a location and vice versa.

**Demographic variables of median age and sex (gender) distribution were introduced in the enhanced model applied in this study.** These impact the climate migration projections through their own relationship with population change (as derived through the spatial autoregressive calibration), and through their interaction with the climate drivers. In the case of Lake Victoria Basin countries, the alignment between these factors means that they amplify the impact of climate. In contrast, in the West Africa region, demographic variables mitigated or dampened climate migration (Rigaud et al. 2021a).

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

## 3.2 POPULATION MODELING METHODS

**Climate impacts on crop production, water availability, ecosystem productivity, and flood depth and extent have important effects on 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).<sup>39</sup> Technical details on the model specification are found in appendix B.

### 3.2.1 Gravity Model

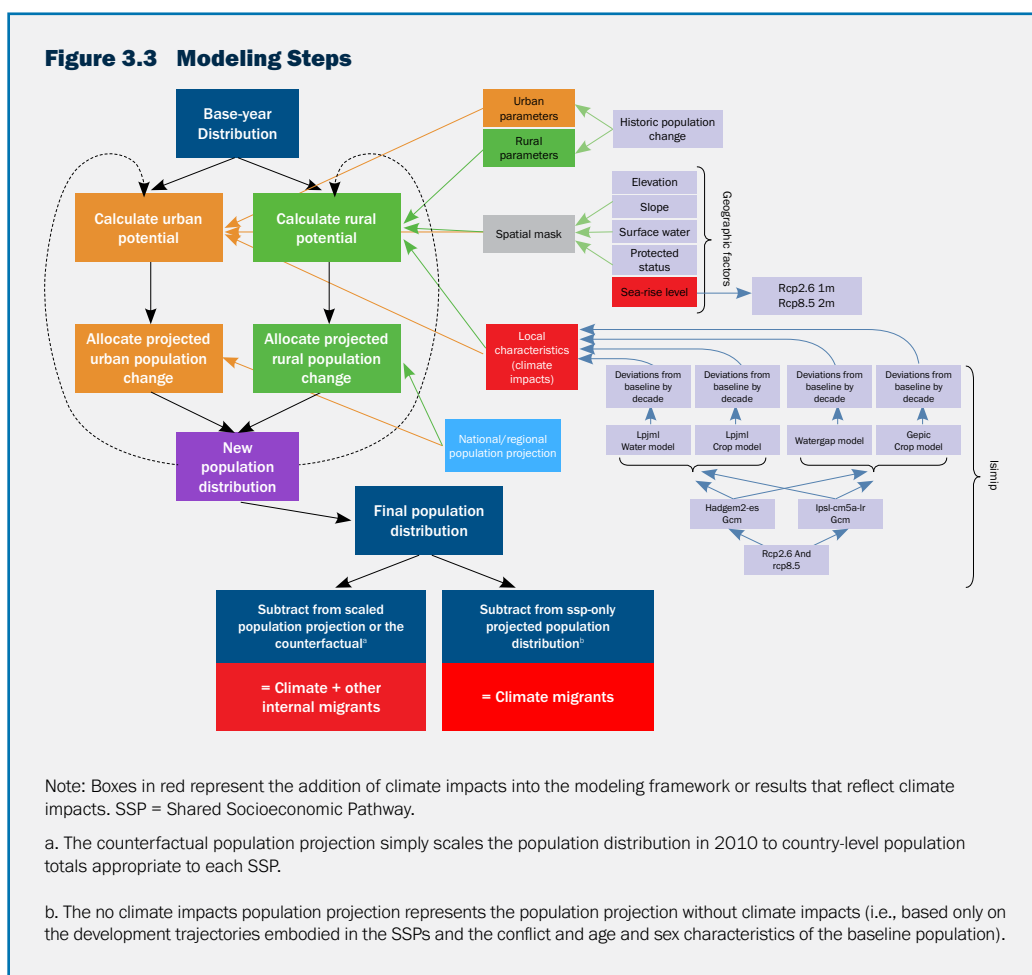
**The NCAR-CIDR model uses a modified form of population potential, a distance-weighted measure of the population taken at any point in space that represents the relative accessibility of that point.** For example, higher values indicate a point more easily accessible by a larger number of people. Population 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 be considered an indicator of the potential for interaction between the population at a given point in space and all other populations (Rich

39. Data for the original SSP-only population projections are available for download through the NASA SEDAC database, available at <https://doi.org/10.7927/H4RF5S0P>. These projections are produced using a baseline 2010 population of GPWv3 rather than GPWv4, as used here.

1980). This potential will be higher at points closer to large populations; potential is thus also an indicator of 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

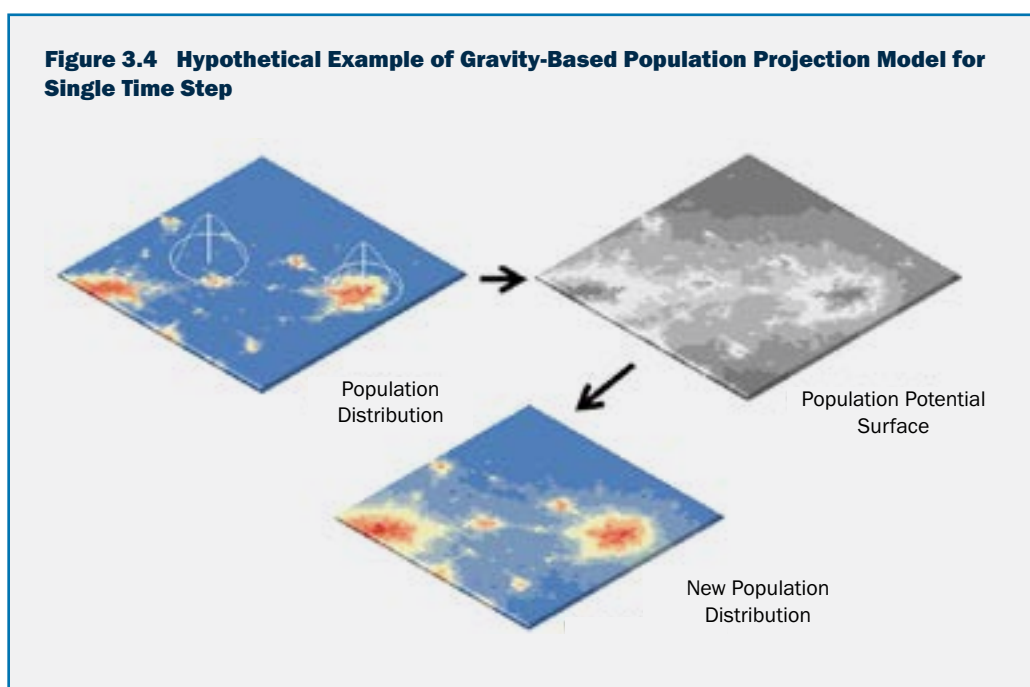
The calculation of potential was modified primarily by adding variables that describe local conditions, including climate impacts, and weighting the attractiveness of each location (grid cell) as a function of the historic relationship between these variables and observed population change. Figure 3.5 is a flow chart of the 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; of assumptions regarding spatial development patterns (for example, sprawl compared to concentration); and of 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 that differentiate between places. In any given grid cell, the drivers may either act in concert, reinforcing one another (e.g., rural grid cells with crop production and water availability decline), or they may offset each other (e.g., flood risk may increase, but water availability declines).



Beginning with the 2010 gridded urban-rural population distribution for each country,<sup>40</sup> this report's modeling incorporates 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 redefinition of population from rural to urban (e.g., 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.

**These steps are then repeated for each five-year time interval.** Figure 3.6 illustrates steps 3 and 4 for a hypothetical population distribution. Note that population potential surfaces, urban and rural, are continuous across all cells; each cell may thus contain urban and rural populations.



40. 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 tend toward agglomeration over smaller geographic areas that can take several different forms (e.g., 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. In fitting the model to historical data, we find substantial variation in many of the parameters driving spatial population change. These two factors, taken together, suggest that modeling urban and rural populations as separate but interacting components of the total population is advantageous in comparison to considering the entire population as a single entity.



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

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

Where:

$A_i$  = Local characteristics

$I_i$  = Spatial mask

$\alpha$  = Population parameter etc.

$P$  = Population

$\beta$  = Distance parameter

$d$  = Distance

(3.2)

**The population potential spatial layer is weighted by a spatial mask<sup>41</sup> ( $I$ ) that prevents population from being allocated to areas protected from development or unsuitable for human habitation, including areas that will likely be 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 ( $\alpha$  and  $\beta$ ) are estimated from observed patterns of historical population change (for urban and rural populations, separately). The  $\beta$  parameter is indicative of the shape of the distance-density gradient describing the broad pattern of the population distribution (e.g., sprawl compared to concentration), typically a function of the cost of travel (with lower costs leading to residential patterns more indicative of sprawl). The  $\alpha$  parameter captures returns on agglomeration externality, interpreted as an indicator of the socioeconomic, demographic, and political characteristics that make a place more or less attractive.

**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 additional spatial data, including ISIMIP sectoral impacts, demographic characteristics of the population, and the distribution of conflict-related fatalities, all of which are likely to 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 decadal 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 demographic composition of the population 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 (e.g., 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.

41. 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 include protected areas or places where the terrain is too rugged to inhabit.

### 3.2.3 Characterizing the Model

**This modeling provides credible, spatially explicit estimates of population distribution changes (and indirectly migration) as a function of climate, demographic, and development trends.** It is important to understand factors the model does and does not account for. 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 be refined and expanded to incorporate additional details, such as environmental parameters that affect the relative attractiveness of locations, typically improving the model's capacity 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, these are crop production, ecosystem productivity, water availability, and flood risk. Development-only (also referred to as the SSP or “no climate” models) 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. The model does not provide information about the directionality of migration. It cannot be inferred that migrants are moving from a given area of out-migration (e.g., 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 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 global climate model/ISIMIP combinations. The ensemble mean (or average) of the four models is the primary result for each scenario. Uncertainty is reflected in the range of outcomes (across the four models) for each grid cell and at levels of aggregation. While some may prefer to have just one figure, in a complex issue like 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.



Sarah Farhat / World Bank

### 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 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 has an impact on 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 took place 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 have the effect of reinforcing 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 used two 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 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 shifts can be short-distance migration. The temporal scale of decadal increments from 2010 to 2050 captures 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.<sup>42</sup> Shorter-term and seasonal migration are not captured by the model.

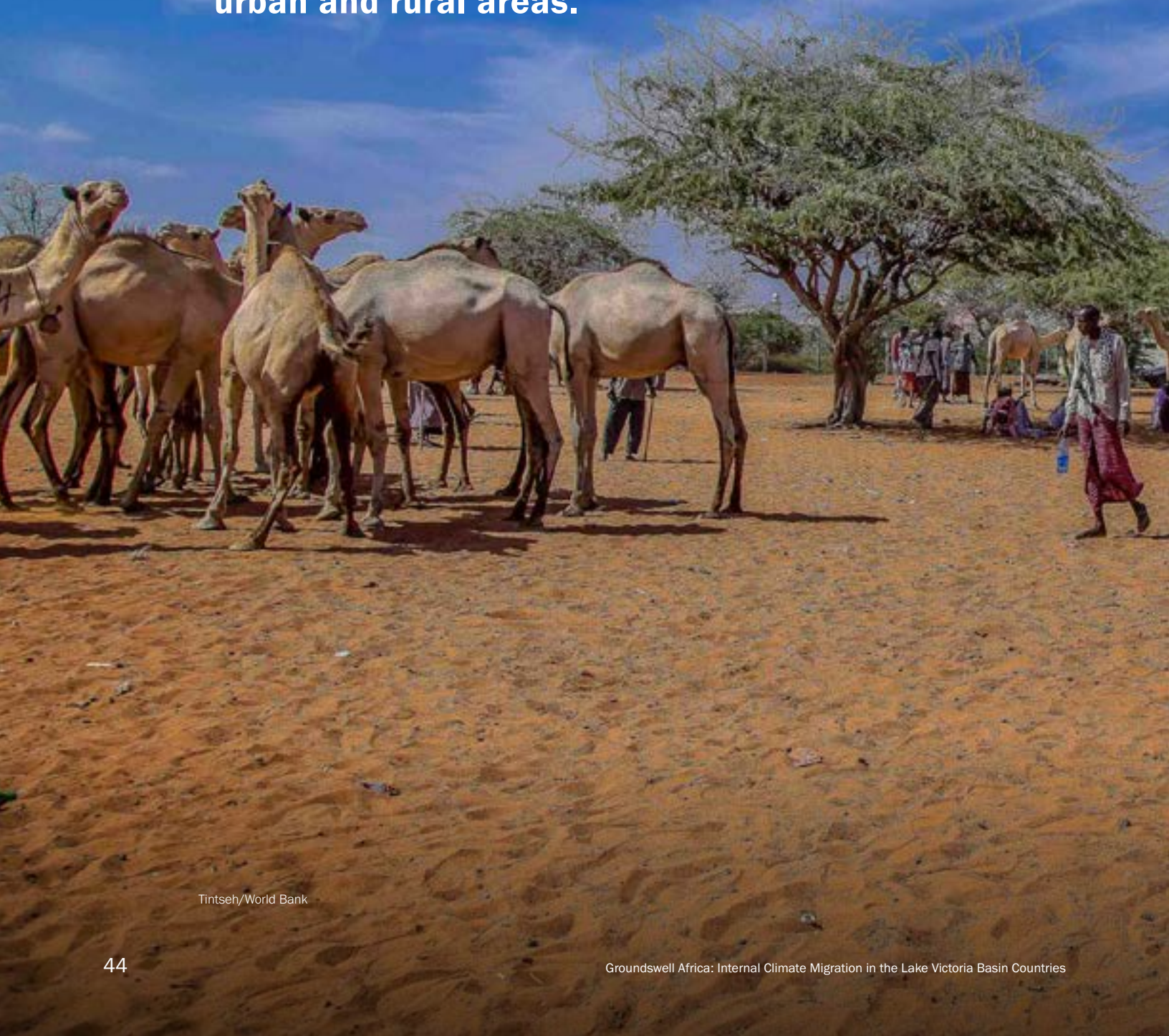
**The focus is on the 30 years between 2020 and 2050, which represent a meaningful planning horizon, especially when considering social dimension of migration.** Chapter 4 of Rigaud et al. (2018) considers water and agriculture sector impacts beyond 2050 by examining ISIMIP outputs for 2050–2100. They suggest that, if anything, the climate signal will become far stronger toward the end of the 21st century. Under RCP8.5, the western portions of the region (Senegal, 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 the impacts on migration.

**The model cannot forecast all future adaptation efforts or conflict, 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 not yet 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 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 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. They can be used to spur policy and action to counter distress-driven climate migration.

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42. 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.

**Climate projections, taking into account crop and water simulation models, indicate that water availability will be the strongest driver of internal climate migration in the Lake Victoria Basin countries in both urban and rural areas.**



## 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), flood risk (derived based on the Intersectoral Impacts Model Intercomparison Project [ISIMIP] simulation models), and sea level rise compounded by storm surge. Results relating to the nonclimate factors (demographic, including median age and sex, and conflict) are also presented. The 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

Figures 4.1–4.3 present the average projected changes in water availability, crop production, and NPP for the 2010–2050 time period, respectively. NPP is used to gap-fill areas where there is no crop production. Appendix C has projections for the 2050–2100 time period. These projections represent the inputs for the estimation of future population shifts induced by climate change as a proxy of climate migration.

#### 4.1.1 Water, Crop, and Ecosystem Productivity

**The analysis reveals that populations are most sensitive to historical deviations in water availability (in both rural and urban areas), followed by historical deviations in crop productivity and changes in NPP that affect rural farmers and pastoralists.** This means that positive deviations in water availability, crop productivity, or NPP are associated with increases in population density in the past. The coefficients are set out in table 3.7.

**Water availability is the strongest factor that will influence migration in the Lake Victoria Basin (Lake Victoria Basin) over the next few decades.** This implies that greater water availability results in increasing attractiveness of a location, and vice versa. The coefficient is particularly high in rural areas, meaning that, other things being equal, areas with better water availability (as measured by the deviation from historic baseline) are projected to have relatively large positive population changes. Figure 4.1, panels a and b, depicts the average index values across the model runs for the 2010–50 period for the water models.

Consistent with patterns found in the Coupled Model Intercomparison Project ver. 5 (CMIP5) archive, the water models all show wetting in northern Uganda and Kenya. The models disagree on Tanzania, which under the Hadley model (HADGEM2-ES) is projected to get drier, while under the IPSL model it is projected to get wetter.

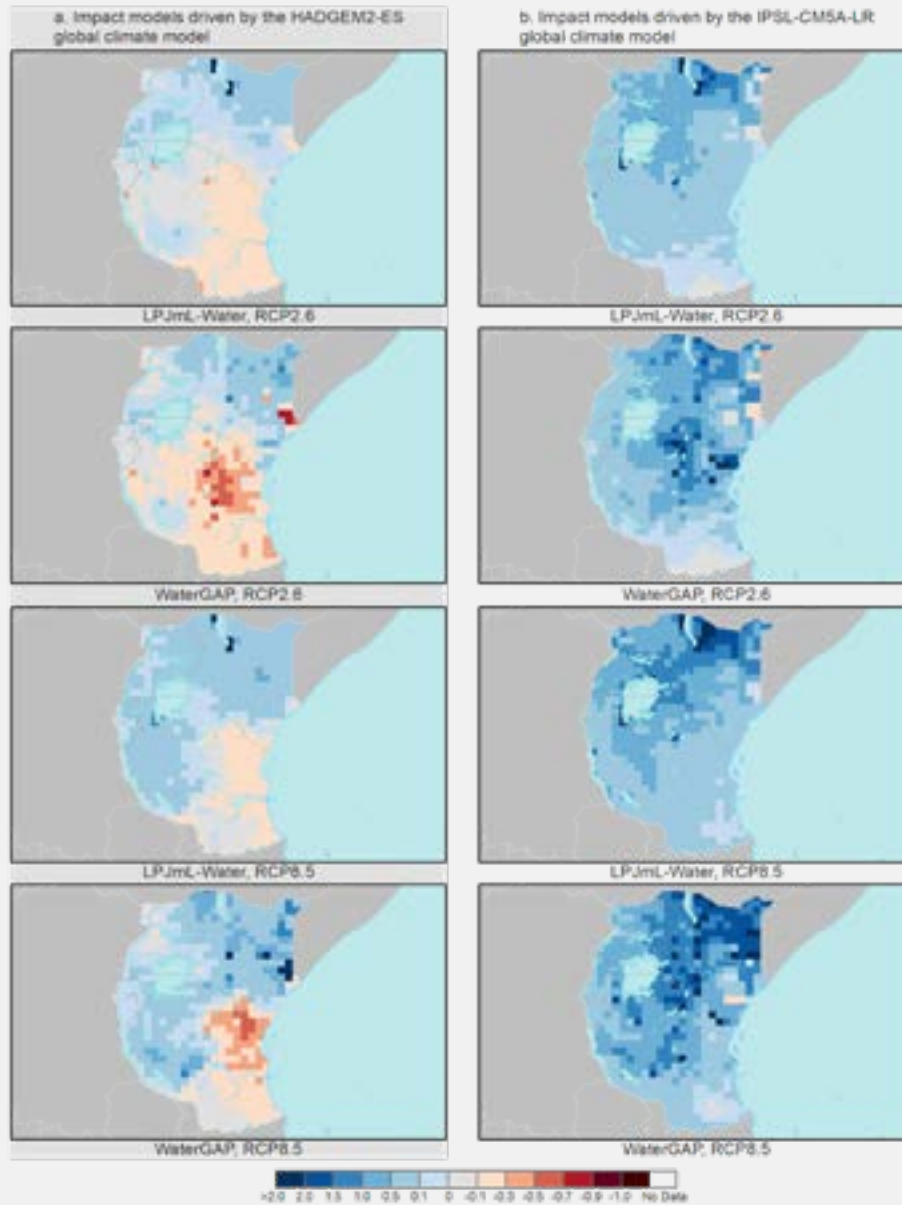
**The modeling results vary considerably among Lake Victoria Basin countries.** The climate models project contrasting results for water availability between 2010 and 2050 in Tanzania. The IPSL-CM5A-LR model projects increase in water availability across most of Tanzania, with the northeast projecting the highest increase in water availability. The HADGEM2-ES model, however, projects drying in the east and northeast (against very low baselines) and increase in water availability in the west and north, with some variations. In Uganda, the average projected water availability from the ISIMIP model runs for the 2010–50 period suggest that Uganda is likely to become wetter, particularly in the east, while some models indicate a drying trend in the northwest and west-central areas.

**In rural areas, high values in crop yields and NPP are positively correlated with larger population change.** The magnitude of the coefficient is smaller, so its effect is not as strong as water availability. Crop production and NPP are not used to calibrate urban grid cells because populations are assumed not to be as dependent on crops and livestock for livelihoods. Figure 4.2, panels a and b, depicts the average index values for the crop models for the 2010–50 period.

**The crop models are more varied than the water models.** Under the LP-JmL model, the highland areas around Mount Elgon on the Uganda-Kenya border and stretching through the highlands toward the southeast, along throughout Rwanda and Burundi, show significant increases in yields. It also consistently shows declines in western Tanzania. The GEPIC model shows declines in crop productivity in northeastern Uganda as well as western Tanzania. Under RCP8.5, declines are significant throughout the region. The results of NPP presented in figure 4.3, panels a and b, should not be seen as very influential except in those few areas of gaps in cropping.

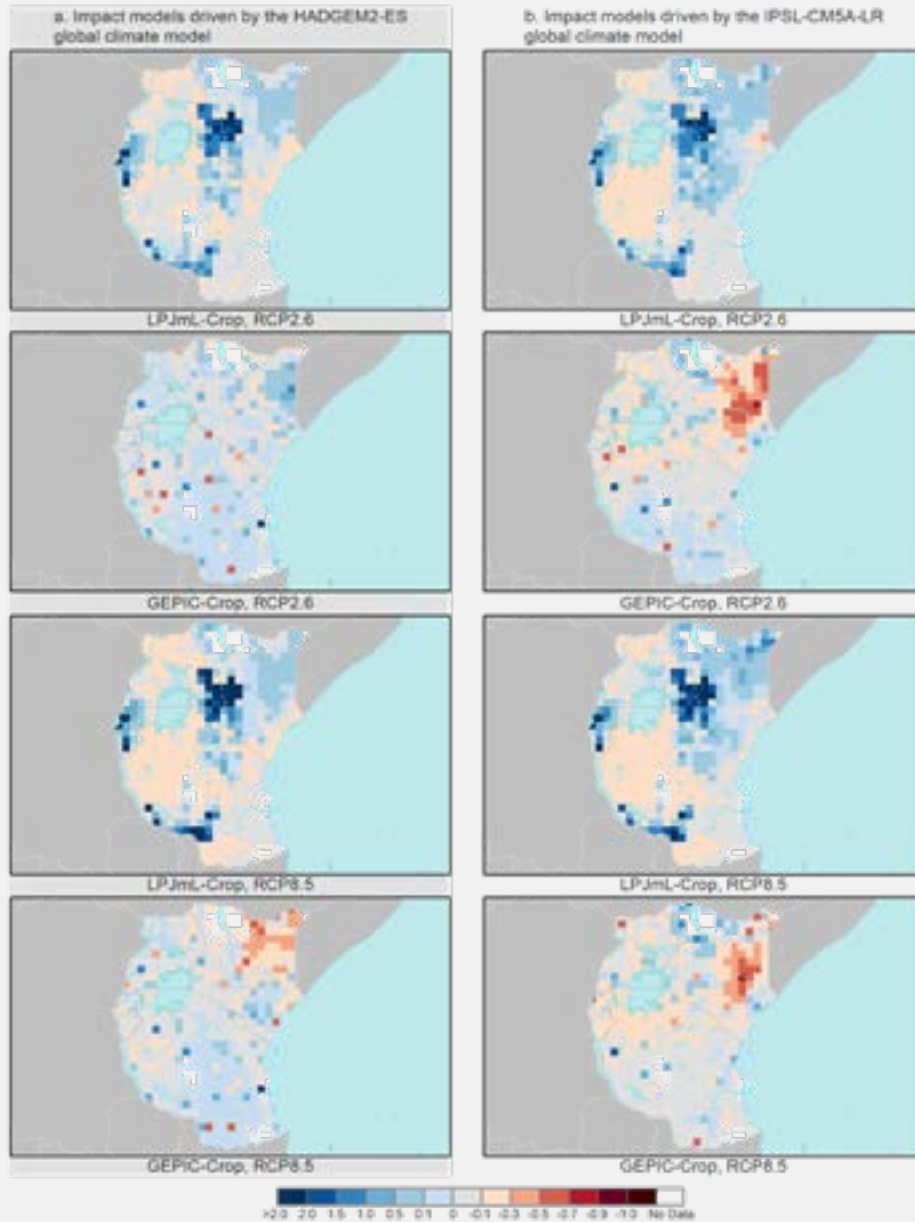


**Figure 4.1 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Lake Victoria Basin, 2010–50**



Note: Data calculated against 1970–2010 baseline for water availability, 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 tan to red areas indicate drying.

**Figure 4.2 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Lake Victoria Basin, 2010–50**



Note: Data calculated against 1970–2010 baseline for crop production, 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 crop production increases relative to the historical baseline, and 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, Lake Victoria Basin, 2010–50**

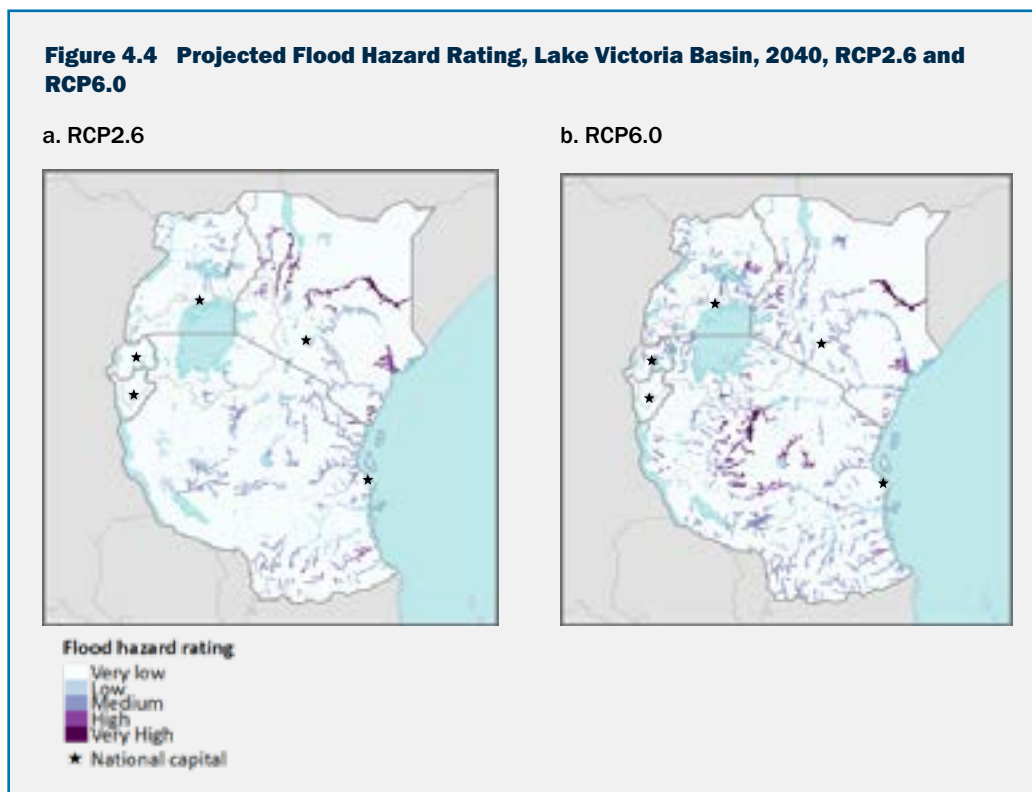


Note: Data calculated against 1970–2010 baseline for ecosystem NPP, from LPJmL (panel a) and VISIT (panel b), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5. Blue areas indicate higher NPP relative to the historical baseline, and tan to red areas indicate lower NPP. These projections were only used to gap-fill in areas without crop production projections. NPP = net primary productivity.

#### 4.1.2 Flood Models Used in 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 the Lake Victoria Basin under RCP2.6 and RCP6.0, representing low and high emission scenarios, respectively. 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 equitable development and pessimistic scenarios. Flood hazards are higher and more extensive under higher emissions: along Tanzania’s section of the Lake Victoria Basin south to Lake Eyasi and Kitangiri. The risks are also high around Lake Kyogo in Uganda and north of the Basin in Kenya.

**Paradoxically, flooded areas tend to attract population in the gravity model, since riparian areas are historically more accessible and often host urban areas.** Thus, flood risk will tend to attract new migrants rather than repel them. This is consistent with the literature on flood risk in developing countries. For example, Jongman, Ward, and Aerts (2012) write 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.” There is a well-documented migration trend toward, and consequently population growth in, low-lying and flood-prone coastal areas (de Sherbinin et al. 2012; Neumann et al. 2015). A new World Bank Study “The Ebb and Flow: Water, Migration and Development” (Borgomeo et al. 2021; Zeveri et al. 2021) found 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.



#### 4.1.3 Sea Level Rise

**The model implements sea level rise and storm surge by progressively removing land from occupation, thereby reducing the population accommodated in a coastal grid cell over time.** The analysis uses sea level rise projections from the IPCC Fifth Assessment Report, augmented by an increment for storm surges (table 3.4). 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. 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.

## 4.2 NONCLIMATE FACTORS—CONFLICT AND DEMOGRAPHIC CHARACTERISTICS

### 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 were obtained from the Armed Conflict Location & Event Data Project (ACLED) database.<sup>43</sup> We developed a spatial layer of point locations of every conflict event between 2009 and 2018, and the values at each point were the number of fatalities.



### 4.2.2 Demographic Characteristics—Median Age and Sex

**Data on median age and sex ratios used to calibrate the model by establishing the relationship between spatial population change and demographic characteristics of the population show weak impacts (see table 3.7 on coefficients).** This is unlike the pattern in the West Africa, in which the attractiveness of higher median age in urban areas, as an underlying demographic pattern in West Africa, dampened the effects of water stress, which would otherwise drive climate out-migration.

43. Armed Conflict Location & Event Data Project (ACLED) (database), accessed September 2018, Madison, WI, <http://www.acled.org>.



**By 2050, up to 10.48 percent of the population across the Lake Victoria Basin countries could be compelled to move as a consequence of climate change, absent adequate climate and development action.**

A'Melody Lee / World Bank

Credit: A'Melody Lee/ The World Bank

An aerial photograph showing a small settlement with several buildings and a dirt road, situated in a hilly, agricultural landscape. The terrain is green with some brown patches, suggesting a mix of vegetation and soil. The settlement is located in a valley or a low-lying area between hills.

## Chapter 5

# Modeling Results: Future Internal Climate Migration Patterns and Trends

This chapter discusses the results of the future internal climate migration patterns for the Lake Victoria Basin region, aggregated from the modeling of climate-induced shifts in population distribution applied at a country level. The results underscore the potential for an increased number of internal climate migrants through 2050, accompanied by new climate in- 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

This section estimates the 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.<sup>44</sup> 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 and crop 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: migration. The white areas around the central trend line represent confidence intervals, which reflect the degree of agreement among the four model runs that provide an estimate for each scenario. Narrower confidence intervals indicate greater agreement among the model runs of each scenario.

44. 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—i.e., 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 captured within the natural population growth patterns as part of the baseline. For details, see appendix A and B.

The number of internal climate migrants are projected to follow an upward trend across all four scenarios between 2025 and 2050. The number of internal climate migrants in the Basin could see anywhere from a 2.9-fold increase (under the optimistic scenario) to a 3.5-fold increase (under the pessimistic scenario) between 2025 and 2050. The projected internal climate migration levels is the highest under the high emissions scenarios, reaching up to 38.5 million migrants in the region by 2050. Uncertainty is greatest in the more climate-friendly scenario and least for the inclusive development scenario. The results reveal that climate-induced migrants could represent up to 10.48 percent of the population by 2050 at the high end of the pessimistic scenario. Table 5.1 shows the results for total climate change-induced internal migration for the region by 2050, and figure 5.1 shows the trajectory of climate migrants and the total numbers up to 2050.

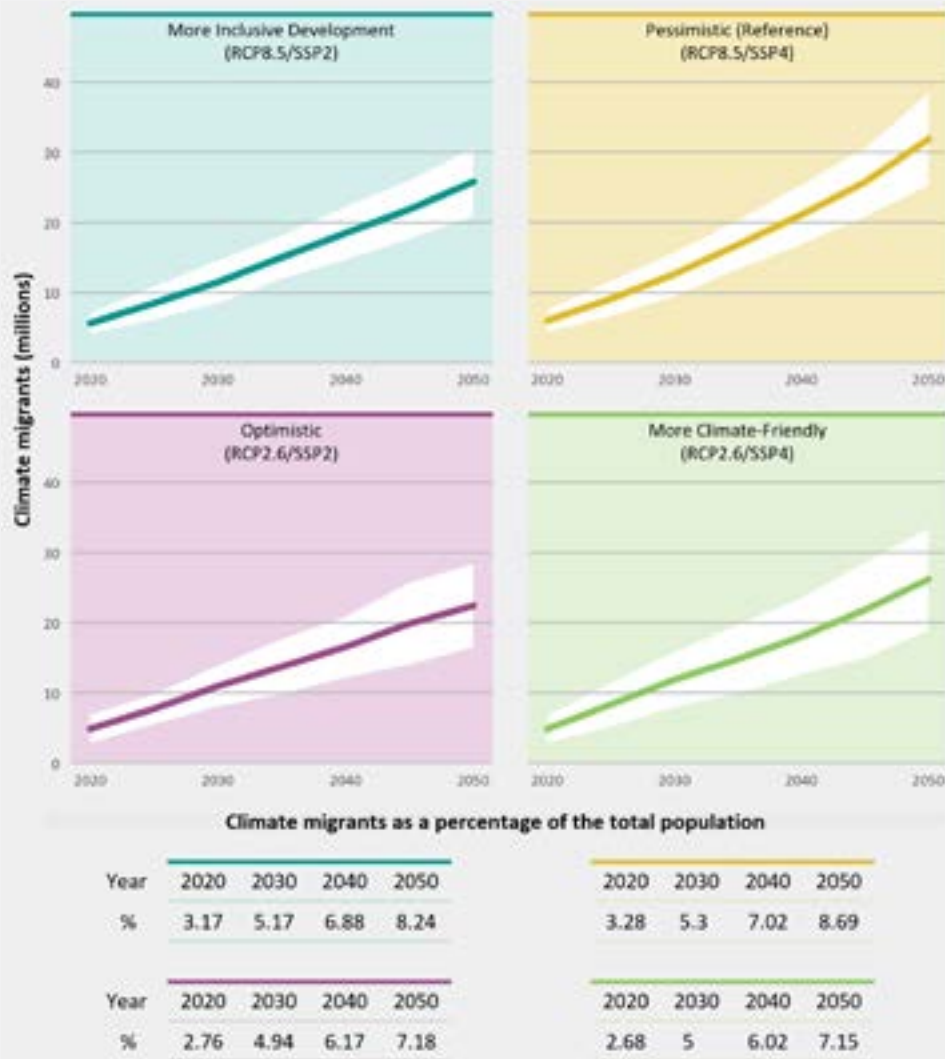
**Table 5.1 Estimated Number and Share of Total Internal Climate Migrants in Lake Victoria Basin countries by 2050**

	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 internal climate migrants by 2050 (million)	31.9		25.8		26.2		22.5	
Minimum (left) and Maximum (right) (million)	25.3	38.5	21.0	30.6	18.9	33.6	16.6	28.4
Internal climate migrants as a percent of population	8.7		8.2		7.2		7.2	
Minimum (left) and Maximum (right) (percent)	6.9	10.5	6.7	9.8	5.2	9.2	5.3	9.1

Note: The countries in the regional totals are Burundi, Kenya, Rwanda, Tanzania, and Uganda.

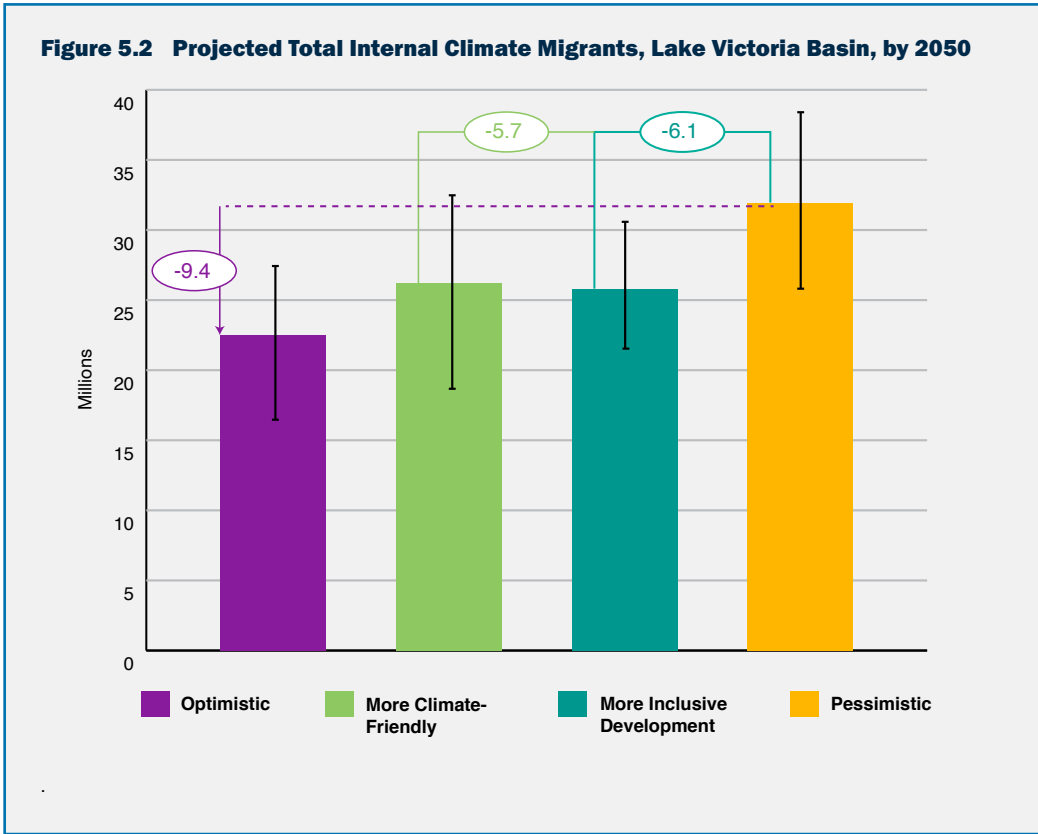


**Figure 5.1 Projected Total Internal Climate Migrants in the Lake Victoria Basin, 2020–50**



The projected total population for the SSP2 and the SSP4 are different. For the Lake Victoria Basin countries, SSP4 is higher.

**Both inclusive development and low emissions are critically important for modulating the scale of climate migration—with the greatest gains from early action.** The more inclusive development scenario is projected to reduce the average number of internal climate migrants by 6.1 million by 2050, while the climate friendly scenario reduces the average number by 5.7 million (Figure 5.2). The greatest gains are made when pursuing the optimistic scenario with low emissions and more inclusive development together, reducing the average number of internal climate migrants by 9.4 million. This suggests the need for Lake Victoria Basin countries to rapidly pursue highly resilient policies and economic transitions and shift towards less climate sensitive sectors at scale. Most importantly, these plausible scenarios provide a roadmap that charts out urgent and concerted action characterized by inclusive development and climate friendly policies to reduce the adverse consequences of climate migration. At the same time, without collective global responsibility and action to meet the Paris target, some of these gains may become more difficult to realize.

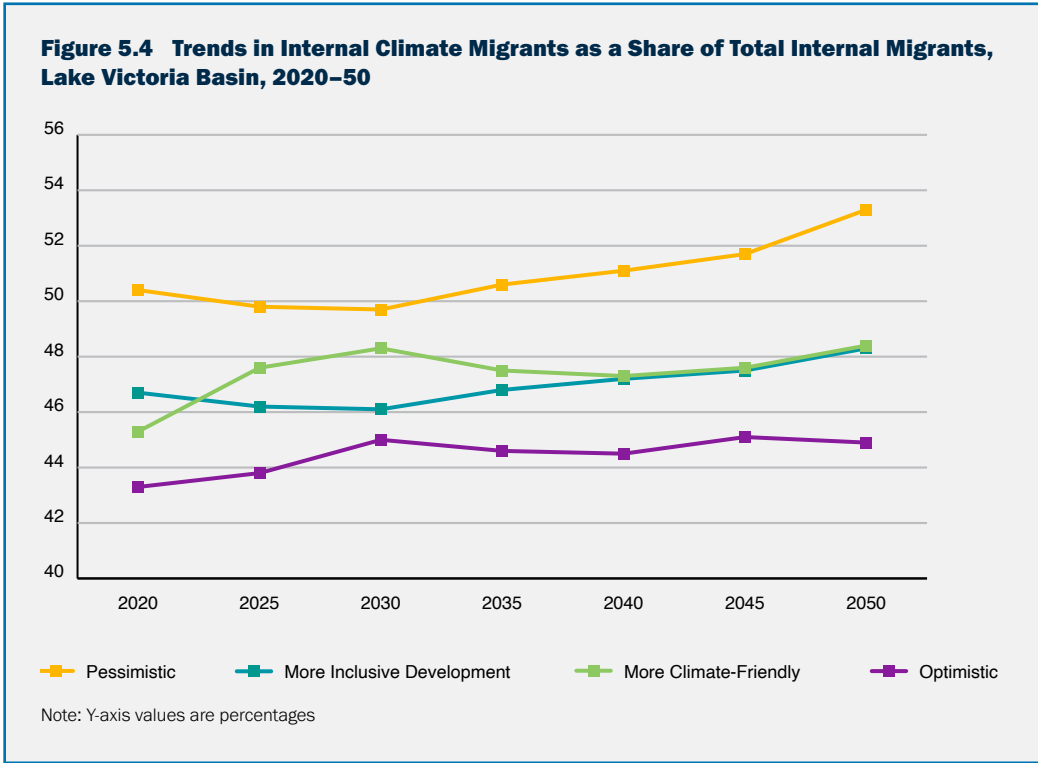
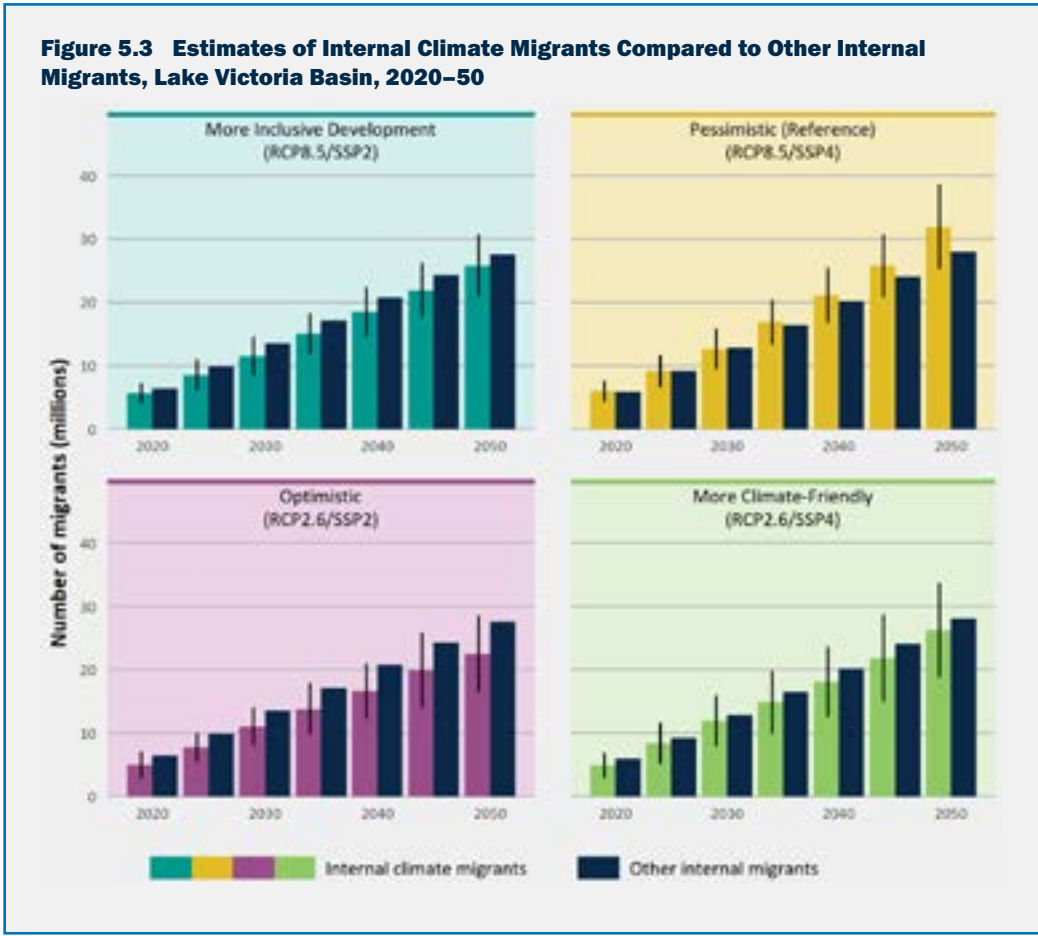


## 5.2 INTERNAL CLIMATE MIGRANTS COMPARED TO OTHER INTERNAL MIGRANTS

Other internal migrants include individuals who move within countries due to changes in population growth, urbanization, income, and education (as set out in the SSPs). 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 represents development or “other” internal migrants.

**The number of internal climate migrants in Lake Victoria Basin countries is projected to exceed that of other internal migrants by 2040, under the pessimistic scenario (figure 5.3).** At the high end of all scenarios, climate migrants could outpace other internal migrants as early as 2030. At the country level, climate migrants could outpace other migrants in Tanzania, Uganda, Kenya, and Burundi as early as 2030 in at least two scenarios, including the pessimistic.

**Across the Basin countries, climate migrants could represent half of all internal migration by 2030 under the pessimistic scenario (figure 5.4).** Tanzania and Uganda are the two most demographically important countries in the region by 2050 (each with between 90 million and 120 million people by 2050 depending on the SSP). They will have the largest numbers of climate migrants (between 6.5 million and 16.7 million in Tanzania and 6.4 million and 12.0 million in Uganda), collectively representing around three-quarters of regional totals.



### 5.3 CLIMATE IN-MIGRATION 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.<sup>45</sup> Climate out-migration will occur in areas where livelihood systems are increasingly compromised by climate impacts, while 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 and 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.

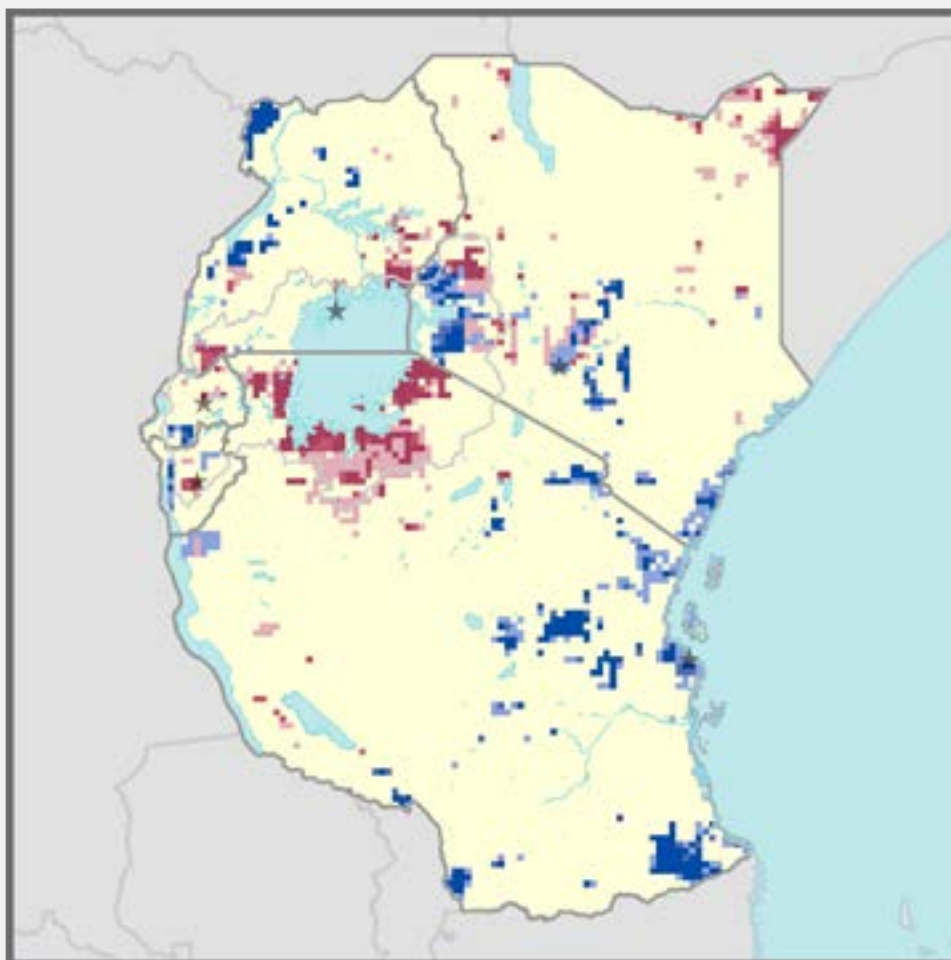
**Impacts of climate change and other drivers are not uniform across the region, and a spatial dimension is important.** The emergence of climate migration hotspots as early as 2030 will increase and spread by 2050. Figure 5.5 presents a regional compilation of country-level hotspots by 2050, and figure 5.6 presents the hotspots for earlier decades by 2030 and 2040. The Lake Victoria Basin (LVB) is projected to be a major climate in-migration hotspot for the five countries in this study. There are projected in-migration hotspots immediately surrounding the lake in Tanzania and in eastern Uganda (near the border with Kenya). In Rwanda, areas with high levels of climate in-migration are found in the central region close to the capital, Kigali, and in the north by the border with Uganda and Tanzania. In Burundi, a long and narrow out-migration spot is located in the west, close to Lake Tanganyika. Southwest Kenya, in the Lake Victoria Basin area, presents one band of high level of climate out-migration, including Kisumu (driven largely by a few model runs with declining water availability and crop productivity), followed by a band of high level of climate in-migration including Eldoret (because of increasing water availability and crop production), which extends to other parts of the Rift Valley.

**Localities around Lake Victoria are projected to emerge as climate in-migration hotspots as early as 2030. Near-term and farsighted action for the conservation and management of the lake’s resources—both within and across countries—is key to secure livelihoods, along with the provision of basic social services and infrastructure.**

45. 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.

**Water availability—a major driver of migration in the model—is projected to remain stable or to increase in the basin, but to decrease (under one of the water models) in much of Tanzania to the southeast of the lake.** Some of those areas (mostly in larger cities such as Dar es Salaam, Dodoma, and Arusha) are out-migration hotspots. There are two alternative ways of defining hotspots. In one, the hotspots are defined based on regional (rather than country-specific) thresholds for the top and bottom 5th percentiles of the distribution in climate migration results. In that map, the in-migration hotspots around the lake in Tanzania and Uganda intensify, but the out-migration hotspots in Kenya shrink. In the second, much of Rwanda and Burundi “light up” as hotspots of either in- or out-migration.

**Figure 5.5 Projected Hotspots of Internal Climate In- and Out-Migration based on Country-Level Compilation, Lake Victoria Basin, by 2050**



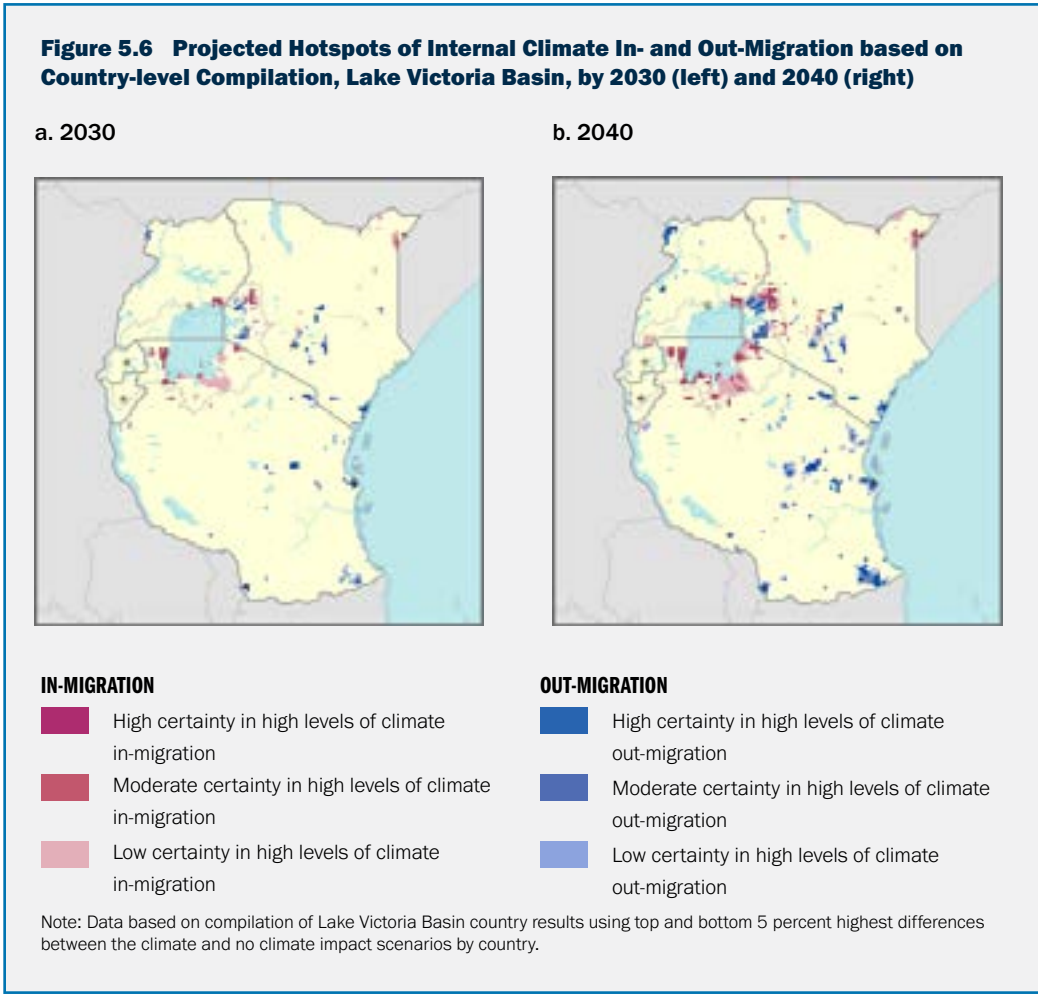
**IN-MIGRATION**

- 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

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



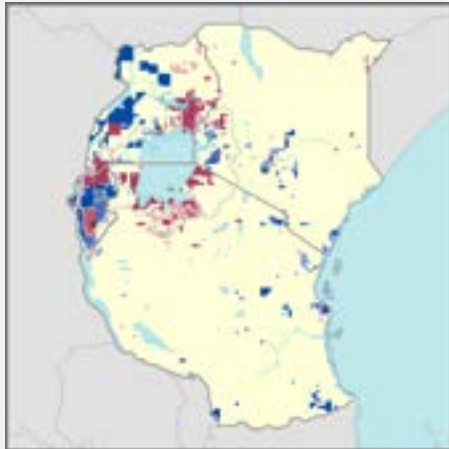
**Alternative representations of the hotspots—based on regional aggregation and normalizing for population—give prominence to different hotspots but with some level of consistency across approaches.** Figure 5.7, panels a–c, shows the hotspots calculated at the regional level, rather than country-by-country. In this map, the in-migration hotspots around the lake in Tanzania and Uganda intensify, but the out-migration hotspots in Kenya shrink. Figure 5.8, panels a–c, shows the hotspots presented at the regional level, but normalized by country population. In this map, the in-migration hotspots around the lake in Tanzania and Uganda intensify, but the out-migration hotspots in Kenya shrink. Regardless of the approach, most of the maps reveal climate in-migration to the Lake Victoria Basin. Again, this does not mean that the populations in other 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.

***Beyond the Hotspots—The Regional Context***

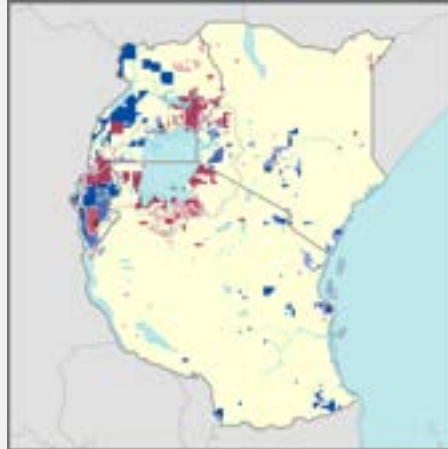
**By 2050, the population redistribution in the Lake Victoria Basin because of climate impacts may be sizable.** Internal climate migrants as a percentage of each country’s population fall in the range of 2 percent to 11 percent in the region. The lowest percentages are in Burundi and Rwanda. The highest percentages are in Uganda and Tanzania, where they are consistently above 7 percent and 10 percent, respectively. Country results are summarized in table 5.2.

**Figure 5.7 Projected Regional Hotspots of Climate In- and Out-Migration Calculated on a Regional Basis, Lake Victoria Basin, 2030, 2040, 2050**

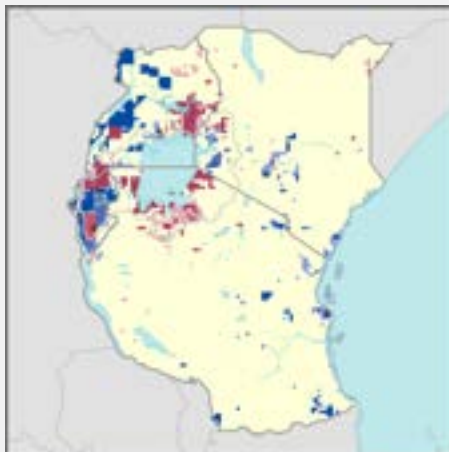
a. 2030



b. 2040



c. 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**

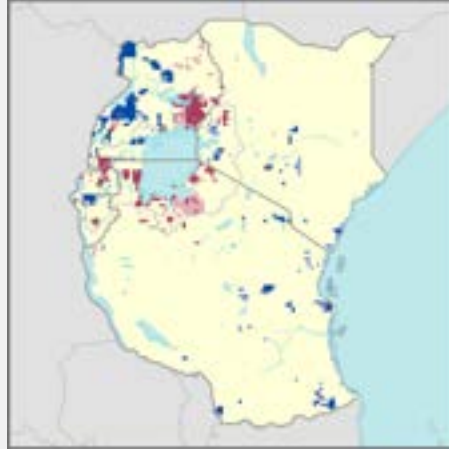
- High certainty in high levels of climate out-migration
- Moderate certainty in high levels of climate out-migration
- Low certainty in high levels of climate out-migration

**Figure 5.8 Projected Hotspots of Climate In- and Out-Migration Normalized by Country Population, Lake Victoria Basin, 2030, 2040, 2050**

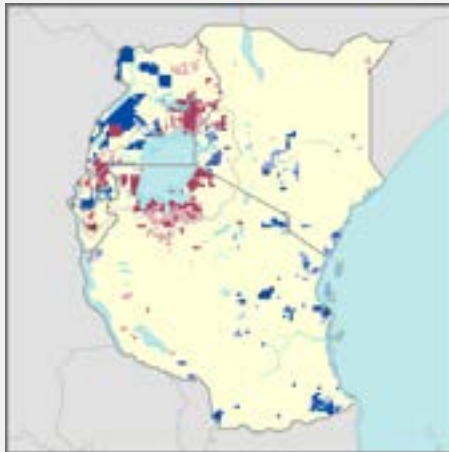
a. 2030



b. 2040



c. 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



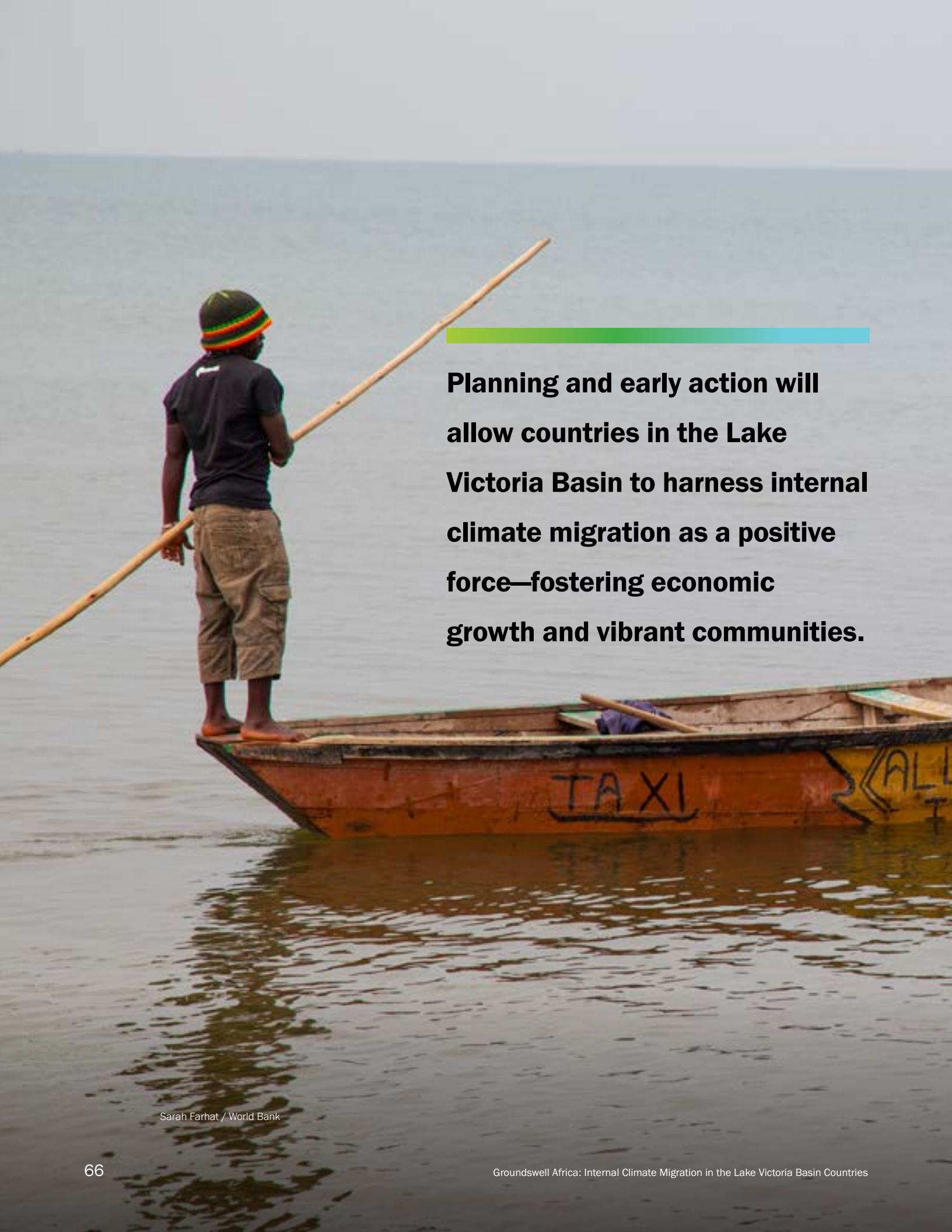


Peter Kapuscinski / World Bank

**Table 5.2 Summary of Results by Country, Lake Victoria Basin**

Result	Kenya	Tanzania
Population in 2050 compared to 2025	Population increases to 78.1 million from 55.7 million (SSP2) or 91.7 million from 58.4 million (SSP4)	Population increases to 102.3 million from 65.6 million (SSP2) or 119.0 million from 68.4 million (SSP4)
Total population, baseline (2010)	40.5 million	44.8 million
Number of climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 5.9 million (6.41% of projected population)	Highest in pessimistic (reference) scenario, with average projection of 13.4 million (11.25% of projected population)
Trajectory	Upward trend in all the scenarios; acceleration in last decade in scenarios based on SSP4, especially in the pessimistic scenario	Upward trend in all the scenarios
Climate in-migration hotspots	External band of climate in-migration including the Eldoret in the LVB area	In-migration hotspots in the north part of the country and particularly in the LVB
	Climate in-migration in northeast corner by the border with Somalia and Ethiopia	In-migration hotspots scattered in the west
Climate out-migration hotspots	Band of climate out-migration in the LVB, including Kisumu	Out-migration hotspots are in the east and south
	Regions of climate out-migration in the center, including Nairobi, and in the southeastern coast, including Mombasa	A lonely out-migration hot spot in the border with Burundi
Climate migration in/out of rural livelihood zones	Pastoral and rangelands, and seminatural and wildlands have positive net migration	Rainfed croplands consistently present positive net migration
	Irrigated and rainfed croplands consistently display negative net migration	Rice-growing croplands, and seminatural and wildlands have mixed results
Climate migrants compared to other migrants by 2050	5.9 million climate migrants compared to 4.5 million other internal migrants in the pessimistic (reference) scenario	13.4 million climate migrants compared to 10.9 million other internal migrants in the pessimistic (reference) scenario

Result	Uganda	Rwanda	Burundi
Population in 2050 compared to 2025	Population increases to 93.2 million from 52.5 million (SSP2) or 112.3 million from 55.3 million (SSP4)	Population increases to 22.9 million from 15.3 million (SSP2) or 26.0 million from 15.9 million (SSP4)	Population increases to 16.8 million from 12.0 million (SSP2) or 18.1 million from 12.3 million (SSP4)
Total population, baseline (2010)	33.4 million	10.6 million	8.4 million
Number of climate migrants by 2050	Highest in pessimistic (reference) scenario, with average projection of 10.9 million (9.68% of projected population)	Highest in pessimistic (reference) scenario, with average projection of 1.1 million (4.37% of projected population)	Highest in pessimistic (reference) scenario, with average projection of 0.63 million (3.48% of projected population)
Trajectory	Upward trend in all the scenarios. It starts slower up to 2030, stepped slope after that	Upward trend in all the scenarios	Upward trend in all the scenarios; acceleration in the last decade in scenarios based on SSP4
Climate in-migration hotspots	High levels of climate in-migration close to the capital, around Mount Elgon	High levels of climate in-migration in the central region close to the capital, Kigali	Large in-migration hotspot in the center of the country, including the new capital, Gitega
	Hotspots of climate in-migration in the southeast and along border with Rwanda	High levels of climate in-migration in the north region by the border with Uganda and Tanzania	
Climate out-migration hotspots	High levels of out-migration in the northwest and central-west	High levels of climate out-migration in the south	Long and narrow out-migration spot in the west, close to Lake Tanganyika, including part of Bujumbura Marie
Climate migration in/out of rural livelihood zones	Net climate in-migration in semi-natural and pasturelands	Positive net climate migration in rainfed areas, except in the pessimistic scenario	Rainfed croplands consistently display positive net migration across scenarios for all decades
	Mixed results in pastoral and rangelands		
	Net climate out-migration from rainfed croplands and rice-growing areas	Generally negative net climate migration in rice-growing and semi-natural and pastoral areas	Rice-growing areas, irrigated croplands, and seminatural and wildlands display negative net migration in almost all scenarios
Climate migrants compared to other migrants by 2050	10.9 million climate migrants compared to 10.5 million other internal migrants in the pessimistic (reference) scenario	1.1 million climate migrants compared to 1.5 million other internal migrants in the pessimistic (reference) scenario	0.63 million climate migrants compared to 0.50 million other internal migrants in the pessimistic (reference) scenario



**Planning and early action will allow countries in the Lake Victoria Basin to harness internal climate migration as a positive force—fostering economic growth and vibrant communities.**

## 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** (Wodon et al. 2014). According to this study, the number of internal climate migrants in the Lake Victoria Basin (LVB) could reach a high of close to 38.5 million by 2050, representing up to 10.48 percent of the population. The population will double in this period (Shared Socioeconomic Pathway [SSP]4), 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 30 percent.

**International frameworks and national policy responses have increasingly recognized climate-induced migration as an underlying cause and threat to sustainable development, but current responses to address the issue continues to lag** (Jong 2019; ODI 2016; 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 2019), with climate impacts amplifying the challenge (FAO et al. 2020; UN 2020; World Bank 2020a).

**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 the Lake Victoria Basin countries (chapter 7) reveal that intensifying climate impacts, the escalating scale of climate-induced migration, and new and spreading

climate migration hotspots as early as 2030 will affect entire countries. These trends will likely accelerate beyond 2050 with worsening climate change. The deepening nature of this crisis, and the entrapment of the most impoverished, means that inaction is not an option. Current policies and strategies must understand and address the climate-migration-development nexus in a more focused manner.

**The international law on human mobility in the context of climate change continues to evolve.** The COP24 Decision of the UNFCCC in 2018 calls for approaches to avert, minimize, and address displacement related to the adverse impacts of climate change as outlined in the Warsaw International Mechanism (WIM) 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-onset and slow-onset natural disasters and the adverse effects of climate change, as well as develop adaptation and resilience strategies that consider the potential implications on migration. 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 (IOM)'s 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 the international processes.

**Migration as an adaptation strategy can be a pathway out of poverty** (Adger et al. 2003; Barnett and O'Neill 2012; Ellis 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 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 2019). 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). Among the Lake Victoria Basin countries, the disaster-related displacement count was the highest in Kenya (335,000) followed by Tanzania (57,000), Burundi (51,000), Uganda (40,000), and Rwanda (6,000). Ex post responses to crises will not suffice. It is imperative to have a step change—transformation at scale—to counter distress-driven climate migration as part of broader development action.

**Lake Victoria Basin countries have integrated climate change, climate internal displacement, and refugees in their legislation and plans.** The National Adaptation Programmes of Action (NAPAs) of Tanzania, Uganda, and Burundi (GoB 2007; GoT 2007; GoU 2007) mention migration of people and livestock as a source of vulnerability and lay out a number of adaptation strategies. The NAPAs of Kenya and Rwanda promote livelihood diversification for vulnerable groups in order to reduce rural to urban migration and new lands for agriculture and animal husbandry (GoK 2016; GoR 2006).

**Climate migration can be harnessed as a factor of growth, jobs, and economic transition within countries** (Scheffran, Marmer, and Sow 2012). A unified approach to addressing climate migration must deliver on the core development needs—food, water, environment—and deliver on the countries' SDGs and the Bank's poverty goals. Climate migration will play out against mega-trends 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

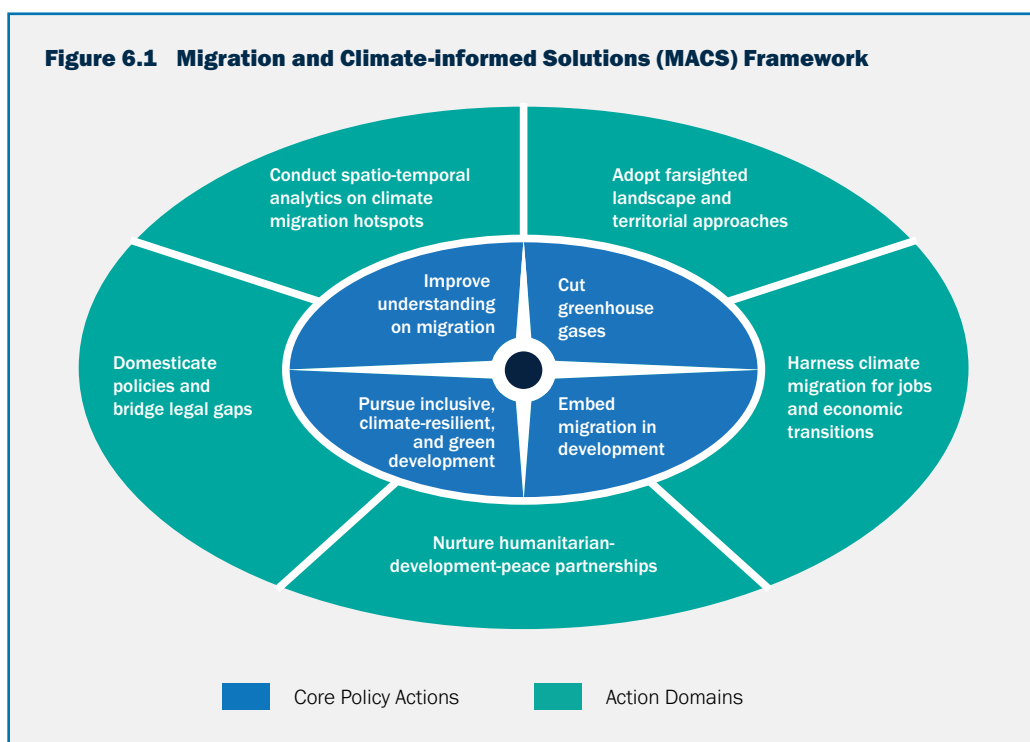
provide an opportunity through proactive global and local and national action to not only reduce the scale of climate migration but also to harness opportunities for growth and jobs as part of the transition to resilient and low carbon economies in the pivotal 2020s. This chapter proposes a strategic response framework for mainstreaming climate migration into development policy and planning.

## 6.2 MIGRATION AND CLIMATE-INFORMED SOLUTIONS (MACS) FRAMEWORK

**Climate migration is a cross-cutting issue that must 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 underscored 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 on migration.

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).



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 the current and future climate risks, and that the countries' 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 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, 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 opportunities for people to stay in place or move under better circumstances. Lake Victoria is a rapidly deteriorating shared natural resource between these countries. It is facing significant environmental challenges that include declining lake levels and fish stocks, resurgence of water hyacinth, and deteriorating water quality (World Bank 2018a). Under the optimistic scenario, the number of migrants could decline from a high of 38.5 million at the high end of the pessimistic reference scenario to a low end of 16.6 million in the optimistic scenario by 2050.

**Stringent global climate action is needed to adhere to the UN's 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, guarding against potential blowback of mitigation measures. Lake Victoria Basin countries have committed to reducing GHG emissions. According to Tanzania's updated NDC, GHG emissions by 2030 are expected to be reduced between 30 and 35 percent (GoT 2021). Kenya committed to reduce greenhouse gas an emission by 30 percent by 2030 relative to the business as usual (BAU) scenario is welcomed (GoK 2018b). Uganda committed to reducing greenhouse gas emissions in the energy supply, forestry, and wetland sectors by 22 percent in 2030 (Uganda Ministry of Water and Environment 2019).

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

**Climate migration demands anticipatory development policies that respond to the issue over the medium to long term.** This is particularly important for low- and lower-middle-income countries (LICs and LMICs) in the Lake Victoria Basin where climate migrants by 2050 could make up 10.48 percent of the population across the scenarios, and will make up a significant proportion of all migration, particularly under the pessimistic scenario. In Kenya, the more inclusive development scenario reduces climate migrants by 1.6 million by 2050. Tanzania and Uganda are the most demographically important countries in the region by 2050 (each with between 100 million and 120 million people by 2050, depending on the SSP). They will have the largest numbers of climate migrants, collectively representing around three-quarters of regional totals.

**The urgency for inclusive climate development and transformative action at scale is even more important because of the lock-in to warming patterns and the slow pace of global emission reduction.** Almost one-third of Tanzania's gross domestic product (GDP) in 2017 came from the agriculture, forestry, and fishing sectors.<sup>46</sup> Because 80 percent of the agriculture is rainfed and smallholder, the sector remains highly climate vulnerable (FAO 2016; Ojoyi 2017; USAID 2018). Annual losses of agricultural productivity from weather-related risks (mainly droughts) are estimated at US\$200 million (CIAT and World Bank 2017), and highly productive areas in the southern and northern highlands are increasingly affected by declining rainfall, frequent droughts, and significant increases in spatial and temporal variability of

46. See World Bank Data at <https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=TZ>

rainfall (GoT 2012). In this context, the focus on building resilience and adopting adaptive strategies must include farsighted planning not just for agriculture, but alongside economic transitions toward less climate-sensitive jobs and livelihood opportunities. Farsighted management of demographic and urban transitions and investment in human capital can also reduce climate vulnerability to both rapid and slow onset. Targeted interventions—through better adapt-in-place options, facilitating informed migration decisions, making social protection portable and scalable, and tapping the potential of financial and social remittances—must be deployed in the short and medium term to support positive and sustainable outcomes while considering the whole range of mobility patterns and displacement.

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

**There is an urgent need for countries to integrate climate migration for all phases and patterns of migration across time scales into national development plans and policies.** 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 an 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 where 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. For example, the Msimbazi Opportunity Plan in Dar es Salaam builds concrete resilience across the migration cycle. It contributes to adapt in place by converting most of the floodplain into city parks and building elevated terraces to guide the water and create higher edges to protect against recurrent flooding that has plagued the Msimbazi Basin (World Bank 2019c).

**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. For example, as early as 2030, Mombasa could see climate-out migration driven by increases in sea levels. In Tanzania, models project that sea level rise compounded by storm surge could result in climate out-migration increases in the east and south. The enable mobility strategy offers risk management that reduces vulnerability, especially of the poor population living in informal areas who have limited access to basic services such as water supply, sanitation, and electricity (Olarinoye et al. 2020). For instance, the Regional Pastoral Livelihoods Resilience Project (P129408) in Uganda and Kenya enhances mobility by building local platforms for conflict resolution and enabling access to water through project infrastructure rehabilitation.

**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 immediate and longer-term population growth from migration. Secondary cities are growth poles that can support large active domestic markets and 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. For example, the Socio-economic Inclusion of Refugees & Host Communities project (P164130) in Rwanda fosters social cohesion through access and provision of basic services and socioeconomic investments and opportunities for refugees and host communities (World Bank 2020c).

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

**More investment is needed to better contextualize and understand climate migration, particularly at regional to local scales, where climate impacts may deviate from the broader trends identified in a global-scale analysis.** There are inherent uncertainties in the way climate impacts will play out in a locale, which affect the magnitude and pattern of climate change–induced movements. Studies, as conducted for this report, provide insights on the scale of the issue. Over time, 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 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, is 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. For instance, Tanzania’s Urban Resilience Programme uses satellites, drones, and community data collection methods to map the urban environment (World Bank 2018d). The mapping campaigns have trained over 350 Tanzanian students and engaged 35,000 households to collect community knowledge in rapidly growing neighborhoods. This exercise has garnered data on houses at risk, transport and drainage networks, flood perceptions in the Msimbazi Valley, solid waste dumps, and community priorities for protection.

## 6.2.2 Domains of Action to Drive Planning and Action at Scale

**As a cross-cutting issue, climate migration has to be addressed through policy-informed action that is farsighted in its approach and execution.** Four domains of action can bolster the delivery of the core policy direction to reduce, avert, and minimize distress-driven internal climate migration.

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

**Climate-induced migration is not uniform within the Lake Victoria Basin: 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 climate migrants will ramp up across the scenarios studied in this report, in Kenya and Tanzania, they could outpace other migrants as early as 2030 (under the pessimistic scenario) compared to Burundi and Uganda, where this will not materialize until 2040 and 2050, respectively.

**The 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.** For example for the Lake Victoria Basin countries, the study shows that median age and sex amplified and dampened climate migration in rural and urban areas, respectively. These findings have important policy implications and require greater scrutiny and analysis. To secure resilience, it is imperative to develop climate migration hotspot maps for each country, and identify spatial climate risks and impacts, and the state of natural resources and plans for their conservation.

**Policy makers must take early, proactive, and informed action, aided by state-of-the-art models on current and future trends of mobility.** Investing in evidence-based research at the national level and mobilizing new data sources—including from satellite imagery and mobile phones—can help contextualize and understand climate migration (particularly at local scales) where climate impacts may deviate from the broader regional or global trends. This study demonstrates 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 affect how governments plan effective responses. In Tanzania, climate in-migration will be in the north, particularly around the Lake Victoria Basin, which has high incidence of poverty, and climate out-migration hotspots will be in the east and south. In Burundi, the new capital, Gitega, is projected to become a climate in-migration hotspot. Investing in iterative scenario modeling, grounded in new data and development progress, will be crucial for policymakers to drive contextualized and informed action. Such investments will be best placed to facilitate long-term planning and investments in adaptive capacity to secure climate resilience.

*(ii) 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, vary uses, and shift the comparative advantage of locations across the landscape** (Childress, Siegel, and Törhönen 2014). According to World Bank's Next Generation Africa Climate Business Plan (World Bank 2020a), slow-onset climate factors will adversely affect water and land resources and food systems. Ultimately, these changes have implications on migration patterns and 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 2020a). In Tanzania, coastal urban centers such as Dar es Salaam are projected to see climate out-migration as early as 2030 and potentially experience a negative net migration balance of -1.3 million (pessimistic scenario) by 2050. In Burundi, several of the plausible scenarios modeled project large areas of positive population change in the center of the country (including the new capital, Gitega) because of such factors as high crop productivity.

**Placing a 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. Its expanded and integrated view of land can support local priorities and natural resource uses and site-specific planning for climate-induced migration. 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. For example, the Uganda Investing in Forests and Protected Areas for Climate-Smart Development will invest in plantation forestry, wood value chains, and tourism infrastructure to meet the development needs of the Albertine landscape, which sustains a large and rapidly growing population, biodiversity, and important ecosystem services (World Bank 2020b). Through these actions, the project brings economic benefits to forests and tourism-dependent communities, including refugees, and builds resilience against climate shocks (World Bank 2020b). Because of lower agricultural productivity and changing precipitation patterns, climate in-migration hotspots could emerge around the periphery of Lake Victoria—increasing resource competition and stress on the lake ecosystem. The Ugandan locality of Mbale, Ntungamo, and the capital Kampala, and the northern Tanzanian cities of Mwanza, Magu, and Geita could become high-certainty climate-in migration hotspots. The central region of Rwanda close to the capital, Kigali, and in the north by the border with Uganda and Tanzania, could see climate-in migration by 2050. In Burundi, a high-certainty in-migration hotspot could emerge in the center of the country. Local, national, and regional level planning are essential to avert conflicts and crises amplified by population increase.

*(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 2019a). Incremental, “low regret” measures alone will not be sufficient to counter the magnitude of climate impacts (Kates, Travis, and Wilbanks 2012). Flexible, incremental adaptation sequences should be explored with those of more transformational adaptation to secure resilience over longer time scales (Pal et al. 2019; Kates, Travis, and Wilbanks 2012). Good management of demographic transitions and investment in human capital can reduce adverse impacts of climate migration. Lower agricultural productivity due to climate change will compel Lake Victoria Basin countries

to absorb labor and a large youth bulge into nonagricultural and less climate-sensitive sectors. To tap the demographic dividend, demographic transitions 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 (PRB 2012).

**Good management of migration, driven by climate change over longer time scales, can produce positive momentum for such shifts** (World Bank 2019a). 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, vibrant cities such as Dar es Salaam and Mombasa could be affected by sea level rise compounded by storm surges. Early action to fortify coastal assets through green and gray infrastructure must be optimized through adapt in place options—and consider participatory planned relocation as part of longer-term solutions. The projected increase in population, amplified by climate in-migration into larger cities (e.g., Kampala) and smaller cities (e.g., Ntungamo) could benefit from targeted interventions, including provision of basic social services, housing, and productive jobs. Anticipatory planning through a focus on climate in-migration to secondary cities or peri-urban areas could lay their foundation as growth poles in place 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 leapfrog opportunities. For example, the Northeastern Transport Improvement Project (NETIP) will focus on improving the movement of people, goods, and digital services in part by upgrading the main transport artery traversing the counties of northeastern Kenya.

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

**Migration is part of a triple nexus of humanitarian-development-peace efforts.** While this report does not focus on cross-border migration, the modeling identifies numerous migration hotspots 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. Cooperation and stepped-up action by development, humanitarian, security, and disaster communities across the mobility continuum could help countries pursue more holistic and durable solutions to climate-induced migration and displacement (World Bank 2019a) in support of peace, stability, and security in the region. In the past, humanitarian efforts were followed by development efforts, and these operated with different objectives, counterparts, instruments, and logic (Guinote 2019).

**Climate change is posing novel challenges and causing hitherto unknown dilemmas to undermine the humanitarian, development, and peace agenda.** Unplanned migration and an absence of policies and strategies to integrate communities can exacerbate social tensions and fault lines into a downward spiral leading to conflicts (Thoha 2020). In the Lake Victoria Basin, climate migrants could reach up to 38.5 million people by 2050, or between 2 percent to 11 percent of each country's population. 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.

**Treating migration as a nexus of the humanitarian-development-peace framework implies overcoming structural barriers and internal divisions around sources of funding, coordination mechanisms, and project timelines (OCHA 2017).** This approach can benefit from the comparative advantage of different actors to strengthen the local capacity (OCHA 2017). Ultimately, this approach is geared to reduce humanitarian need, risk, and vulnerability through aligned short-, medium- and longer-term contributions by humanitarian and development actors (OCHA 2017). The linkages need to happen in a contiguuum<sup>47</sup>

47. “‘Contiguuum’ (1) 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).

to secure peace, address the humanitarian objectives to save lives and alleviate human suffering, and alleviate poverty. For example, through the Development Response to Displacement Impacts Project in the Horn of Africa (DRDIP), the World Bank and the United Nations High Commissioner for Refugees (UNHCR) worked closely with the Government of Kenya (GoK) to address development goals of ending extreme poverty and sharing prosperity, humanitarian goals of protecting the poor and displaced from fragility and violence, and security goals of containing regional spill overs of conflict (World Bank 2019b). As part of the project, the Intergovernmental Authority on Development (IGAD) was provided financial support for capacity building of countries and institutions in the Horn of Africa to innovatively respond to forced displacement and mixed migration. The project sought to forge partnerships between humanitarian and development actors in the Horn of Africa to rethink the application of durable solutions (World Bank 2019b).

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

**Comprehensive and coherent legal architecture is needed to address climate-induced mobility** (Leighton 2010; Kuusipalo 2020). Adequate protections under international law is generally not afforded to those moving primarily due to environmental factors (Kuusipalo 2020). As the impacts of climate change intensify, there will be more migrants and displaced people uncovered by law. The Groundswell report (Rigaud et al. 2018) posits that the Lake Victoria Basin could become more attractive under climate change because of its higher elevation and more stable and plentiful rainfall, compared to semiarid and arid regions of Uganda, Kenya, and Tanzania. Water availability, a major driver of migration in the model, is projected to remain stable or to increase in the basin. The porous borders in the Lake Victoria Basin, scarce natural resources, and pressure on livelihoods can lead to complex challenges that require sound legal mandates and frameworks (LVBC 2018; Mwiturubani van Wyk 2010).

**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 (Kuusipalo 2020). For instance, the Kenya Development Response to Displacement Impacts project was informed by a Resettlement Policy Framework (RPF) and extensive participation of local communities as part of the resettlement process. Policy makers considered the Kenyan legal framework and World Bank guidelines and agreement was sought with the Office of the President to provide a screening tool, allocate responsibilities, and define the principles that will guide resettlement action plans. As part of this participatory process, sacred sites were protected from use by individuals, communities, homesteads, and county governments (GoK 2018a).

## **6.3 CALL TO ACTION**

**The development vision and plans of countries and World Bank projects in the Lake Victoria Basin provide multiple entry points to mainstream climate-induced migration.** The plausible scale of internal climate migration and spread of climate migration hotspots in countries such as Tanzania and Rwanda require holistic responses aligned with the MACS framework and the Five-Year Development Plans (FYDPs), Country Partnership Frameworks (CPFs), and Systematic Country Diagnostics (SCDs). For instance, Tanzania's strategic priority interventions fall under four categories: (i) to foster economic growth and industrialization; (ii) to foster human development and social transformation; (iii) to improve the environment for business and enterprise development; and (iv) to strengthen implementation effectiveness.

**An anticipatory focus on climate-in migration hotspots to secondary cities or peri-urban areas could lay their foundation as growth poles in place of sprawling poverty.** For example, climate in-migration hotspots projected around Tanzania's Mwanza and Geita, areas of high poverty, could benefit from socially inclusive approaches that go beyond livelihood strategies to drive climate-smart urban transitions that combine sustainable use and management of nearby Lake Victoria resources. Migration, seen through this lens, can be leveraged to consolidate human capital gains, which run across SCDs, CPFs, and FYDs.

**Rwanda's Vision 2020 document aspires to “a modern, strong and united nation, without discrimination between its citizens” (GoR 2000) (table 6.1).** Its long-term development is built around six pillars and three cross-cutting issues. The cross-cutting issues, in particular, share common ground with the MACS framework. Rwanda has experienced degradation of fragile ecosystems, such as swamps and wetlands, compounded by poor waste management. The degradation of the environment and natural resources can undermine the country's ability to sustain economic growth vital to improvements in livelihoods (REMA 2009). Landscape and territorial approaches for farsighted planning, which form an integral element of the MACS framework, can enable “Protection of environment and sustainable natural resource management” (GoR 2000). It provides for forest management, water management plans, integrated community programs, and land use plans to avert, minimize, and address climate-induced migration.

**Inclusive and climate-resilient development policies with targeted investments, part of the MACS framework, align with “gender equality” and “good governance and a capable state” aspects of Rwanda's Vision 2020.** Climate-induced migration carries disproportionate challenges for marginalized communities, including women. Women make up 53 percent of Rwanda's population, and they actively participate in agriculture (REMA 2009). Embedding climate migration in development planning for all phases of migration and across time scales will help Rwanda address these challenges in a holistic and inclusive manner.

**Table 6.1 Pillars of the Rwanda VISION 2020 and Its Cross-Cutting Areas**

Pillars	Cross-Cutting Areas
1. Good governance and a capable state	Gender equality
2. Human resource development and a knowledge-based economy	Protection of environment and sustainable natural resource management
3. Private sector-led economy	Science and technology, including ICT
4. Infrastructure development	
5. Productive and market-oriented agriculture	
6. Regional and international economic integration	

Note: ICT = information communications technology.

**Acting on climate migration aligns with Uganda's NDP, which recognizes climate change as a driver of forced displacement, and calls for “integrat[ing] migration and refugee planning and all other cross-cutting issues in national, sectoral and local government plans.** The objectives and development strategies outlined in the NDP III present untapped opportunities to leverage and further embed climate migration. The NDP has four key objectives: (i) enhance value addition in key growth opportunities; (ii) strengthen the private sector to create jobs; (iii) consolidate and increase the stock and quality of productive infrastructure; and (iv) enhance the productivity and social well-being of the population. To achieve these objectives, the NDP has identified key development strategies, including promoting agro-industrialization; increasing local content participation; institutionalizing infrastructure maintenance; developing intermodal transport infrastructure to enhance interoperability; increasing access to stable, reliable, and affordable energy; leveraging urbanization as a driver for socioeconomic transformation; improving access and quality of social services; promoting science, technology, engineering, and innovation as well as information and communications technology (ICT); and increasing access to social protection. Mainstreaming migration into these strategic priorities offers a win-win opportunity for the country.

**The World Bank goals in Uganda are aligned with mainstreaming climate migration.** Uganda's SCD and CPF recognize that the country is highly vulnerable to climate changes, including rising temperatures, floods, storms, droughts, and heat waves. They also consider climate-related shocks and the long-term degradation of natural resources as key constraints in Uganda's economy and development goals, particularly affecting poor households dependent on agriculture.

**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 in Lake Victoria Basin** (box 6.1). The Regional Pastoral Livelihoods Resilience Project (P129408) in Uganda and Kenya addresses the urgent needs of migrants and those displaced while considering the underlying factors of migration. Pastoralism in Uganda and Kenya is hampered by the vagaries of climate, animal disease, dwindling access to water resources and grazing lands, and poor market infrastructure (World Bank 2014). The project addressed these structural issues and immediate problems through improved access to water, infrastructure rehabilitation and development, access to natural resources and markets, and alternative livelihoods strategies (World Bank 2014).


### **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.



Sarah Farhat / World Bank





**Urgent action is needed on two fronts to avert and reduce the scale of internal climate migration: first, collective global action to rapidly cut greenhouse gas emissions, and second, for the Basin countries to pursue green, resilient, and inclusive development.**

The DRDIP in the Horn of Africa, operating in Djibouti, Ethiopia, and Uganda, focuses on gender inequality, youth empowerment, and gender-based violence, with extensive analytical work targeting those who are disproportionately affected by displacement (World Bank 2016). It provided gender training programs, reduced drudgery in terms of time and energy spent by women and girls collecting wood for fuel, lowered their exposure to risk of violence while collecting it, and improved health and indoor air pollution through the use of cleaner fuels and fuel-saving cooking technologies.

**Internal climate migration in the Lake Victoria Basin<sup>48</sup> will ramp up by 2050 in response to slow-onset climate factors, and urgent action is needed.** Climate-induced migration can be reduced by around 30 percent by advancing low carbon pathways with better development outcomes across the Lake Victoria Basin.

**No country in the Lake Victoria Basin is immune to a 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 the Lake Victoria Basin, other countries in 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.

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48. Produced as part of this study and the parallel study, Groundswell Africa: Internal Climate Migration in West Africa (Rigaud et. al. 2021a). This report focuses on the Lake Victoria Basin.



**No country in the Lake Victoria Basin is immune to internal climate migration. Without concerted action, for example, Tanzania and Uganda are projected to have 16.6 million and 12.0 million internal climate migrants, respectively, by 2050.**

## Chapter 7

# Country Snapshots on Internal Climate Migration

The Groundswell Africa study in the Lake Victoria Basin (LVB) region covered five countries: Burundi, Kenya, Rwanda, Tanzania, and Uganda. This chapter provides country snapshots for Burundi, Kenya, and Rwanda—summarizing the country context and key results for internal climate migration.

For Tanzania and Uganda, stand-alone country deep dive reports were produced which include a deeper review of the literature and modeled results on internal climate migration, to better inform policy dialogue and action. These reports can be accessed at the World Bank website.<sup>49</sup>

### 7.1 BURUNDI

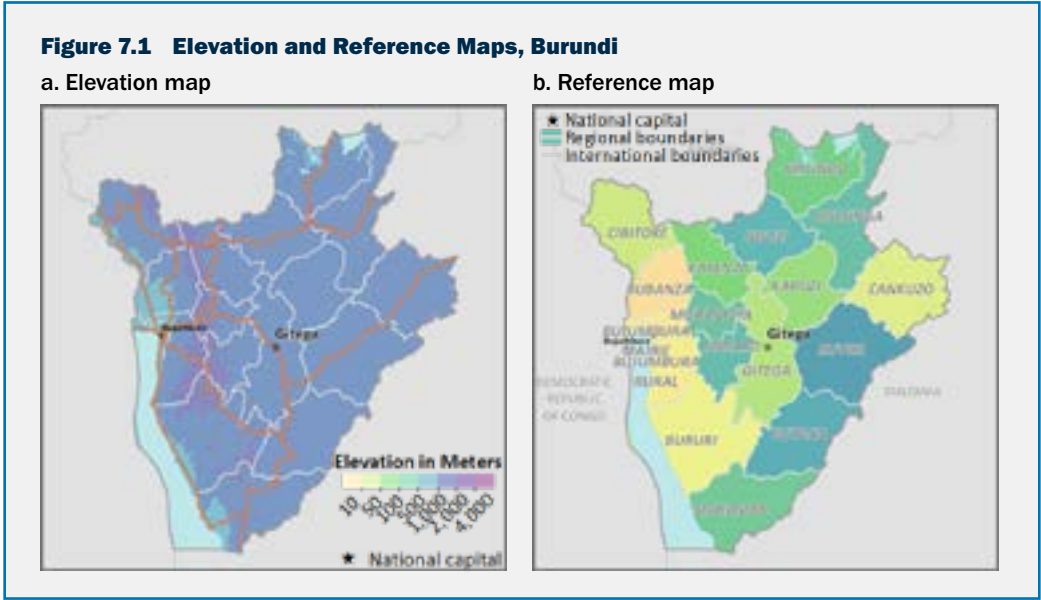
#### 7.1.1 Population and Development Context

Burundi's population of more than 11 million in an area of 28,000 square kilometers makes it one of the densest countries in Sub-Saharan Africa (UNDP 2020) (figure 7.1, panels a and b). Years of political instability, high population growth, and soil erosion have contributed to high rates of poverty, with over half of the country's inhabitants surviving on less than one dollar a day. Rural farmers are particularly impoverished, a situation that threatens to grow more dire as arable land grows increasingly scarce (World Bank 2018c). Food insecurity is nearly twice the average rate of food insecurity across Sub-Saharan Africa. Clean water, sanitation, and electricity are not widely accessible. Less than 5 percent of the population have access to electricity, with rates near 50 percent in urban areas and 2 percent in rural areas.

Burundi, a low-income country (LIC), has an economy that has displayed a modest and erratic upward trend since the early 2000s, with its gross domestic product (GDP) rising from US\$0.9 billion in 2000 to US\$3 billion in 2018 (in current dollars), resulting in an annual average growth of 2.5 percent for the period. Over the same period, the GDP per capita increased from US\$136 to US\$272 (in 2020 dollars).<sup>50</sup>

49. Rigaud, Kanta Kumari; de Sherbinin, Alex; Jones, Bryan; Casals Fernandez, Anna Taeko; and Adamo, Susana. 2021. *Groundswell Africa: A Deep Dive into Internal Climate Migration in Uganda*. World Bank, Washington, DC. Rigaud, Kanta Kumari; de Sherbinin, Alex; Jones, Bryan; Arora, Anmol; and Adamo, Susana. 2021. *Groundswell Africa: A Deep Dive into Internal Climate Migration in Tanzania*. World Bank, Washington, DC.

50. Data from World Development (Indicators (database), World Bank, Washington, DC, accessed 2020, <https://datacatalog.worldbank.org/dataset/world-development-indicators>).



**Rainfed agriculture employs 90 percent of the population and constitutes 95 percent of the national food supply** (MFAN 2018). Despite its significance to individual subsistence, agriculture contributed only 42 percent of the national GDP during 2005-14 (World Bank 2020c). The country is heavily dependent on wood for energy. Higher coffee exports contributed to a 3.3 percent increase in real GDP in 2019 (AfDB 2020b). Higher future GDP is likely should coffee exports continue, but the fiscal deficit is projected to grow as the export base remains small and the economy highly contingent on weather patterns. The country continues to grapple with a precarious economic future because the youth unemployment rate remains around 65 percent.

**Table 7.1 Development Indicators for Burundi**

Population	
Population (thousands) (2018)	11,175.4
Annual population growth (%) (2018)	3.2
Population in 2050 under SSP2 (thousands)	16,810.2
Population in 2050 under SSP4 (thousands)	18,099.2
Urban share of population (%) (2018)	13.3
Employment in agriculture (% of total employment) (2019)	92.0
GDP	
GDP (current US\$, billions) (2018)	3.0
Annual GDP growth (%) (2018)	1.6
GDP per capita (current US\$) (2018)	271.8
Value added of agriculture (% GDP) (2018)	29.0
Poverty	
Poverty headcount ratio at US\$1.90 a day (2011 PPP) (% of population) (2013)	71.8
Climate and disaster risk indexes	
ND GAIN Index	
Rank (2017)	171
Score (2107)	32.3

Sources: WDI database<sup>51</sup>

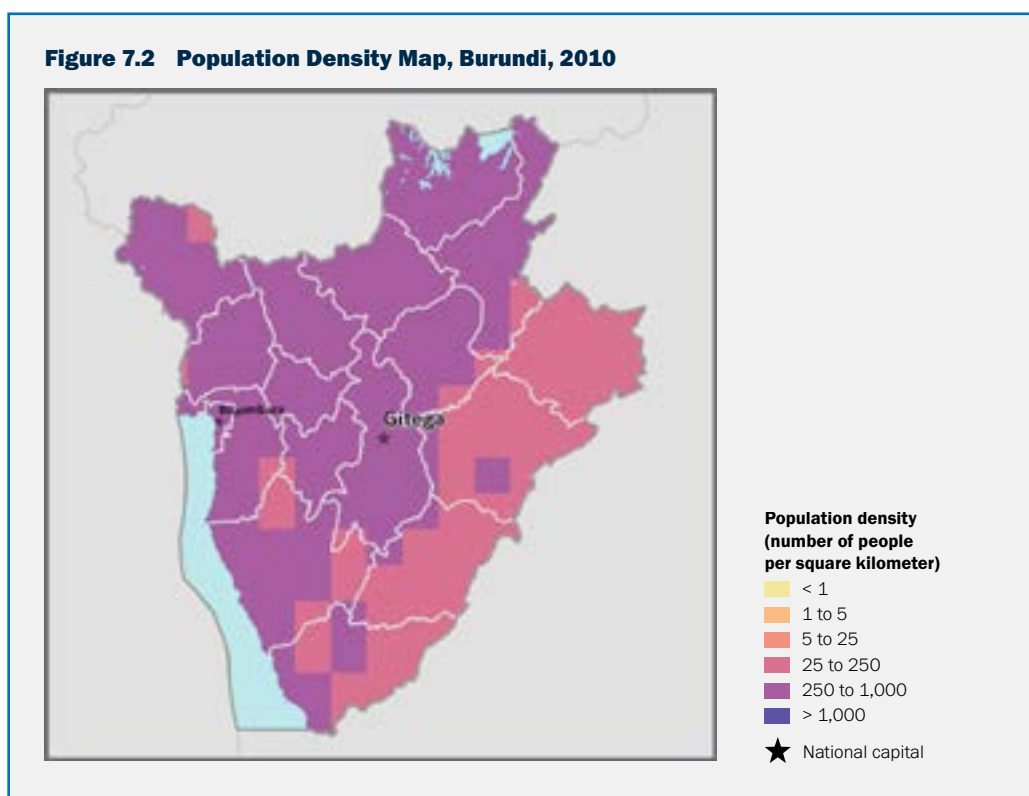
Note: The ND-GAIN Country Index, a project of the University of Notre Dame Global Adaptation Initiative (ND-GAIN), summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. A higher score is better. For more information on ND-GAIN, see: <https://gain.nd.edu/>

51. See the World Bank Development Indicators (WDI) database, <https://datacatalog.worldbank.org/dataset/world-development-indicators>

Burundi's annual population growth rate was 3.15 percent for the period 2015–20 with a fertility rate of 5.4 children per woman, the highest of the Lake Victoria Basin region. The country has a very young age structure, with 50 percent of the population below age 17 in 2020. UN population projections estimate a total population of 15.7 million by 2030 and of 25.3 million by 2050, more than double the estimated 11.2 million in 2018.<sup>52</sup>

**Along with existing poverty and food insecurity, diseases such as malaria contribute to a high mortality rate.** The infant mortality rate is 41 per 1,000 live births (UNICEF 2019). Malaria is a critical health concern throughout the region, with particularly dire consequences on Burundi's low-income population. The incidence of malaria is 156.2 per 1,000 people at risk (AfDB 2020b, 141). Since the Ebola epidemic spread to the country in June 2018, public health has become a key concern for local and international humanitarian efforts, but progress has been slow compared with other countries in the region (Iyer et al. 2018). Life expectancy fell from 57 years to 52.6 years between 2014 and 2017.

**Burundi is densely populated, but population density is not homogenous across the regions (figure 7.2).** It is higher in and around Bujumbura Mairie on the shores of Lake Tanganyika, and in the north-central and northwest, and the eastern areas are less densely populated. High densities and population growth have led to scarcity of land resources, intensification of agriculture, reduction of fallow periods and pasture area, all of which compromises the efficacy of traditional resilience mechanisms and could eventually lead to widespread environmental degradation (e.g., deforestation, erosion) (Niragira et al. 2019).



**Urbanization levels are still very low in Burundi, reaching 13 percent in 2018 and projected to be about 28 percent by 2050.** Recently, Gitega (second largest urban center with an estimated 2020 population of about 130,000) was designated as the new capital. The largest city is the former capital, Bujumbura, with an estimated population of about 1 million people in 2020.<sup>53</sup> Recent studies show that the city is expanding into flood-prone zones, increasing vulnerability to flash floods and torrential rains (Kubwarugira, Mayoussi, and El Khalki 2019; Niyongabire and Rhinane 2019).

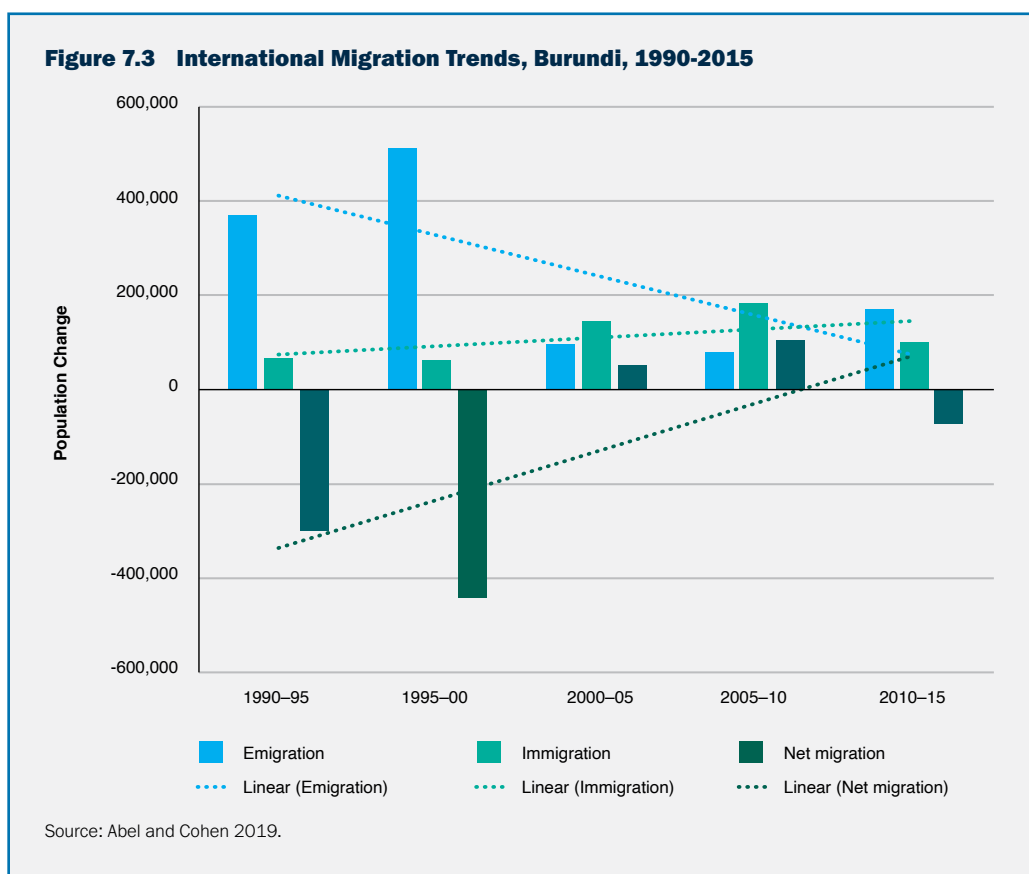
52. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.

53. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.

## 7.1.2 Historical and Current Migration Patterns

**Internal migration includes rural-urban migration and internal displacement.** Migration from rural to urban areas has resulted in marginally higher growth rates in urban areas than rural areas (2.8 percent compared to 2.7 percent annually, respectively, in 2015–20)<sup>54</sup> despite urban areas having lower fertility rates (4.1 compared to 5.7 children per woman, respectively, in 2016–17) (MPBGP et al. 2017).

**International migration patterns (figure 7.3) indicate a sharp decline in emigration and a modest increase in immigration in the 2000s, which resulted in positive net migration during that decade.** This trend was reversed in the first half of the 2010s, when net migration was once again negative. Main destinations for this period were Tanzania, the Democratic Republic of Congo, Rwanda, Uganda, and South Africa. Remittances from international migrants represented 1.4 percent of Burundi's GDP in 2019.



### Conflict Mobility

**Burundi has a history of conflict displacement, including both refugee flows and internal displacement.** Burundi used to host refugees from neighboring countries (Fransen and Ong'ayo 2010), but is more recently a sending country. Political violence since 2015 has resulted in about 383,000 Burundians fleeing to other countries in the region (mainly to Tanzania, but also to Uganda, Rwanda, and the Democratic Republic of Congo). Although conflict continues, around 52,000 refugees have returned voluntarily from Tanzania after an agreement was signed in September 2017 (IOM ROEHA 2019).

54. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.

**Civil conflict during the 2000s resulted in thousands of internally displaced people (IDPs), many of whom live in camps in the central and northern regions.** Over time, some IDPs have returned home while others have integrated into other areas of the country. Given the scarcity of land in Burundi, resettlement has created disputes with the host communities (Fransen and Ong'ayo 2010). As of September 2018, there were 150,000 IDPs. However, internal displacement decreased by around 20 percent from January 2018 to December 2018 as IDPs returned home or resettled (IDMC 2019a; IOM ROEHA 2019, 1). In addition to forced migration, conflict and violence have disrupted livelihoods by limiting or blocking access to resources (land, services, markets) and even restricting mobility in some cases (Vervisch, Vlassenroot, and Braeckman 2013).

### *Environmental Migration*

**Burundi is highly vulnerable to the impacts of natural disasters, which are responsible for most of the internal displacement** (AfDB 2020b, 141). Natural disasters caused 75 percent of the displacement in 2018: Rumonge Province had the most displacement (52 percent), followed by Bubanza and Cibitoke provinces (IOM ROEHA 2019, 14). Flash floods, heavy rains, and droughts are linked to the largest displacement flows (IDMC 2020a). For example, approximately 4,000 people were displaced by torrential rains in 2018, mainly in Rutana, Rumonge, Cibitoke, and Bubanza provinces. Most IDPs were sustained by host communities (53 percent), and a quarter of the displaced lived in rented properties (IOM ROEHA 2019, 14).

### 7.1.3 Climate Trends and Population Projections

**Landlocked by Rwanda, Tanzania, and the Democratic Republic of Congo, Burundi is a small but ecologically diverse country covering 27,834 square kilometers** (Lawin, Manirakiza, and Lamboni 2019). Temperatures range from 25°C to 29.5°C on average with significant variation across the colder high altitudes and warmer lowlands. The lowlands of Imbo and the Ruzizi plain see the lowest average precipitation, typically below 900 millimeters per year (MFAN 2018). The highlands of the Congo-Nile watershed see more than 1,600 millimeters per year. Much of the country is prone to extreme climatic events, from droughts and erosion in Buragane to droughts, famine, and severe rains in the eastern depressions and dry plateaus, to extreme rainfall and periodic precipitation shortages in the northern Imbo plains.

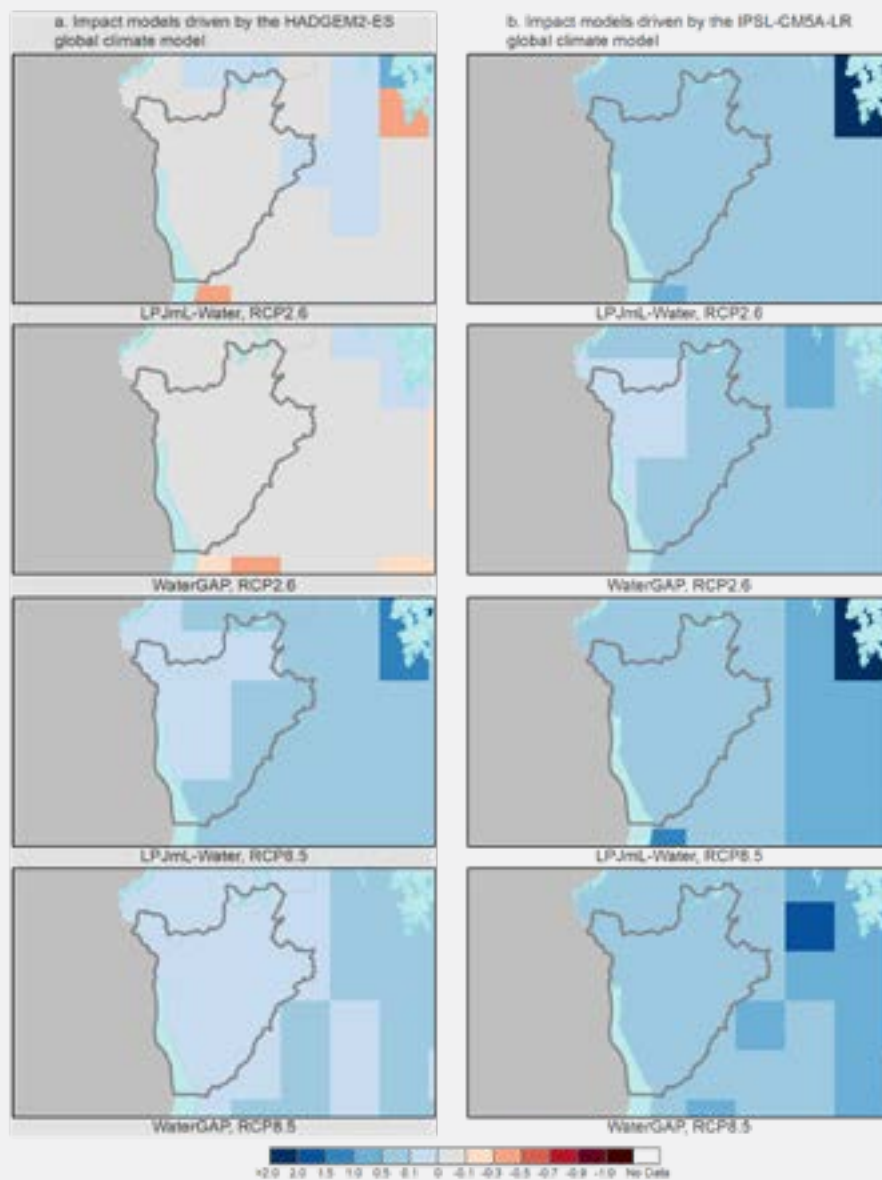
**Studies have observed rising temperatures of around 0.8°C over the last century as well as decreased precipitation and a longer dry season in recent decades.** As temperatures continue to rise at a projected rate of 0.4°C per decade, by 2050, mean annual rainfall is likely to increase (MFAN 2018). Should emissions continue at their current rate, the mean annual temperature could increase by more than 2°C by mid-century (Niang et al. 2014).

**Burundi's emissions are one of the lowest in the world, contributing a mere 0.01 percent of global emissions, yet it is the 14th most climate vulnerable country globally (MFAN 2018).** Agriculture is a primary employer, but a considerable portion of the population are food insecure. Insecurity is highest during the long dry season between May and September. This period has been steadily growing in duration and intensity. Increased drought and soil erosion threaten to exacerbate food and water security.

**Panels in figures 7.4–7.6 show the average projected changes in water availability, crop production, and net primary productivity (NPP) from 2010–50, 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 2.8 times higher than that of crop production and 4.7 times that of 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. The average projected water availability from the Intersectoral Impacts Model Intercomparison Project (ISIMIP) model runs for the 2010–50 time period suggests modest increases in water availability, with two model runs under RCP2.6, suggesting

slight declines. There is not a high degree of spatial differentiation in the model outputs, though the east may be slightly wetter in the future than the western portions. Crop production is more spatially varied, with declines in some areas of the southwest. NPP projections are provided for information purposes only, because they do not contribute to the modeling of the future population distribution.

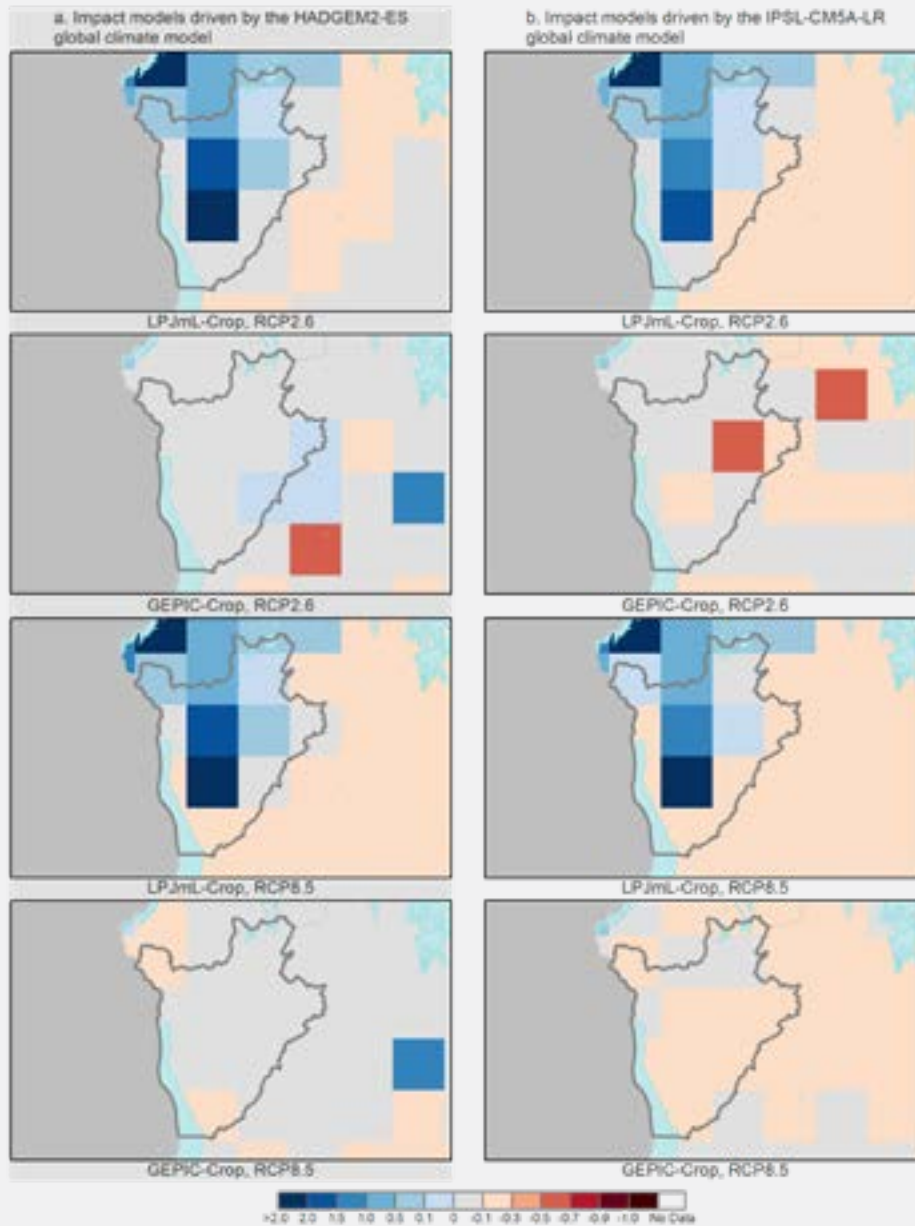
**Figure 7.4 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Burundi, 2010–50**



Note: Data calculated against 1970–2010 baseline for water availability, from LPJmL/water and WaterGap, forced with the HadGEM2-ES climate model (panel a) and IPSL-CM5A (panel b) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline, and gray to tan to red areas indicate drying.



**Figure 7.5 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Burundi, 2010–50**



Note: Data calculated against 1970–2010 baseline for crop production. Blue areas indicate increased crop production relative to the historical baseline, and gray to tan to red areas indicate decreased crop production.

**Figure 7.6 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Burundi, 2010–50**

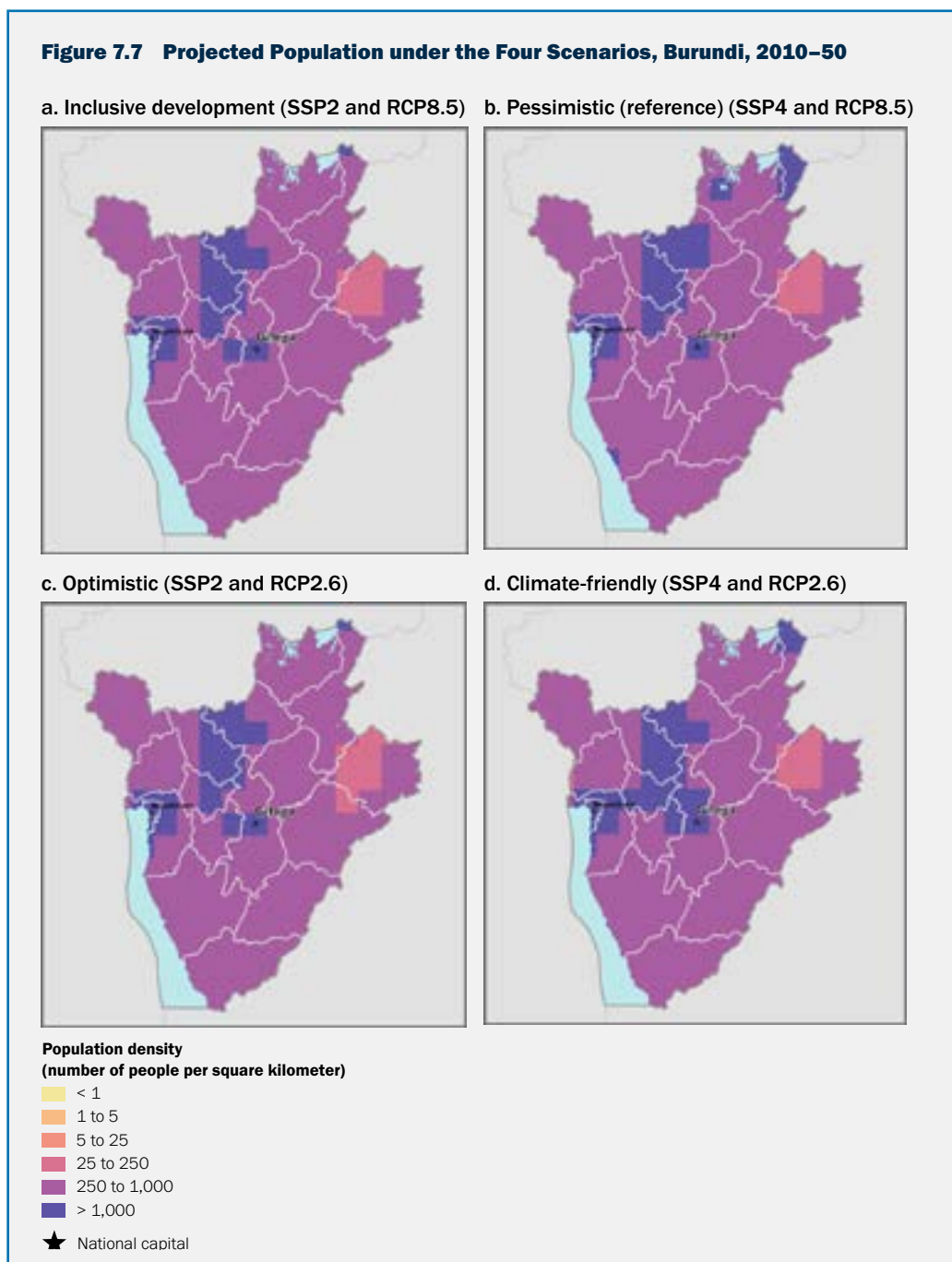


Note: Data calculated against 1970–2010 baseline for NPP. Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is only used to gap-fill crop production, and therefore is not used to model future population distribution in Burundi. NPP = net primary production.

### Projected Changes in Population

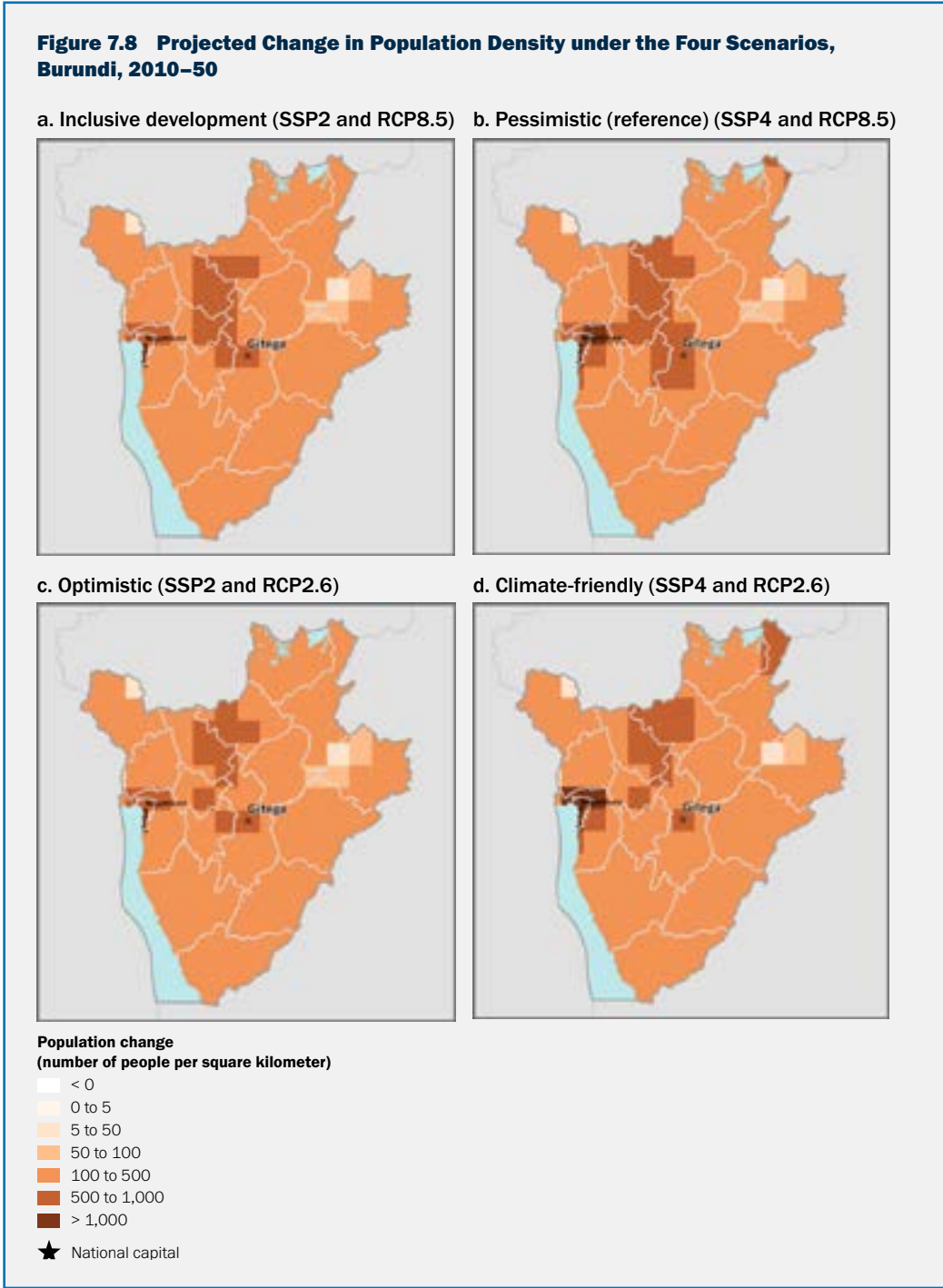
Figure 7.7, panels a–d, presents the projected population of Burundi across the four scenarios. Differences are subtle and sometimes difficult to detect, in part owing to the binning of population density into broad categories. Another reason is because the combination of development trends and climate impacts over the 40-year time horizon represented by these projections will subtly shift the evolution of each country’s population distribution but not result in dramatic reconfigurations. Compared with that of

2010 (figure 7.2), there is an expansion of high-density areas in the northeast, around Gitega, and in the central-north area. The pessimistic scenario includes a high-density area by Kigwena, on the coast of Lake Tanganyika in the Bururi Province. In addition, the two scenarios based on SSP4 (pessimistic and climate-friendly) display very high density in Bujumbura Mairie (by the northeast coast of Lake Tanganyika).



**Figure 7.8, panels a–d, displays changes in population density between 2010 and 2050.** It clearly shows that population growth will be positive in all regions across all scenarios, even accounting for climate impacts. Therefore, in the context of the rapidly growing populations of East Africa, climate change impacts may redistribute population from one area to another, but will generally not cause population

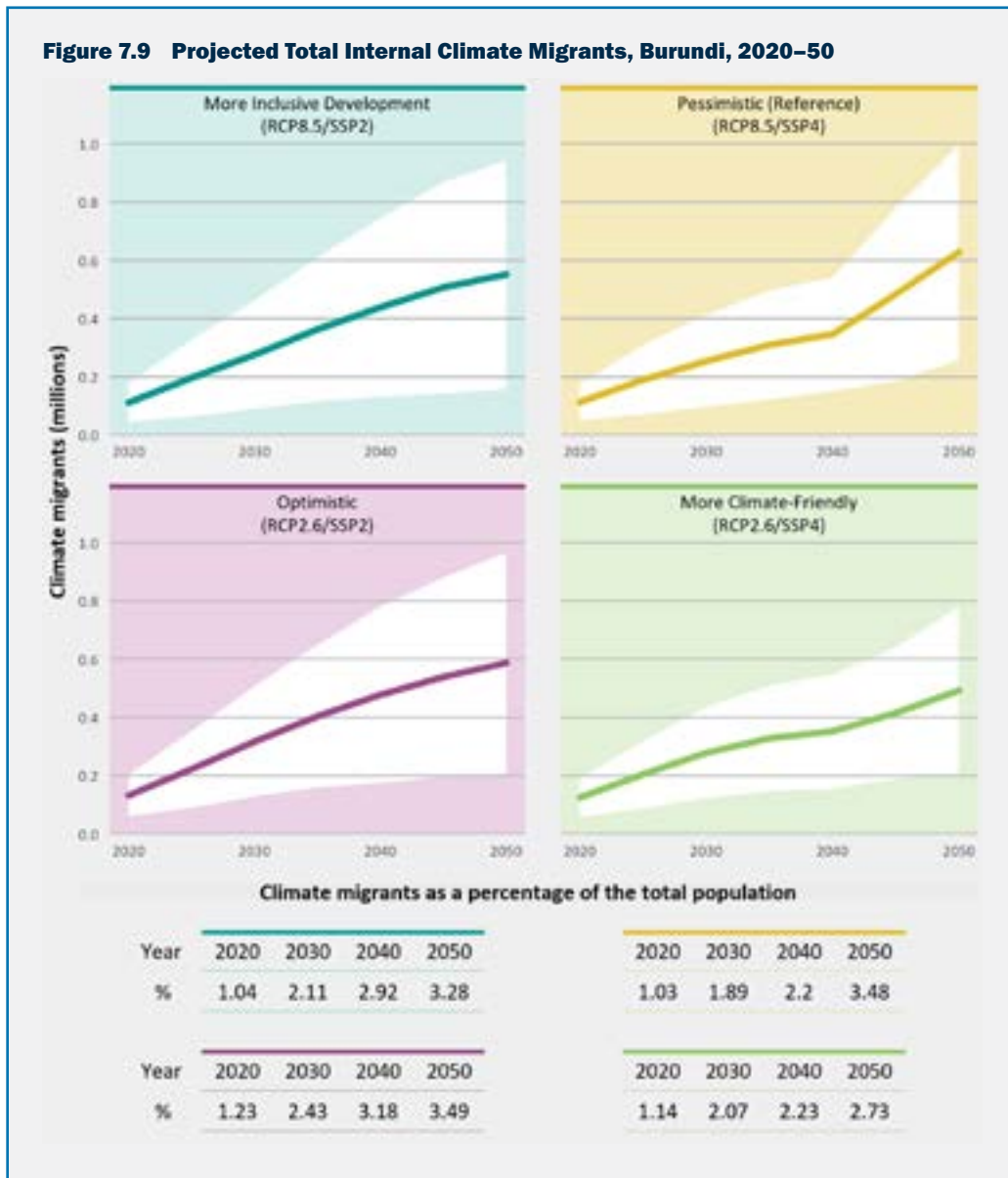
declines. Because of the rapid population growth in Burundi, all scenarios show positive changes in all regions. Changes appear more intense in the pessimistic scenario, but there are few differences between them. Areas of relatively smaller change on the northeast of the country correspond to Ruvubu National Park (on the northeast) and Nyungwe Forest National Park (on the northwest).



## 7.1.4 Climate Migration Futures and Trends

### Scale and Trajectory of Internal Climate Migration

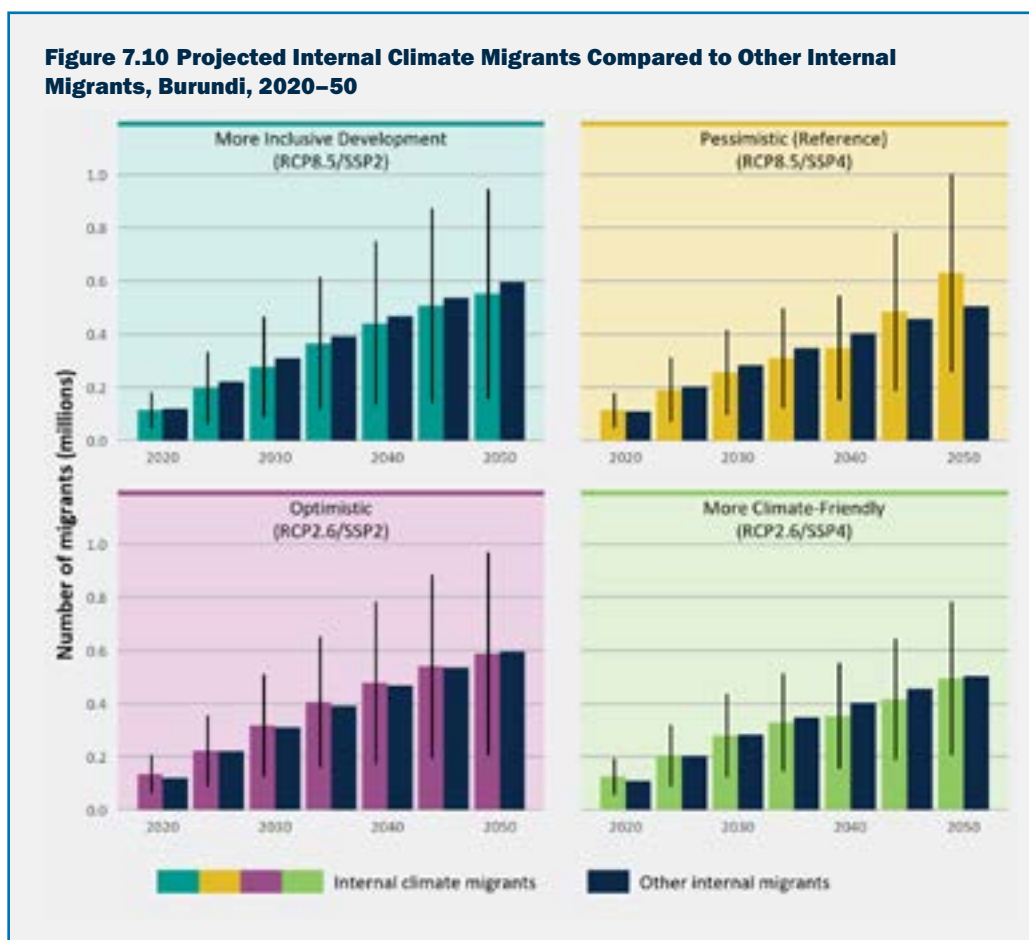
Figure 7.9, presents the estimated number of internal climate migrants in Burundi by scenario and decade from 2020 to 2050, and table 7.2 shows the average, low, and high values for climate migration by 2050. There is an overall upward trend across the four scenarios, with some differences. Scenarios based on SSP2 display a faster increase in climate migrants up to 2045, followed by a slightly slower trend to 2050. Scenarios based on SSP4 show a steeper rise in climate migrants after 2040. The optimistic scenario displays the largest numbers in all decades except 2050 (when the pessimistic scenario takes the lead) and the largest proportions of climate migrants in relation to the total population in every decade. The smallest numbers and proportions belong to the climate-friendly scenario. These results likely reflect the combined influence of changes in water availability, the strongest driver according to the model results (see Table 3.7) and population growth trends.



**Table 7.2 Projected Total Internal Climate Migrants by 2050, Burundi**

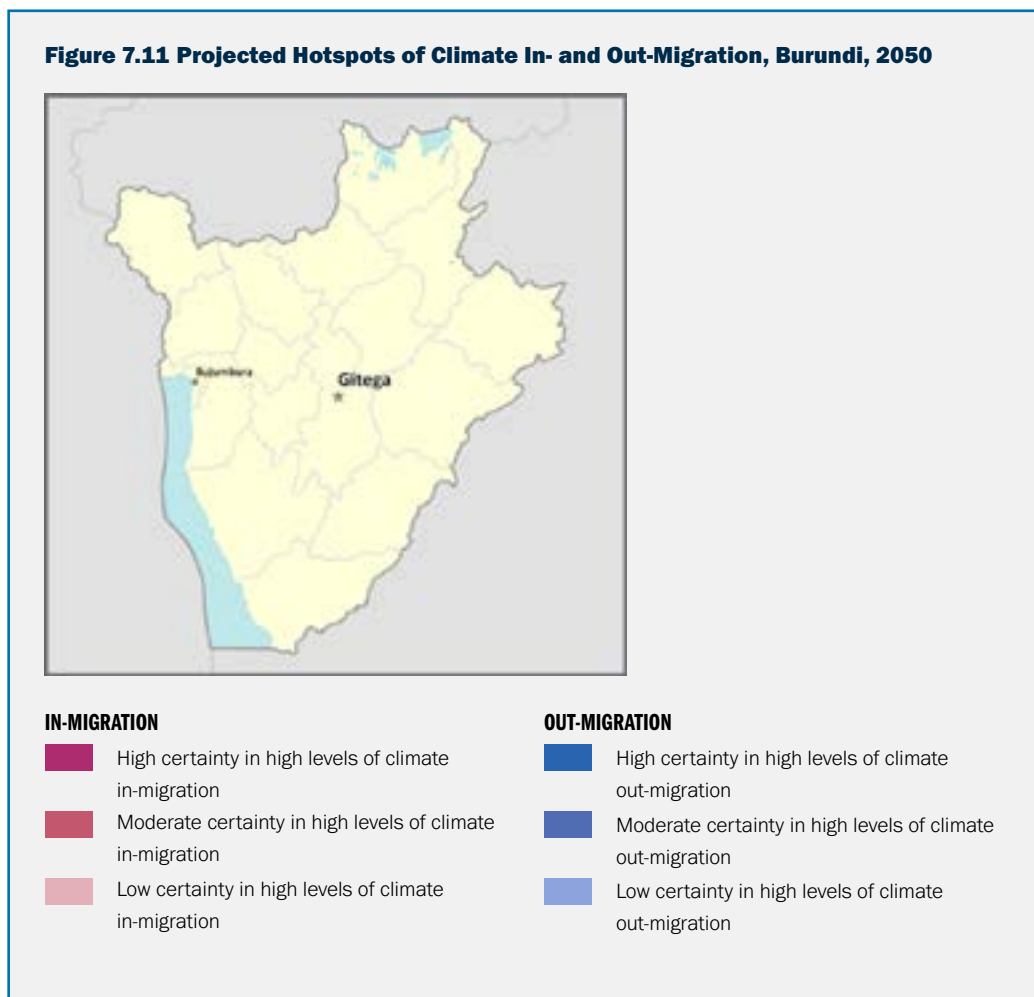
	Pessimistic (reference) (RCP8.5, SSP4)		More inclusive development (RCP8.5, SSP2)		More climate-friendly (RCP2.6, SSP4)		Optimistic (RCP2.6, SSP2)	
Average number of internal climate migrants by 2050 (millions)	0.6		0.6		0.5		0.6	
Min. (left) and max. (right) (millions)	0.3	1.0	0.2	0.9	0.2	0.8	0.2	1.0
Internal climate migrants as % of pop.	3.5		3.3		2.7		3.5	
Min. (left) and max. (right) (%)	1.4	5.5	0.9	5.6	1.1	4.3	1.2	5.7

Figure 7.10, displays the number of internal climate migrants compared to that of other internal migrants. Overall, the two categories of migrants show very similar magnitudes across scenarios and decades. Under the optimistic scenario, there are slightly more climate migrants in each time slice except for 2050. For the pessimistic scenario, climate migrants largely surpass other migrants by 2050, after lagging until 2040.



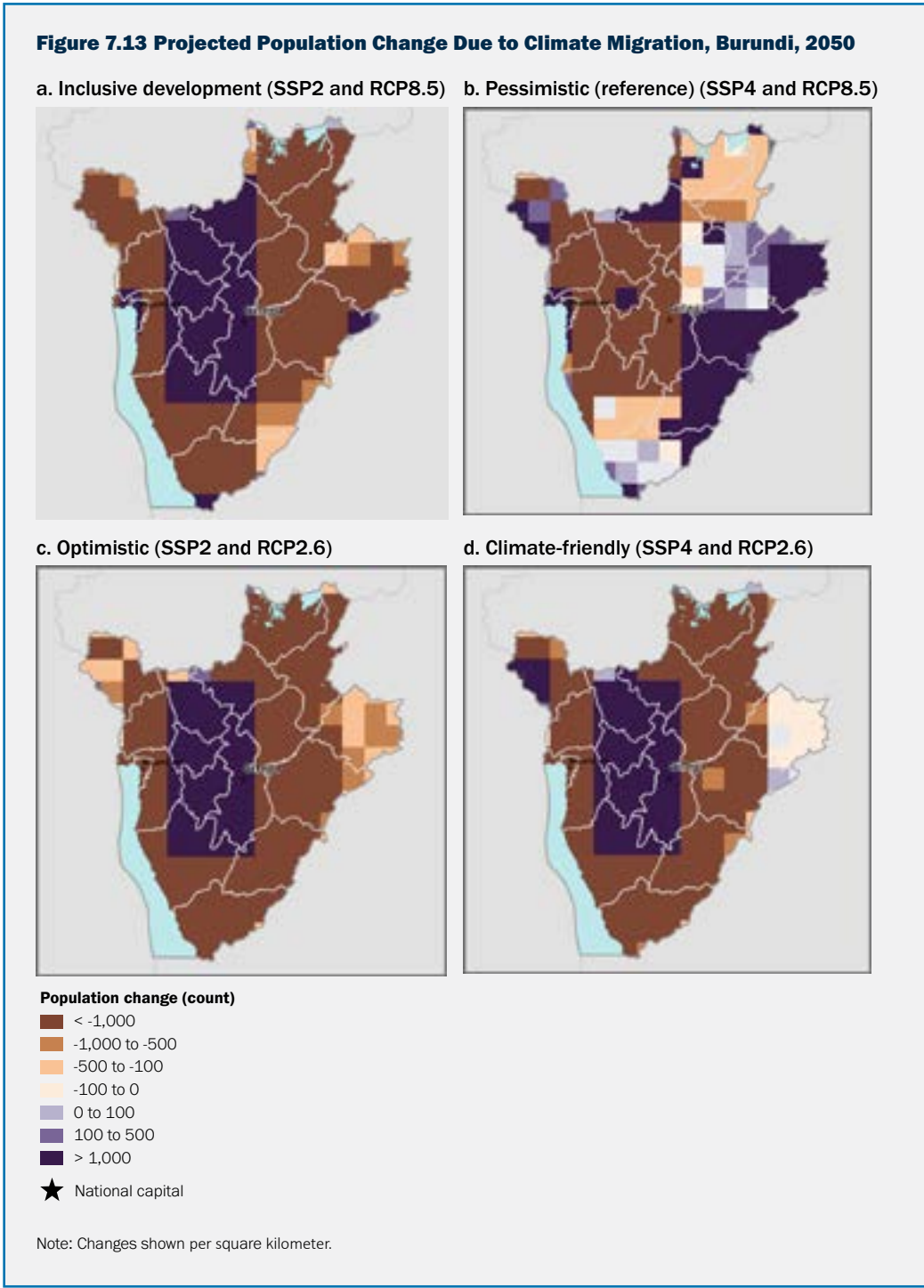
### Internal Climate Migration Hotspots

Figure 7.11 displays hotspots of climate in- and out-migration for 2050, and figure 7.12, panels a and b, shows hotspots for 2030 and 2040. A large, high-certainty in-migration hotspot is visible in the center of the country, including the new capital, Gitega. A long, narrow out-migration spot could emerge on the west, close to Lake Tanganyika and including a part of Bujumbura Marie, one of Burundi's most populous areas. The water model inputs—despite their far higher coefficients as compared to coprs and NPP—appear to have a relatively modest impact on the migration hotspots, perhaps because of their lack of spatial variation. Instead, crop model outputs, which show significant projected increases in and around Gitega, when combined with the higher population distribution in this region, produce an in-migration hotspot. Slight to moderate declines in crop productivity just to the west, along the shores of Lake Tanganyika, could produce the out-migration hotspots.

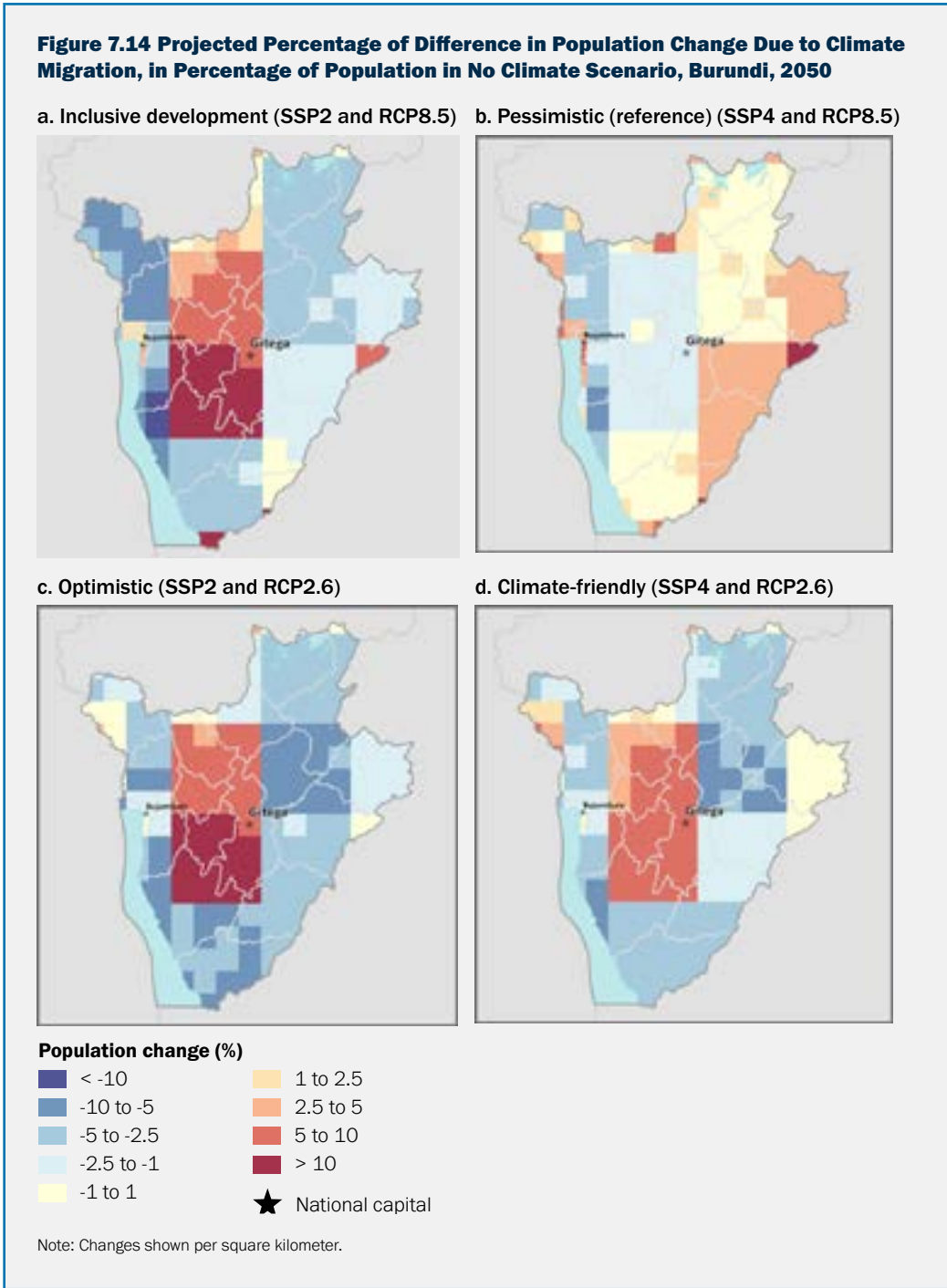








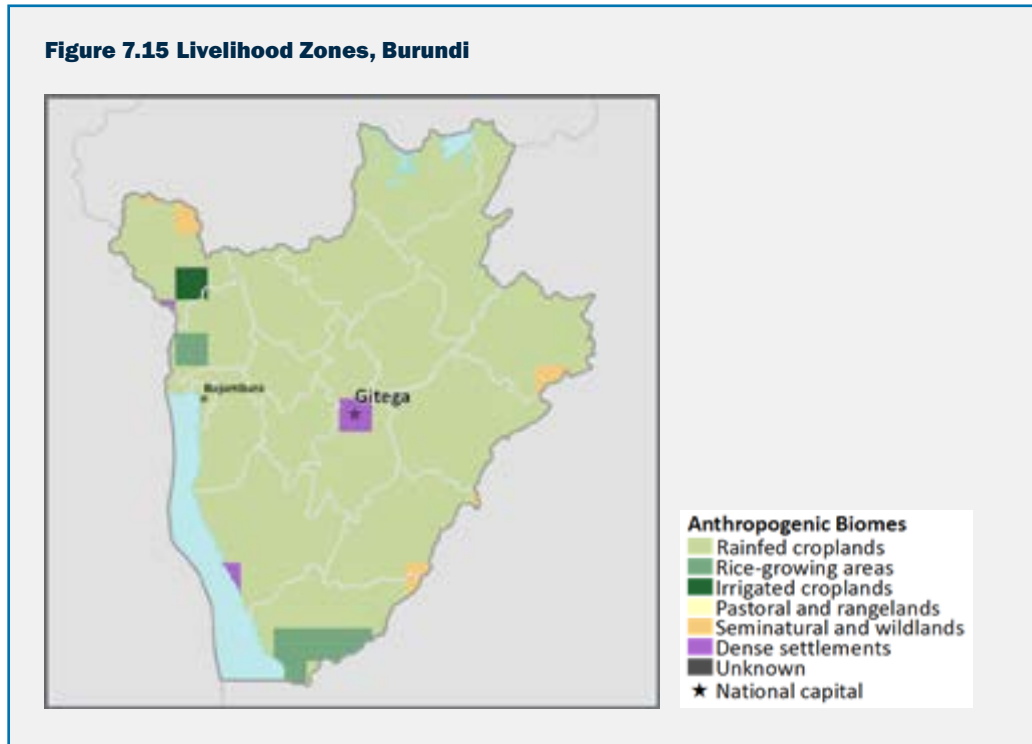
**Figure 7.14**, displays climate migrants as a percentage of the population under the no climate impact (SSP-only) scenario in each grid cell. This highlights changes in less densely settled areas, since even small changes in thinly settled areas will show up as high in percentage terms. Once again, the impact of the 0.5 degree ISIMIP grid cells is visible in the pattern. Also, patterns of percentages are overall smaller under the pessimistic scenario, and they are smaller compared with the rest of the scenarios (except for a spot on the east).



*Climate Migration by Livelihoods*

Figure 7.15 shows Burundi's livelihood zones, which are based on an aggregation of anthropogenic biomes produced by Ellis et al. (2010 and 2013). Livelihood zones are static, meaning they are not projected into the future based on likely climate influences on ecosystems (Williams, Jackson, and Kutzbach 2007), but reflect the historical climate period from 1970 to 2010. The distribution of zones in the future could obviously be altered by climate impacts on the water and agriculture sectors and natural ecosystems. Further, livelihood zones are land-based, and therefore do not consider livelihoods dependent on marine fisheries along the coast.

Regarding croplands, almost all the country is covered by rainfed land, with small rice-growing areas visible in the south and west. There are two spots of dense settlements (Gitega and Mugara on the west),<sup>55</sup> and a few patches of seminatural and wildlands on the northwest and east. Rainfed croplands consistently display positive net migration across scenarios for all decades, which is similar for dense settlements, except for the pessimistic scenario in 2050. In contrast, rice-growing areas and irrigated croplands—located in areas projected to have negative changes in water availability as per ISIMIP results—consistently display negative net migration. Areas of seminatural and wildlands display negative net migration, except for the pessimistic scenario in 2050.



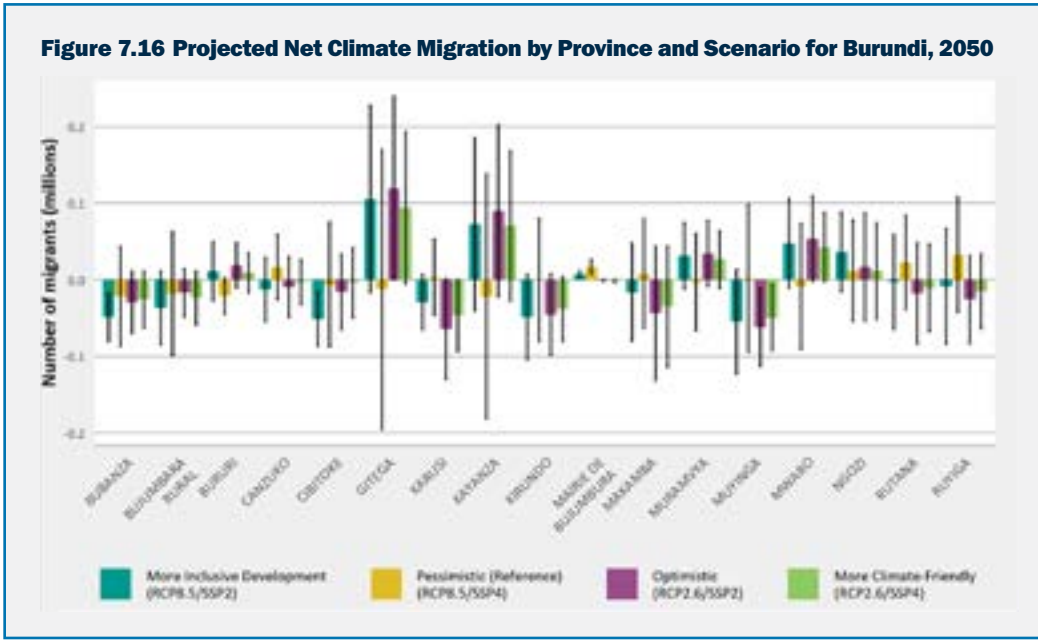
55. Bujumbura, Burundi's largest city, does not appear as a dense settlement because of the way zones are calculated. Each 15-kilometer grid cell is assigned the type that makes up most of the area. Bujumbura is split between four grid cells so it does not make up the majority of any of them.

**Table 7.3 Projected Net Climate Migration by Scenario and Livelihood Zone and Decade, Burundi**

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)
<b>2030</b>				
Dense settlements	6,597	6,610	7,705	5,569
Irrigated croplands	-3,026	-4,681	-3,469	-4,624
Pastoral and rangelands	-8	-3	-12	-1
Rainfed croplands	5,195	5,291	6,582	4,755
Rice-growing areas	-7,668	-5,827	-9,349	-4,509
Seminatural and wildlands	-1,089	-1,391	-1,458	-1,191
<b>2040</b>				
Dense settlements	8,391	9,646	12,065	6,509
Irrigated croplands	-3,295	-7,734	-4,659	-6,732
Pastoral and rangelands	-13	-6	-24	2
Rainfed croplands	7,043	9,394	11,023	5,781
Rice-growing areas	-10,707	-8,823	-15,795	-4,152
Seminatural and wildlands	-1,419	-2,477	-2,610	-1,408
<b>2050</b>				
Dense settlements	11,838	11,755	14,719	-4,614
Irrigated croplands	-4,578	-9,640	-5,623	-3,868
Pastoral and rangelands	-20	-6	-31	27
Rainfed croplands	11,669	10,571	14,409	6,008
Rice-growing areas	-16,541	-9,568	-20,248	-1,129
Seminatural and wildlands	-2,367	-3,113	-3,225	3,576

**Climate Migration by Province**

Figure 7.16 and table 7.4 display net climate migration by scenario at the province level for Burundi. There is high uncertainty across all results, with most confidence intervals spanning both positive and negative net migration. For Mairie de Bujumbura Province, the more-inclusive development and the pessimistic scenarios indicate a small positive balance. For Gitega and Kayanza, in all but the pessimistic scenario there could be net climate in-migration, possibly because all the LPjML model runs show significant increases in crop production in these two areas of very high projected population density (figure 7.5). In the northeast, Karusi, Kirundo, and Muyinga all show net climate out-migration, driven in part by the young median age and low sex ratio characteristic of rural areas.



**Table 7.4 Projected Net Migration by Scenario and Province, Burundi, 2050**

Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Bubanza	-121,761	-211,487	-142,494	-154,378
Bujumbura Rural	-101,491	-170,947	-85,158	-126,750
Bururi	58,254	45,601	94,402	-22,494
Canzuko	-18,158	-50,281	-43,918	16,026
Cibitoke	-41,054	-225,852	-87,554	-119,982
Gitega	421,709	470,877	544,819	190,076
Karusi	-214,665	-125,751	-288,891	-52,581
Kayanza	297,405	321,314	391,096	91,342
Kirundo	-167,326	-208,026	-208,986	-97,395
Mairie de Bujumbura	-6,999	27,252	-5,158	58,005
Makamba	-129,278	-89,397	-172,989	-14,907
Muramvya	112,139	136,947	150,464	53,226
Muyinga	-218,218	-233,224	-279,510	-104,451
Mwaro	190,422	214,425	245,844	83,034
Ngozi	29,091	160,876	53,007	104,338
Rutana	-29,906	-21,839	-60,204	42,858
Ruyiga	-60,164	-40,488	-104,769	54,034

## 7.2 KENYA

### 7.2.1 Population and Development Context

**The World Bank classifies Kenya as a lower-middle-income economy.** Its GDP has shown an upward trend over the last 20 years, going from US\$12.7 billion in 2000 to US\$87.9 billion in 2018 (in current US dollars). During the same period, its GDP growth averaged 4.7 percent per year, and the GDP per capita increased from US\$397.50 in 2000 to US\$1,710.50 in 2018 (in current US dollars) (table 7.5).<sup>56</sup>

**The agriculture, forestry, and fishing sector represented about 34 percent of the GDP in 2018, the largest economic sector after services, and 54 percent of all employment** (49 percent and 61 percent of male and female employment, respectively).<sup>57</sup> This weight of the agricultural sector in the country's economy and relative poverty make Kenya highly vulnerable to the impacts of climate variability and change (World Bank 2013). For example, the 2018/19 drought slowed economic growth and increased food insecurity, making it even more urgent for transformations in agriculture to reduce subsistence, rainfed farming (AfDB 2020).

**Poverty reduction remains one of Kenya's challenges.** Despite substantial declines, 37 percent of the population still subsisted with US\$1.90 a day (2011 PPP) and large intracountry heterogeneities persist: a large proportion of the poor population are concentrated in the semiarid areas highly susceptible to climate change impacts (Lacroix 2011). Growth in the agriculture sector has been the main driver of the reduction of poverty, but the agricultural sector continues to be vulnerable to internal and external shocks (Awiti et al. 2018).

**Kenya's total population reached 51.4 million in 2018 (UN WPP 2018), with an annual population growth of 2.3 percent, and a projected 2050 population of 91.6 million (UN medium variant).**<sup>58</sup> Population growth is expected to decline over time, with a projected growth rate of 0.17 percent by 2100 (UN medium variant). Fertility is expected to continue declining, going from the current 3.5 children per woman to 1.8 children per woman in 2095–2100. Life expectancy is projected to increase from 66.18 years in 2015–2020 to 79.74 years in 2095–2100.<sup>59</sup>

56. Data from World Development Indicators (database), World Bank, Washington, DC, accessed 2020, <https://datacatalog.worldbank.org/dataset/world-development-indicators>.

57. Data from World Development Indicators (database), World Bank, Washington, DC, accessed 2020, <https://datacatalog.worldbank.org/dataset/world-development-indicators>.

58. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wpp>.

59. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.

**Table 7.5 Development Indicators for Kenya**

Population	
Population (thousands) (2018)	51,393
Annual population growth (%) (2018)	2.3
Population in 2050 under SSP2 (thousands)	78,055.6
Population in 2050 under SSP4 (thousands)	91,674.7
Urban share of population (%) (2018)	27
Employment in agriculture (% of total employment) (2019)	54.4
GDP	
GDP (US\$, billions) (2018)	87.9
Annual GDP growth (%) (2018)	6.3
GDP per capita (US\$) (2018)	1,710.5
Value added of agriculture (% GDP) (2018)	34.2
Poverty	
Poverty headcount ratio at US\$1.90 a day (2011 PPP) (% of population) (2015)	36.8
Climate and disaster risk indexes	
ND GAIN Index	
Rank (2017)	150
Score (2017)	36.9

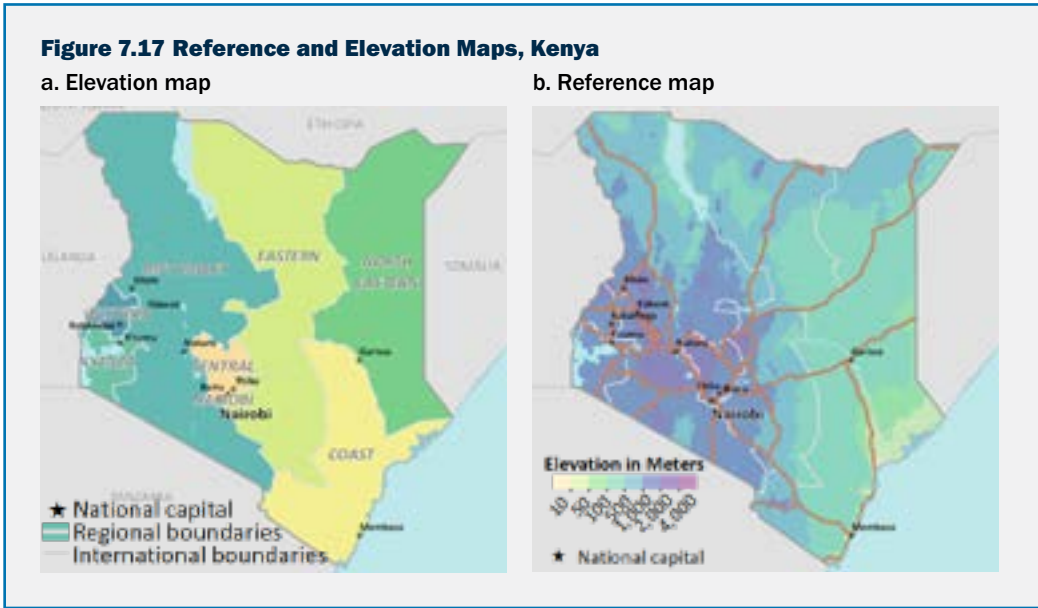
Source: WDI database<sup>60</sup>

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. For more information on ND-GAIN, see: <https://gain.nd.edu/>

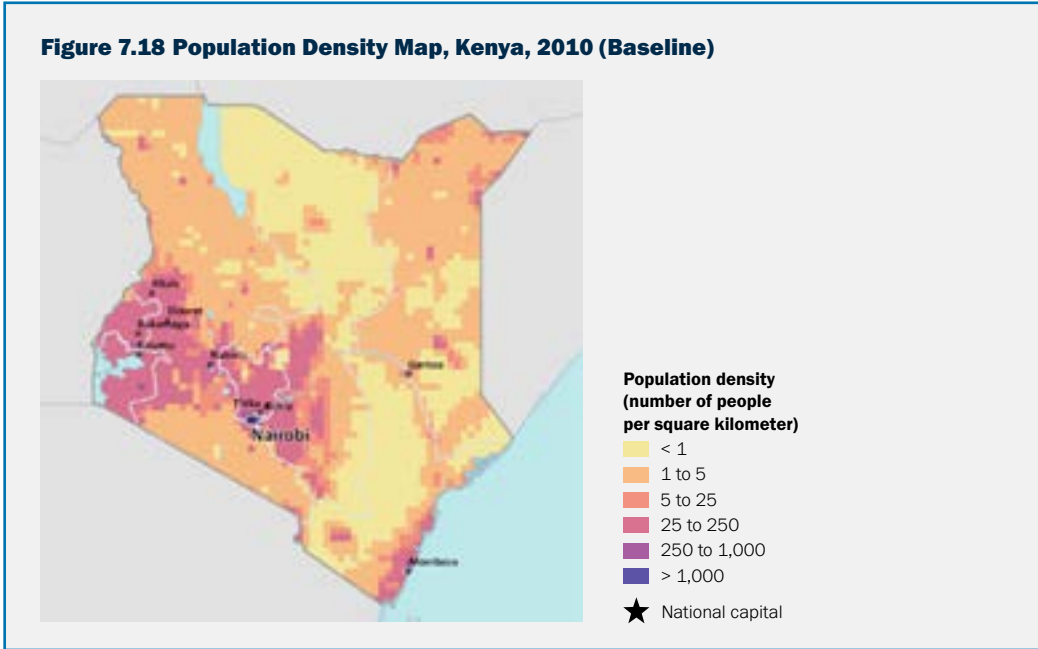
**These age transitions are visible in the population median age of 20.1 years, older than the regional median age for East Africa (18.1 years) and Africa (19.7).** As fertility and mortality decline, median age is expected to reach 40.3 years by 2100. The sex ratio (males per 100 females) was 98.8 in 2020, lower than the global ratio of 101.7, similar to the African ratio of 99.9, and higher than the East African ratio of 97.7 (UN WWP 2019).<sup>61</sup>

**Population distribution in Kenya is quite uneven (figure 7.17, panels a and b), reflecting historical patterns related to agro-ecological zones and colonial infrastructure development** (e.g., railroads), as well as present differences in agricultural potential and employment opportunities (urban areas), with least populated areas corresponding to arid and semiarid conditions. According to the National Council on Population and Development (NCPD), "Kenya has done little to open new parts of the country for new settlement, resulting in overpopulation in the areas that are viable for farming, under-population in the pastoralist areas, and rural out-migration to the main urban center" (NCPD and UNFPA 2013). The more densely populated areas correspond to the Lake Victoria Basin and surrounding counties in western Nyanza, the central region, and Nairobi, the corridor connecting these two areas in the Rift Valley region, the central sections of the eastern region, and the coastal areas closer to Mombasa in the southeast.

60. See the World Bank Development Indicators (WDI) database, <https://datacatalog.worldbank.org/dataset/world-development-indicators>  
 61. World Urbanization Prospects, 2019 (database), UNDESA, New York, <https://population.un.org/wpp>.



Kenya is still a rural country, with only 27 percent of its population living in urban areas in 2018, but the urban population is growing rapidly (average annual rate was 4.2 percent in 2015–20) and it is expected to be 46 percent by 2050.<sup>62</sup> The largest city is the capital Nairobi, with 4.7 million people in 2020 and projected to reach 8.5 million in 2035. The second largest city is Mombasa, on the Indian Ocean coast, with 1.3 million inhabitants in 2020. Eldoret (0.4 million) and Kisumu (0.35 million), the third and sixth largest cities, are in the Lake Victoria Basin region. See figure 7.18.



### 7.2.2 Historical and Current Migration Patterns

Kenya's internal migration system includes multiple forms of mobility to and from urban and rural areas (IOM 2018b), including seasonal migration to cash crop areas, rural-urban flows to large and medium cities, and nomadism of pastoral groups in the northern regions (figure 7.19) (Lacroix 2011). Nairobi is the preferred destination of rural-urban, urban-urban and also international in-migration (NCPD and UNFPA 2013).

62. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.

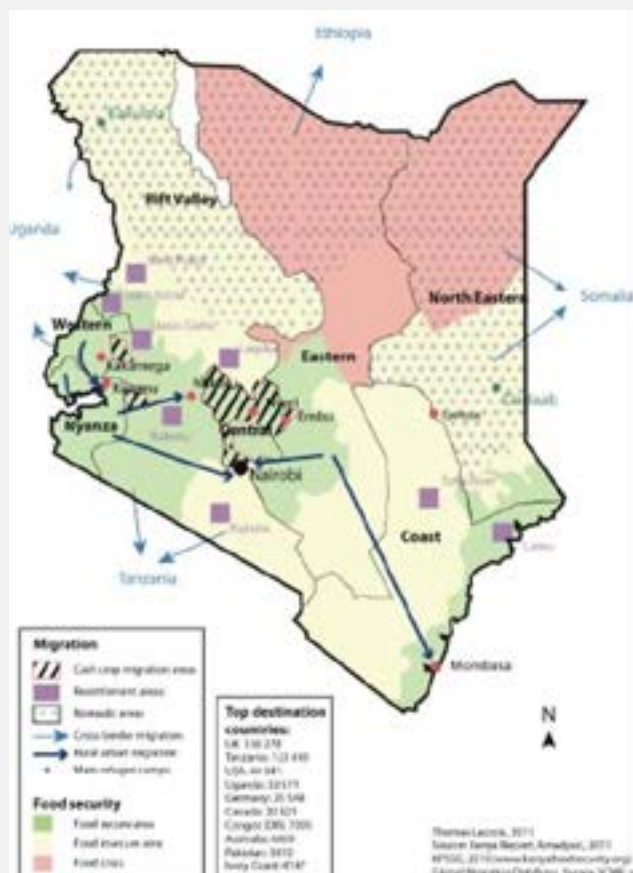


**Rural-urban migration flows are also directed to medium cities.** In the case of Eldoret, the country's third largest city and located in the Lake Victoria Basin, migration has been key to the city's growth since the 1970s. While this has enhanced Eldoret's national significance, it has also resulted in numerous challenges for the provision of services and housing, competition for the urban space, and expansion of informal settlements (RVI 2018a).

**Remittances from internal migrants are important for rural households' budgets** (Lacroix 2011; RVI 2018a). In a 2009 national survey, 46 percent of recent internal migrants aged 16 and over reported to have sent money, food, or goods back to their families within the past 12 months (De Brauw et al. 2014).

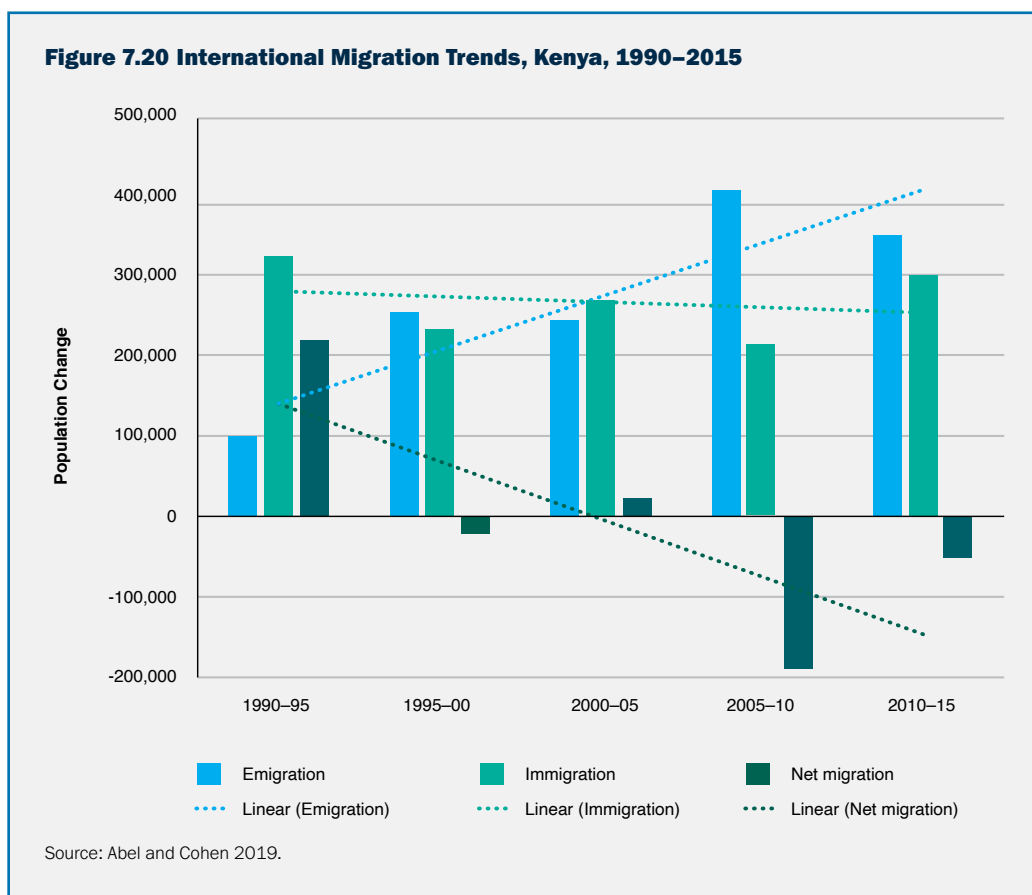
**Age, sex, human capital, and context are relevant factors to understand who is likely to move.** A study using in-depth data for three Health and Demographic Surveillance System sites in Kenya (two mostly rural with large populations—Kisumu on the Lake Victoria Basin, and Kilifi on the Indian Ocean coast—and one urban covering slums with high densities in the capital, Nairobi) finds that out-migration rates were higher for young adults (aged 20–24), with some gender differences: rates were higher for female migrants in Nairobi, and for male migrants in Kisumu and Kilifi. In-migration rates for the same age group were even higher for Nairobi (around 43 percent), consistent with the city being a major urban destination, and Kisumu displayed the lowest in-migration rates in the study. Out- and in-migration rates in Nairobi and out-migration rates in Kisumu and Kilifi showed a strong positive association with education, particularly with secondary education (Ginsburg et al. 2016).

**Figure 7.19 Migration System, Kenya, 2011**



Source: Adapted from Lacroix 2011, 43.

**Figure 7.20 displays international migration trends for Kenya from 1990 to 2015.** Over this period, emigration increased, and immigration decreased, with a peak of negative net migration in the late 2000s (Abel and Cohen 2019). International movements include cross-border mobility with neighboring countries, intra-African migration (Democratic Republic of Congo, Côte d'Ivoire), and intercontinental migration to the United States and United Kingdom, among other destinations (Abel and Cohen 2019; Lacroix 2011). Remittances from Kenya emigrants represent an important portion of all African remittances, but just 2.9 percent of the country's 2019 GDP (AfDB 2020a).



### Conflict Mobility

**In 2017, there were about 500,000 refugees and asylum seekers in Kenya, most from Somalia (300,000) and South Sudan (100,000).** National regulations require them to stay in refugee camps to receive humanitarian assistance, but in practice refugees and asylum seekers have also settled in Nairobi and other urban areas across the country. The encampment policy has often resulted in refugees having little or no access to higher education, employment, or travel. They usually remain in the camps for a long time. The largest camp complexes are Dadaab in the east and Kakuma in the northwest. Citing security concerns, the Government of Kenya (GoK) has been trying to close the camps and repatriate the refugee population (MGSoG 2017). In comparison, the number of Kenyan refugees is much smaller (around 7,500 in 2017), many of them in Ethiopia.

**The IDMC (2020b) estimates about 162,000 IDPs in December 2019, with 1,800 new displacements that year due to violence and conflict.** Most of the internal displacement is because of ethnic, political, and land-related violence, but disasters also play a role (MGSoG 2017).

### *Environmental Migration*

**Environmental drivers are related to both internal and cross-border displacement.** For example, the 2011 and 2017 droughts in the Horn of Africa resulted in massive cross-border displacement to Kenya, particularly from Somalia, with many displaced persons staying at the Dadaab camp in East Kenya (MGSoG 2017; World Bank 2013). Drought-related displacement of pastoralists (not to be confused with the regular transhumance patterns) have led to conflicts over land and water resources among pastoralists and between pastoralists and settled farmers (IOM 2018b).



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**Migration as a strategy to cope with adverse environmental conditions is common among Kenyan rural households.** In his study of the effects of soil quality on migration patterns of grain-producing households in Kenya's highlands, Gray (2011) finds that low soil quality affecting crop yields increased the odds of internal migration, particularly temporal labor mobility, to increase household income, particularly among small farmholders. Gray and Wise (2016) find that cool and rainy climate conditions were more likely to result in high levels of migration, especially for internal female labor migrants.

### 7.2.3 Climate Trends and Population Projections

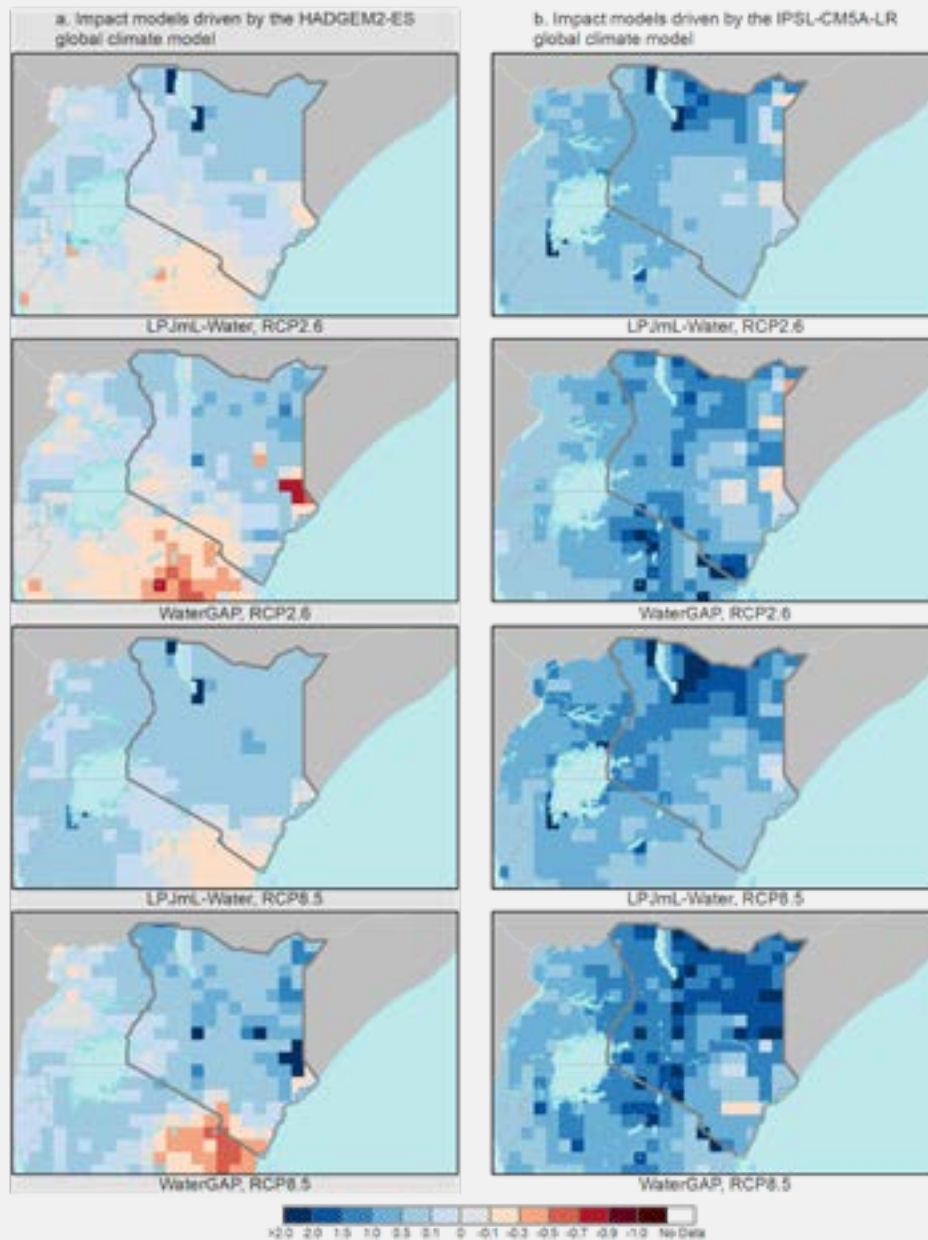
**Kenya is an equatorial country notable for its diverse geography, from a large tropical coastal zone to savannah grasslands, deserts, and snow-capped mountains in its interior.** Seasonal trends are shaped by the El Niño–Southern Oscillation (ENSO) and the movement of the Inter-Tropical Convergence Zone (ITCZ) (World Bank 2020b). The long rainy season typically lasts from March to June, followed by a dry season and another, shorter rainy season from September to December. Although local temperatures vary across the diverse terrain, the country's average annual temperature between 1901 and 2016 was 24.3°C. Rainfall is extremely variable from region to region and year to year.

**The average annual temperature has been steadily increasing at a rate of approximately 0.21°C per decade since 1960** (World Bank 2020b). Although rainfall is contingent on a number of variables and fluctuates year to year, the duration and severity of rainy and dry seasons offer useful insights to how warming temperatures will shape Kenya's climate future. A 100-millimeter decline in the level of precipitation during the long rainy season between the 1970s and 2010, for example, suggests that rainfall is diverging slightly from historic patterns (USGS 2010). Models also suggest that an increasingly large proportion of annual rainfall will fall in heavy events (McSweeney et al. 2006). A drop in precipitation levels in August and September by the turn of the 21st century could occur due to a weakening in the Somali Jet and Indian monsoon (Niang et al. 2014).

**Studies consistently note a tendency toward more extreme weather events, a pattern likely to increase in the coming decades.** Warm nights, characterized by temperatures above the 90th percentile, are expected to become more frequent (McSweeney et al. 2006). While rainfall may vary, precipitation events are likely to be more intense and droughts more severe. The increased severity of floods poses a serious risk to individual and national livelihoods. The 2002 floods were catastrophic to people in impacted communities in Kenya (Niang et al. 2014). By 2030, 10,000 to 86,000 people could be impacted by floods at a serious economic, agricultural, and physical cost.

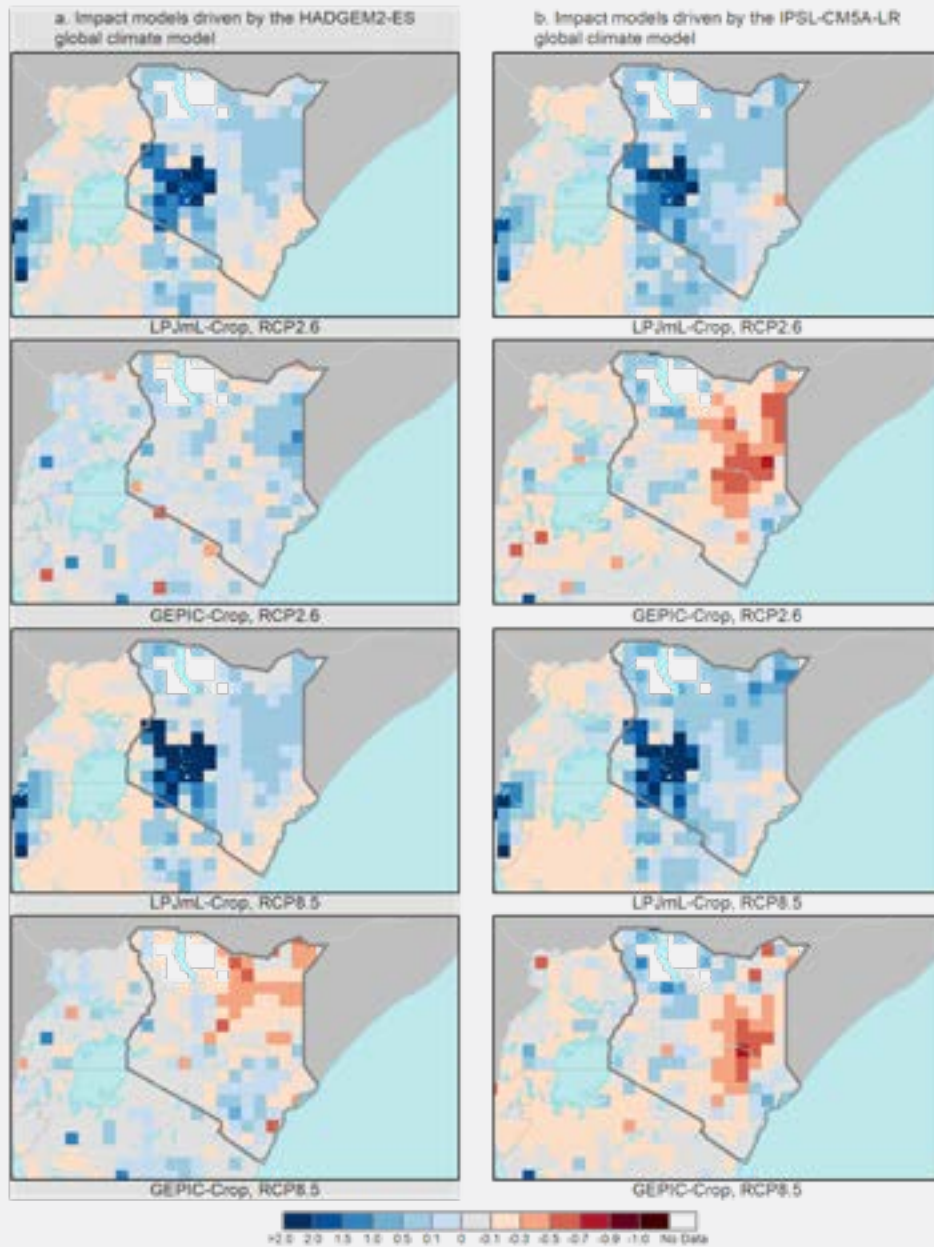
**Panels of figures 7.21–7.23 show the average projected changes in water availability, crop production, and NPP for the 2010–50 time period, respectively.** NPP is used to gap-fill areas where there is no crop production. Note that the coefficient for water availability in rural areas is around 2.8 times higher than that of crop production and 4.7 times that of 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. Under most scenarios, the ISIMIP models suggest there will be increases in water availability. The projected changes in the north, however, are against a very low baseline. Climate projections in this region, especially the coastal portions of Kenya, are challenged by the inability of the climate models from the CMIP5 archive to accurately capture the effect of sea surface temperature gradients in the Indian Ocean. Crop production is generally positive except under the IPSL climate model when coupled with the GEPIC crop model, which show areas in the northeast with significant declines. The LPJML crop model shows significant increases just to the east of Lake Victoria up to the eastern edge of the Rift Valley. NPP is used to gap-fill the areas without crop production around Lake Turkana, and the model runs mostly show significant increases in ecosystem productivity in this region.

**Figure 7.21 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Kenya, 2010–50**



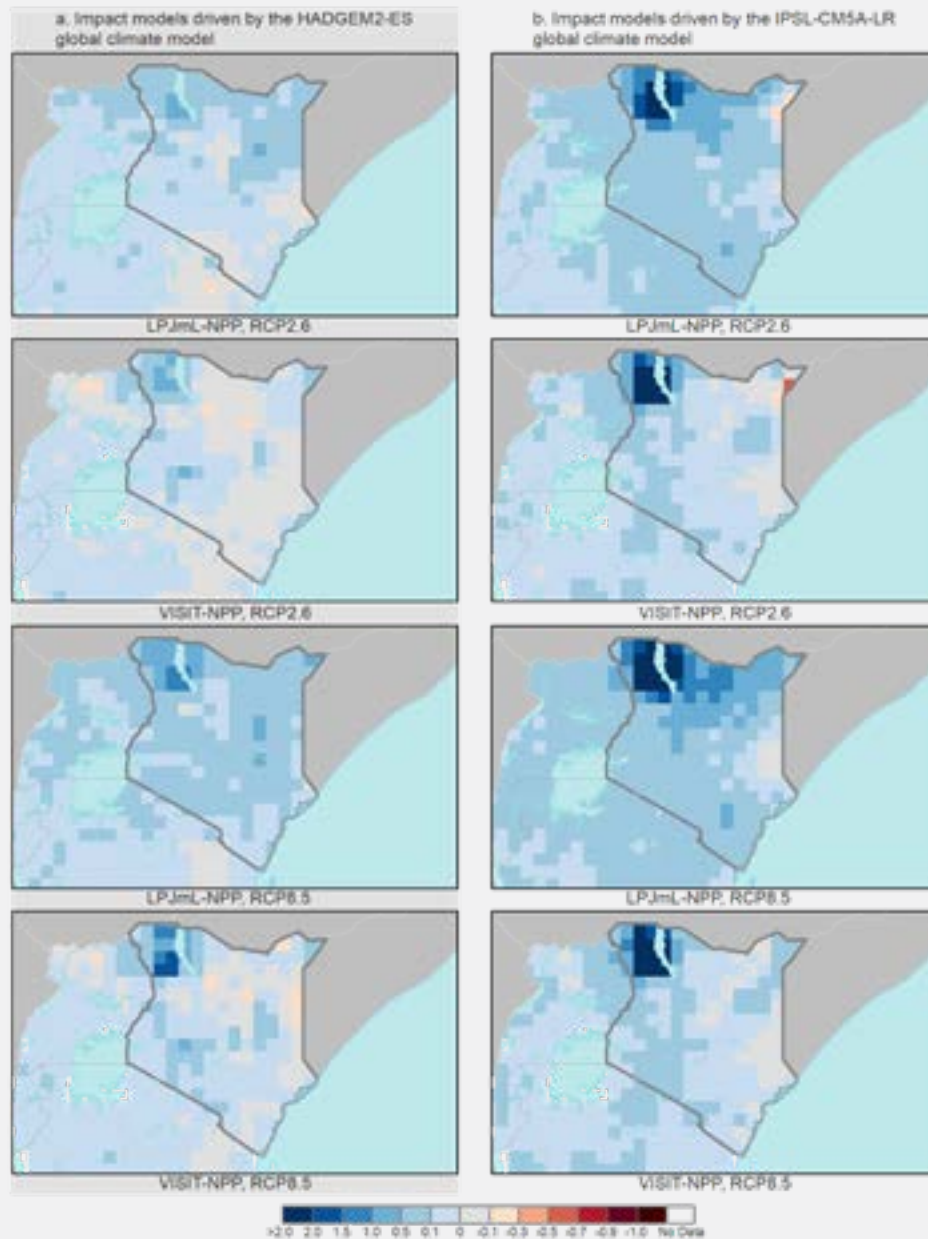
Note: Data calculated against 1970–2010 baseline for water availability, from LPJmL/water and WaterGap, forced with the HadGEM2-ES climate model (panel a) and IPSL-CM5A (panel b) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline, and tan to red areas indicate drying.

**Figure 7.22 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Kenya, 2010–50**



Note: Data calculated against 1970–2010 baseline for crop production. 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 production.

**Figure 7.23 ISIMIP Average Index Values against 1970–2010 Baseline NPP, Kenya, 2010–50**



Note: Data calculated against 1970–2010 baseline for NPP. Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is only used to gap-fill crop production. NPP = net primary production.

### Projected Changes in Population

Figure 7.24, panels a–d, displays Kenya’s projected population to 2050 for the four scenarios. Comparing with population density in 2010 (figure 7.25, panels a–d), the results show an intensification of essentially the same distribution pattern. There is a small decline in areas of very low density, and an increase of very high density close to the urban areas. Differences across scenarios are minimal.

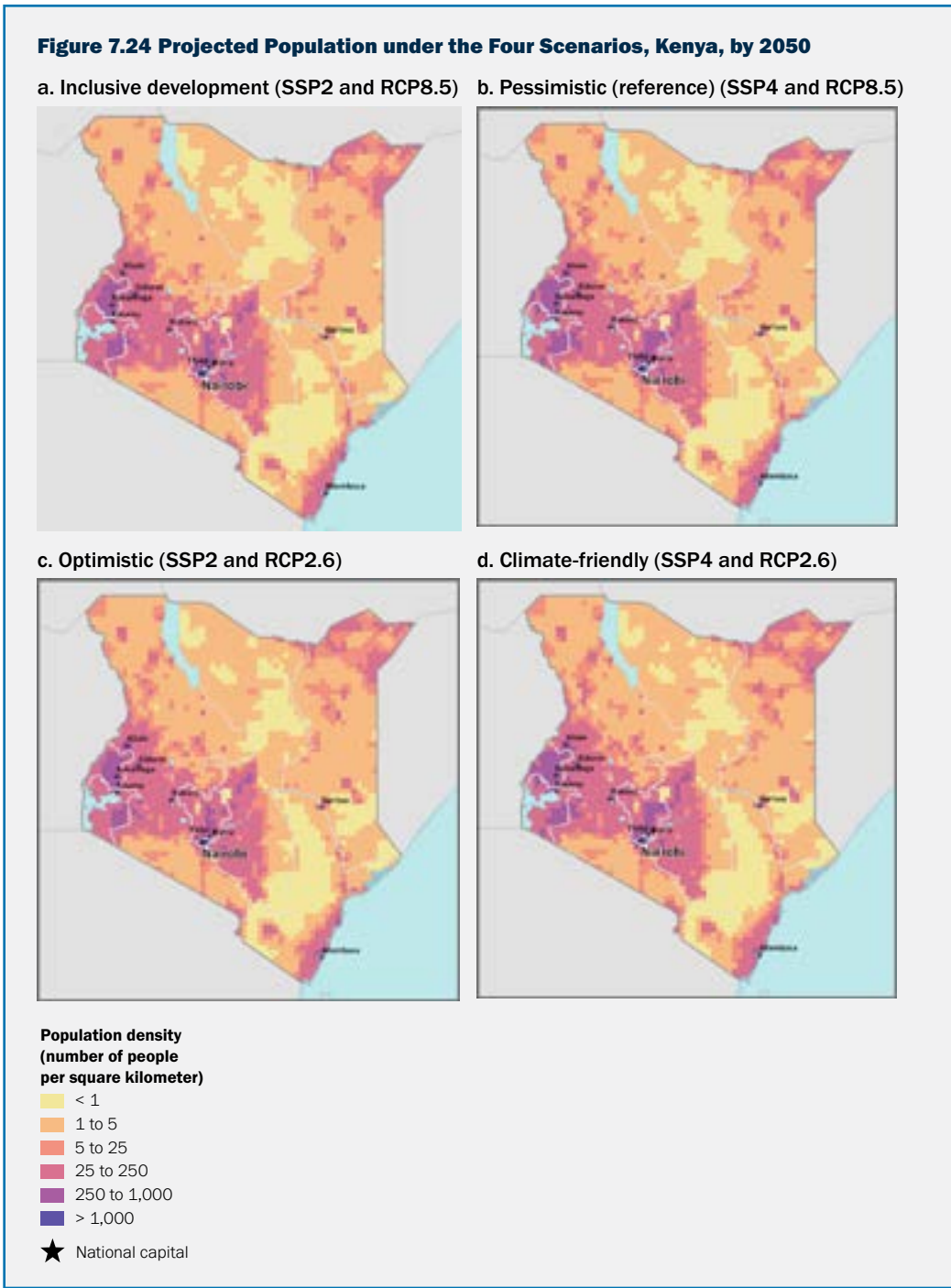
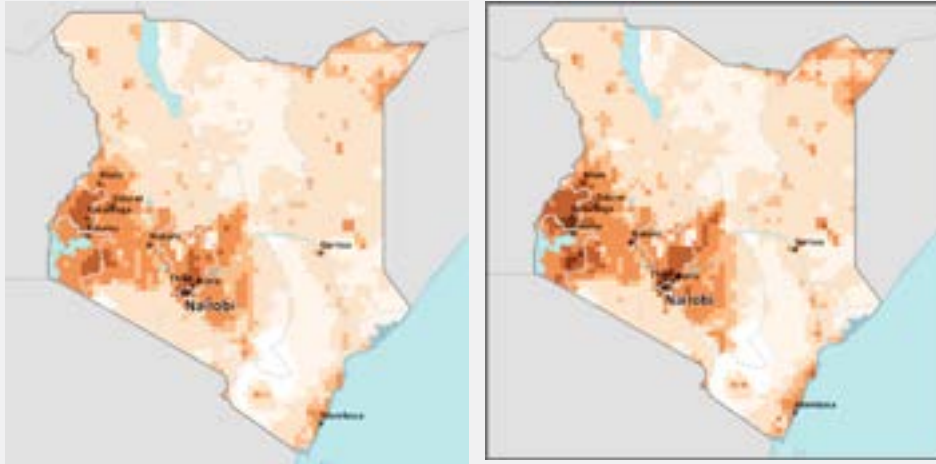


Figure 7.25, panels a–d, displays changes in population density between 2010 and 2050, projected to be positive in almost all areas across the four scenarios, except for a spot in the southeast, home to the Tsavo National Park. Changes appear larger in the pessimistic and more climate-friendly scenarios, based on SSP4, which forecasts higher population growth. Kenya’s Lake Victoria Basin displays large positive changes in the four scenarios, particularly in urban areas.



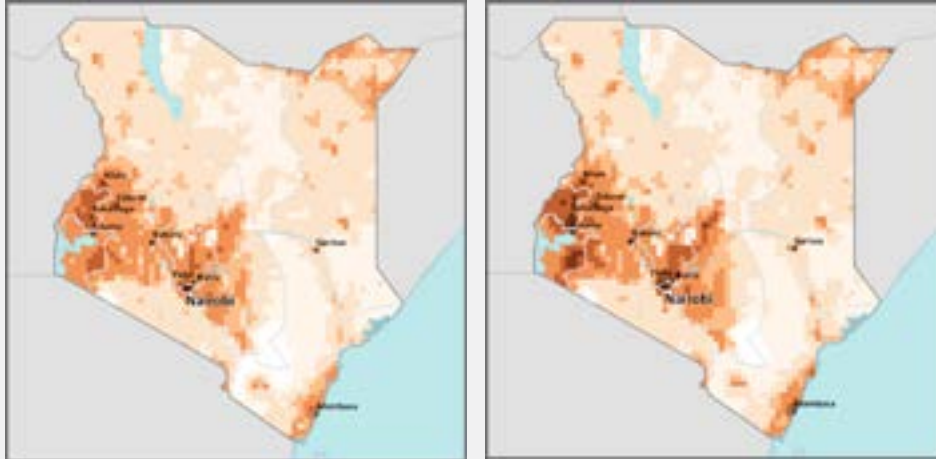
**Figure 7.25 Projected Change in Population Density under the Four Scenarios, Kenya, 2010–50**

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)



**Population change**  
(number of people per square kilometer)

- < 0
- 0 to 5
- 5 to 50
- 50 to 100
- 100 to 500
- 500 to 1,000
- > 1,000

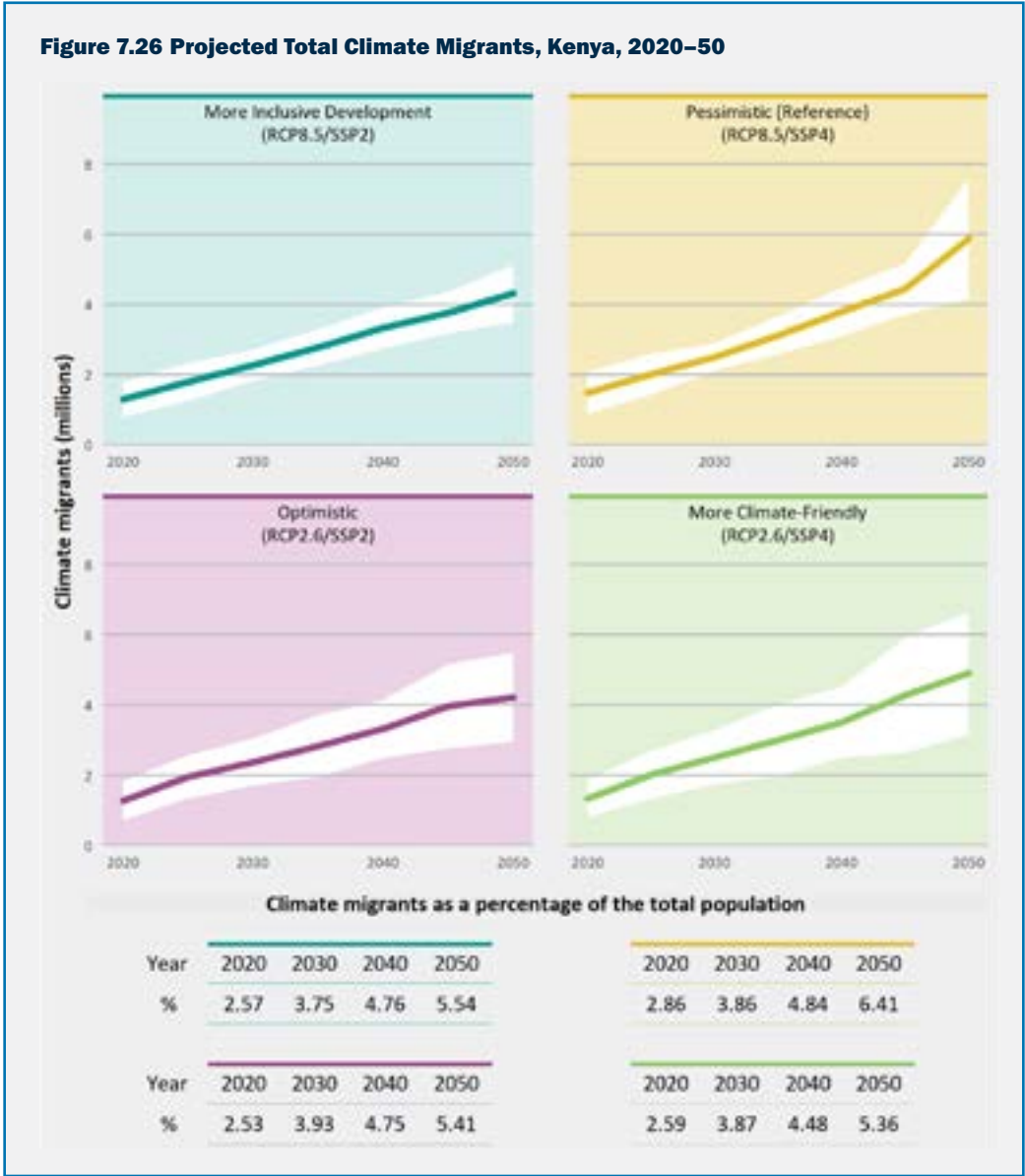
★ National capital

## 7.2.4 Climate Migration Futures and Trends

### *Scale and Trajectory of Internal Climate Migration*

Figure 7.26, presents the estimated number of internal climate migrants in Kenya by scenario and decade from 2020 to 2050, and table 7.6 shows the average, low, and high values for 2050. All the scenarios display an upward trend, with some differences. The pessimistic scenario displays the higher numbers to 2050, with 5.6 million; followed by the more climate-friendly scenario, with 4.9 million. The optimistic scenario shows the lowest numbers, with 4.2 million, very close to the more inclusive

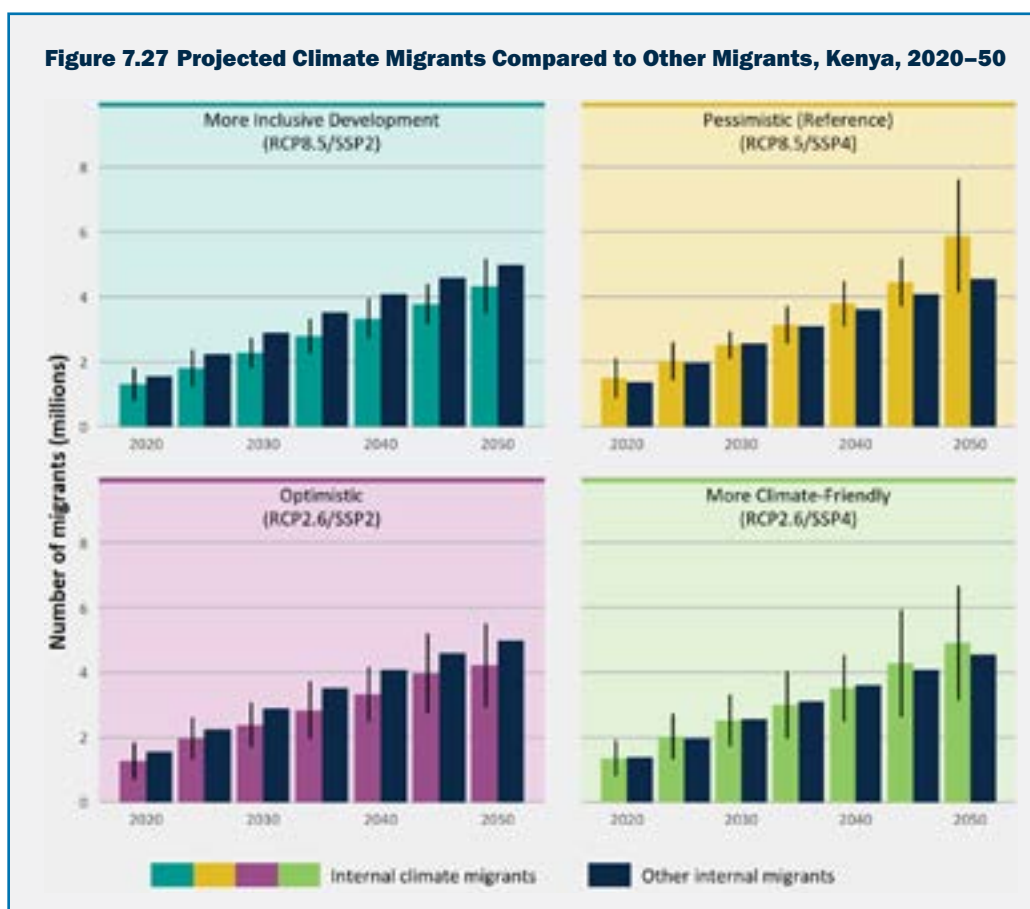
development scenario (4.3 million). Under the pessimistic scenario, climate migrants could represent 6.4 percent of the total population in 2050. The smallest proportion corresponds to the more climate-friendly scenario, 5.3 percent. These results suggest that both a lower population growth and moderating emission could reduce the number of climate migrants.



**Table 7.6 Projected Total Climate Migrants by 2050, Kenya**

	Pessimistic reference (RCP8.5; SSP4)		More inclusive development (RCP8.5; SSP2)		More climate-friendly (RCP2.6; SSP4)		Optimistic (RCP2.6; SSP2)	
Average number of internal climate migrants by 2050 (millions)	5.9		4.3		4.9		4.2	
Min. (left) and max. (right) (millions)	4.1	7.6	3.5	5.1	3.2	6.7	2.9	5.5
Internal climate migrants as % of pop.	6.4		5.5		5.4		5.4	
Min. (left) and max. (right) (%)	4.5	8.3	4.5	6.6	3.5	7.3	3.8	7.0

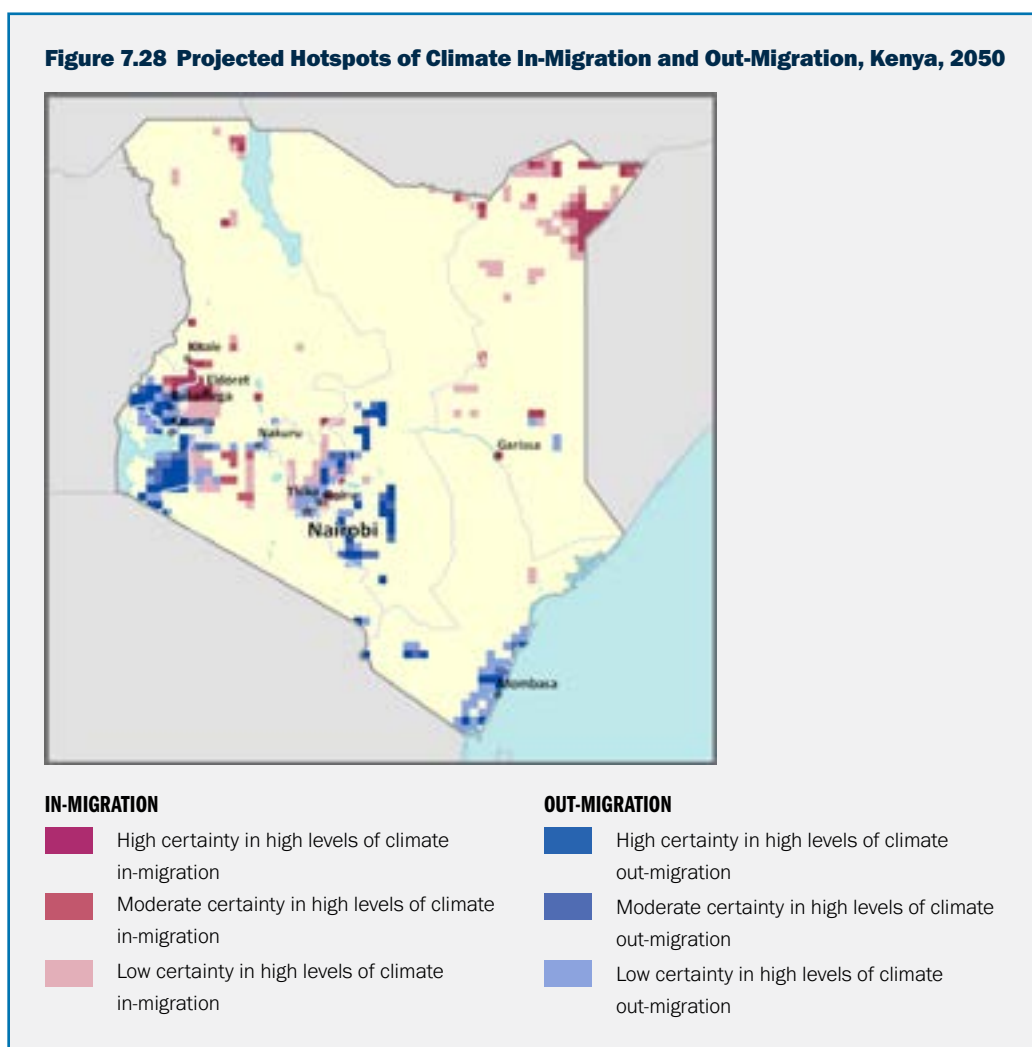
Figure 7.27, displays the projected number of migrants compared to the number of other internal migrants (i.e., those who migrate because of development factors). By 2050, internal climate migrants could largely surpass the number of other internal migrants in the pessimistic scenario, and to lesser extent in the more climate-friendly scenario. In contrast, the number of climate migrants is close but lower to the number of other migrants in the more inclusive and optimistic scenarios. This suggests that climate factors could be relevant factors in future internal mobility.



### Internal Climate Migration Hotspots

Figure 7.28 displays hotspots of climate in- and out-migration by 2050, and figure 7.29, panels a and b, shows the hotspots in 2030 and 2040. Water availability will have a strong impact on migration, and because the country will largely see increases in water availability (if the projections come true), it is the relative degrees of increase and not the differences between areas that will see increases or declines in water availability (as in many other countries) and that will exert the greatest influence on future population distribution. The increases are highest in the Rift Valley and in the northeast.

The Lake Victoria Basin area could see one band of climate out-migration, including Kisumu (driven largely by a few model runs with declining water availability and crop productivity), followed by a band of climate in-migration, including Eldoret (because of increasing water availability and crop production), which extends to other parts of the Rift Valley. Outside the Lake Victoria Basin, there could be climate in-migration in the northeast corner by the border with Somalia and Ethiopia. Regions of high levels of climate out-migration are in the center of the country, including Nairobi, and in the southeastern coast, including Mombasa. These areas correspond to areas of positive and negative changes in water availability in the ISIMIP results (figure 7.22), respectively. However, as in the rest of Sub-Saharan Africa, urbanization rates are likely to remain high, and these model results indicate only a slight decrease in the rates of population growth in Nairobi and Mombasa linked to climate factors.



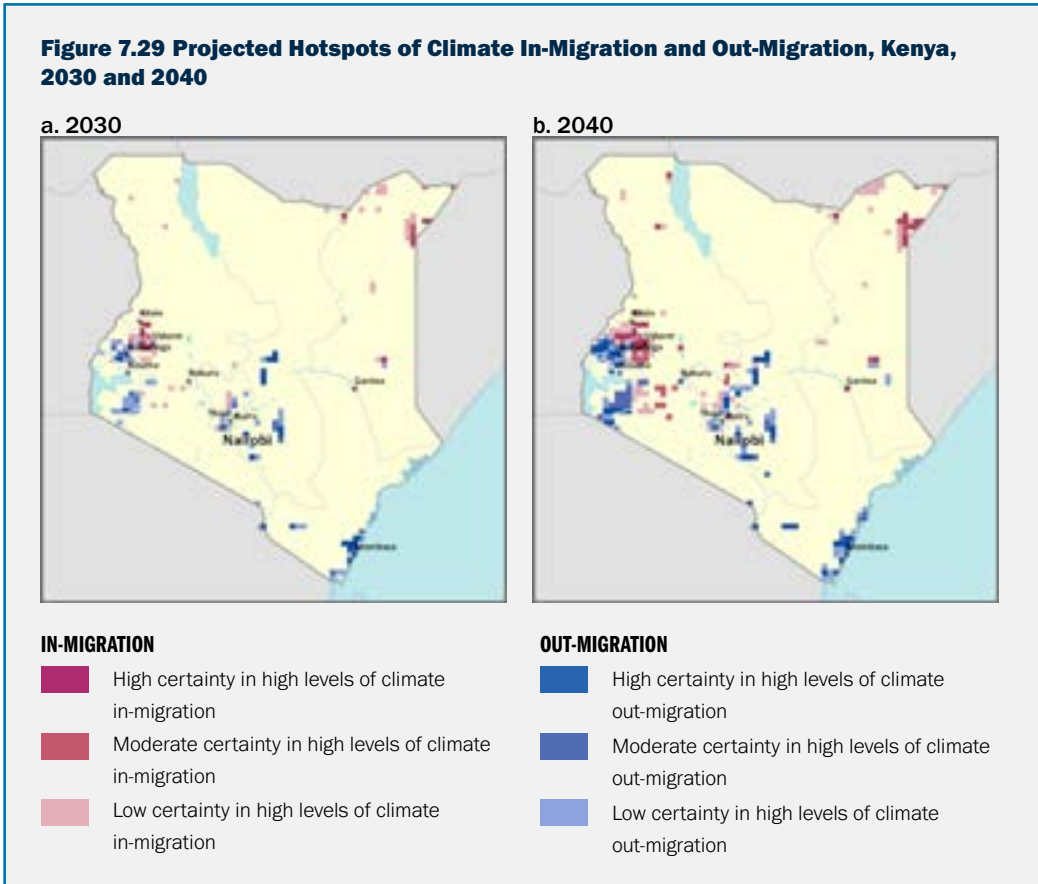
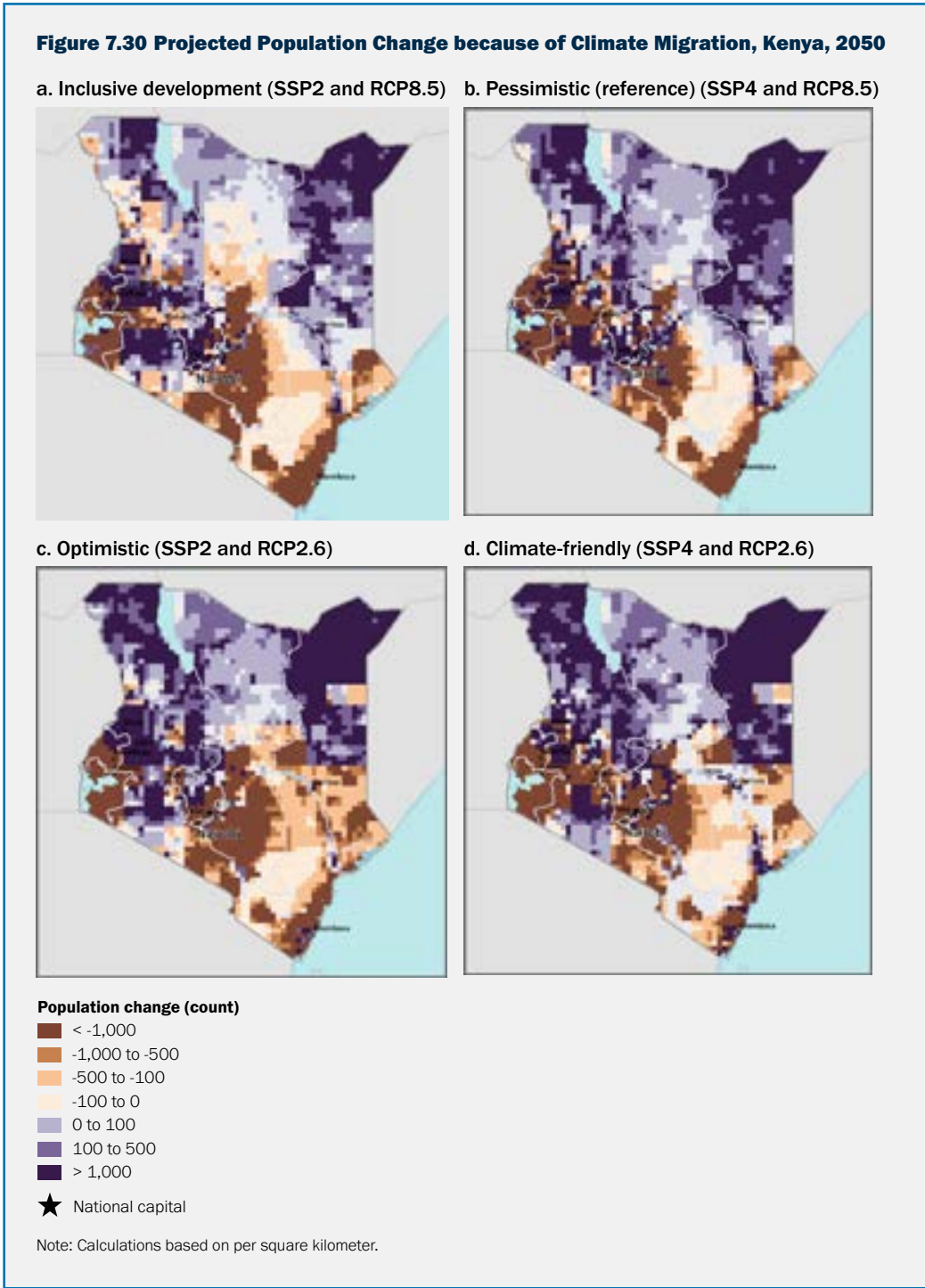
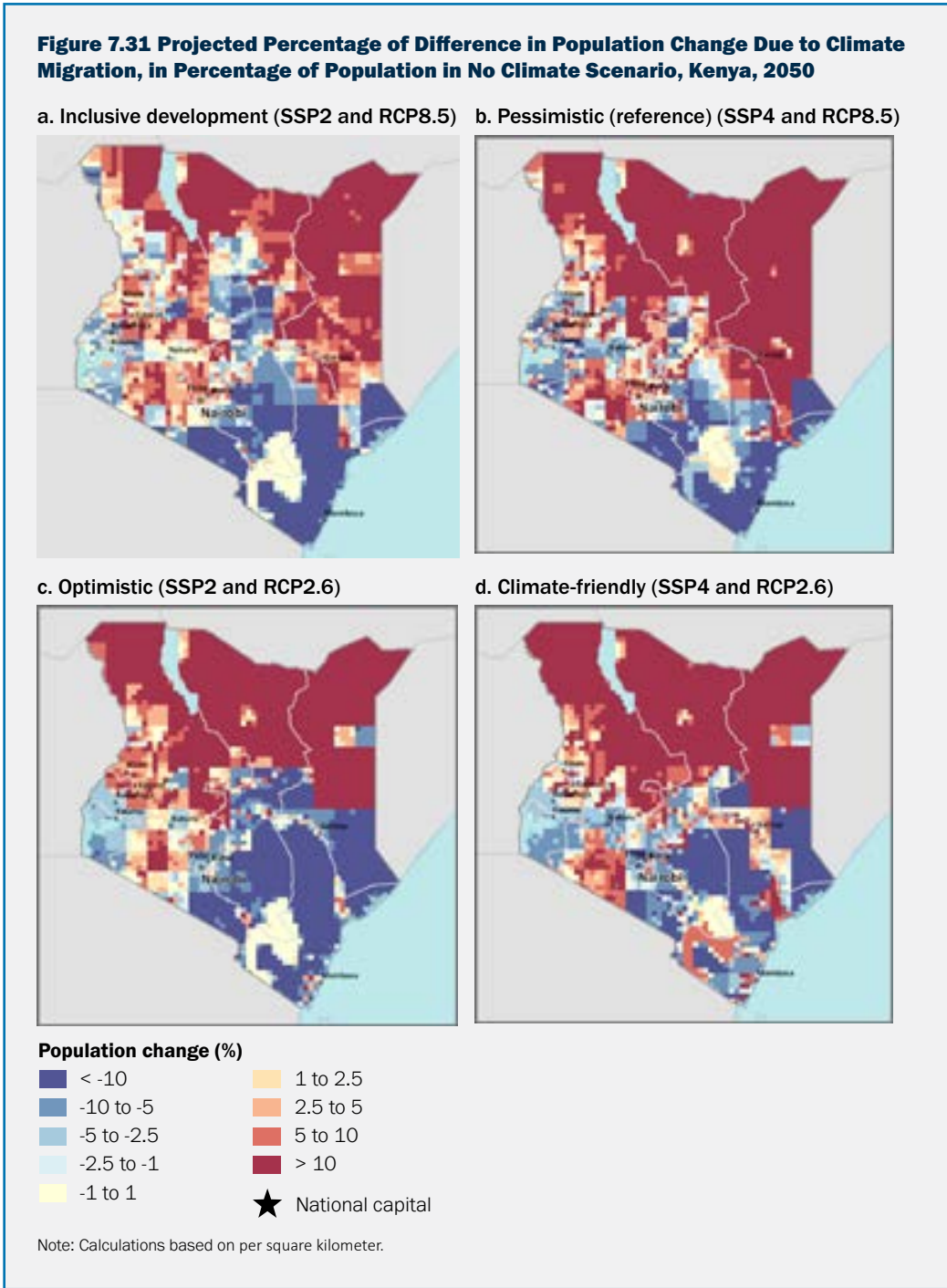


Figure 7.30, panels a–d, displays the population change per square kilometer because of climate migration by 2050 (in essence the difference between the climate and no climate impact scenarios). Areas of negative differences do not necessarily mean that the population will decline in these areas, but because of climate impacts, growth may be slower than it otherwise would have been. Overall, there is agreement across the four scenarios, although the areas with the highest positive and negative differences seem larger in the optimistic and climate-friendly scenarios. These patterns reflect the effects of changes in water availability, the driver with the largest coefficient in urban and rural areas (Table 3.7). For rural areas, changes in crop production or net primary productivity are also relevant.

**Climate in-migration could emerge in response to positive crop and precipitation trends in Eldoret, and due to precipitation increases in the northeast. Coastal areas in Mombasa could witness climate out-migration as early as 2030 due to rising sea levels.**



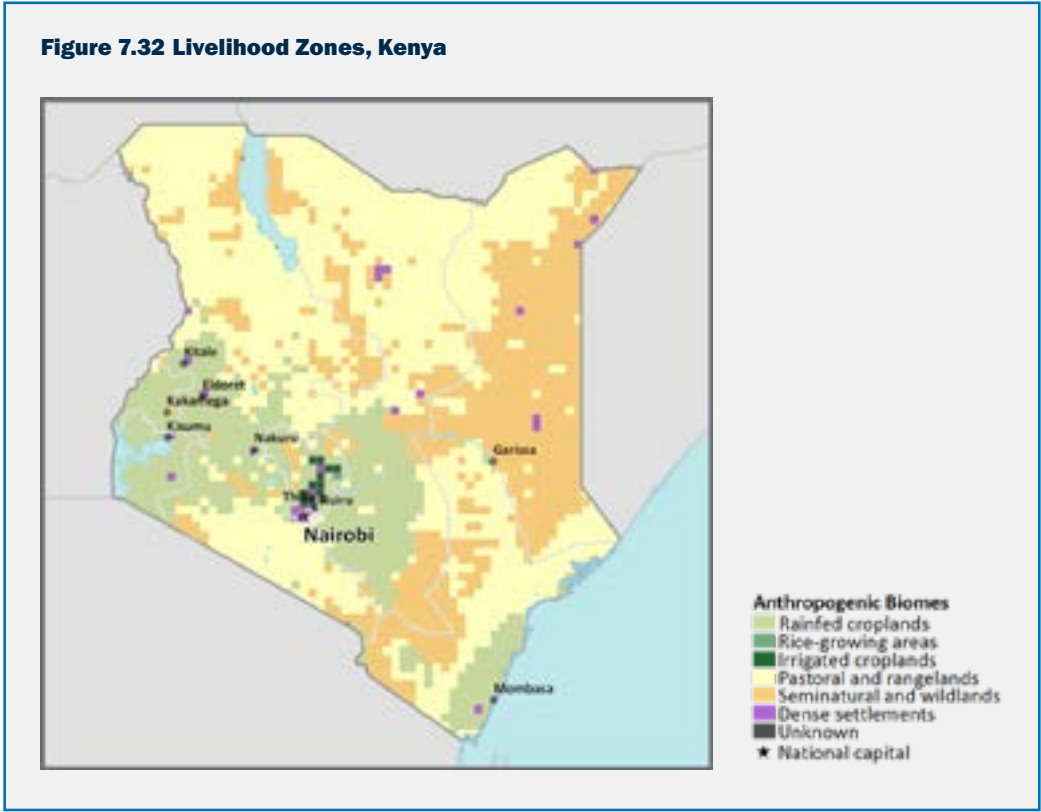
**Figure 7.31** panels a–d, displays climate migrants as a percentage of the population under the no climate impact (SSP-only) scenario in each grid cell, showing small differences across the scenarios. This tends to highlight changes in less densely settled areas. Large positive differences are concentrated in the north and east, and negative differences concentrate in the south and east. Areas of large positive differences (over 10 percent) are smaller in the inclusive-development scenario, and areas of large negative differences are smaller in the pessimistic scenario.



*Climate Migration by Livelihoods*

Figure 7.32 shows the distribution of livelihood zones in Kenya. A large part of the country is covered by pastoral and rangelands, while seminatural and wildlands abound on the east and southeast. Rainfed areas cover the highlands, including the Lake Victoria Basin area, and a narrow coastal band in the southeast. A spot of irrigated croplands is visible in the central highlands, and dense settlements are found, not surprisingly, in urban areas.

Table 7.7 provides the net migration by scenario, livelihood zone, and decade. Irrigated and rainfed croplands consistently display negative values, and pastoral and rangelands, seminatural, and wildlands have positive values. Dense settlements show mixed results: positive in the more-inclusive development and pessimistic scenarios (based on RCP8.5) and negative in the more climate-friendly and optimistic scenarios (based on RCP2.6).



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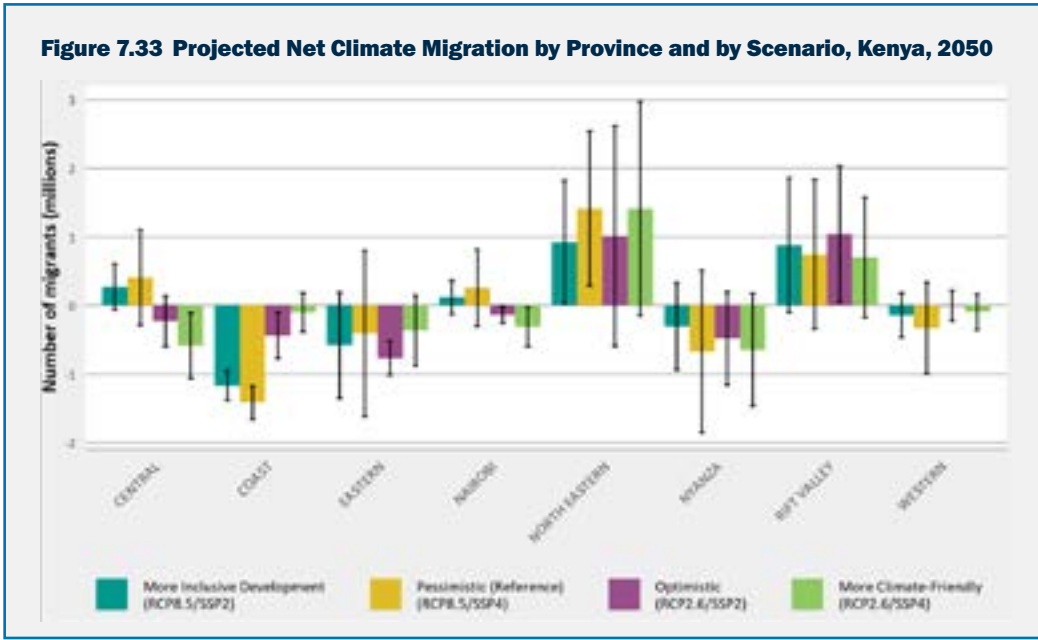


**Table 7.7 Projected Net Migration by Scenario, Livelihood Zone, and Decade, Kenya**

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)
<b>2030</b>				
Dense settlements	-131,053	79,273	-60,501	91,244
Irrigated croplands	-68,061	-4,150	-24,774	-32,579
Pastoral and rangelands	843,293	402,999	616,617	654,418
Rainfed croplands	-1,110,434	-926,212	-873,508	-1,260,315
Rice-growing areas	-4,172	-4,210	-2,885	-5,842
Seminatural and wildlands	471,161	453,589	346,169	553,969
Unknown	-734	-1,289	-1,118	-895
<b>2040</b>				
Dense settlements	-155,166	35,533	-67,877	2,946
Irrigated croplands	-93,477	-14,066	-37,356	-49,630
Pastoral and rangelands	1,142,908	526,006	808,324	815,211
Rainfed croplands	-1,503,976	-1,042,121	-1,114,681	-1,417,030
Rice-growing areas	-6,177	-6,823	-4,991	-8,095
Seminatural and wildlands	616,754	503,290	417,845	657,891
Unknown	-866	-1,819	-1,264	-1,292
<b>2050</b>				
Dense settlements	-382,165	273,856	982	
Irrigated croplands	-169,872	30,954	-94,314	59,441
Pastoral and rangelands	1,492,280	678,924	1,045,237	1,257,369
Rainfed croplands	-1,806,709	-1,431,352	-1,346,711	-2,544,843
Rice-growing areas	-8,825	-6,683	-9,449	-6,447
Seminatural and wildlands	875,370	573,768	568,330	952,728
Unknown	-79	-2,375	-1,363	-2,682

*Climate Migration by Province*

**Figure 7.33 and table 7.8 display net migration by province to 2050.** Coast, Eastern, Nyanza, and Western (these last two within the Lake Victoria Basin) show negative balances for climate migration, the Rift Valley and North Eastern display positive balances, and results are mixed for Central and Nairobi. Confidence intervals are very large in some of the provinces. However, North Eastern and Rift Valley could gain population because of increased water availability, and the Coast and Eastern provinces could see climate out-migration because of crop production declines in both cases, combined with sea level rise and declines in water availability under three model runs in Coast. Median age has a negative coefficient in urban areas of the Lake Victoria Basin countries, which means that high median ages in Nairobi and Mombasa reduce the attractiveness of these cities to climate migrants, reinforcing the climate factors with Mombasa, and potentially offsetting the impact of higher projected water availability in the capital.



**Table 7.8 Projected Net Migration by Scenario and Province, Kenya, 2050**

Province	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Central	-589,342	271,044	-228,013	406,246
Coast	-101,281	-1,168,180	-438,531	-1,412,859
Eastern	-365,560	-582,365	-767,365	-406,982
Nairobi	-312,107	117,047	-134,258	256,678
North Eastern	1,409,504	926,120	1,013,460	1,413,276
Nyanza	-648,119	-301,885	-483,331	-674,971
Rift Valley	700,346	879,743	1,040,257	746,637
Western	-93,441	-141,524	-2,219	-328,026

## 7.3 RWANDA

### 7.3.1 Population and Development Context

Classified as an LIC, Rwanda's GDP has grown steadily over the last 20 years, going from US\$1.7 billion in 2000 to \$9.5 billion in 2018 (dollars), with an average annual GDP growth of 7.8 percent. During the same period, the GDP per capita increased from US\$219 to US\$773 (in current dollars).<sup>63</sup> Public investment has been the main driver of economic growth (World Bank 2020a). Despite the improvement in macroeconomic indicators, poverty is still quite high in the country (in 2016, 55 percent of the population lived on less than US\$1.90 a day at 2011 international prices) (table 7.9). Rwanda is a rural country: 62 percent of the employed population works in the agricultural sector, a large proportion of them as subsistence farmers (NISR 2020). Transportation is a critical issue for the development of the country's economy.

63. See the World Bank Development Indicators (WDI) database, <https://datacatalog.worldbank.org/dataset/world-development-indicators>

**Table 7.9 Development Indicators for Rwanda**

Population	
Population (thousands) (2018)	12,301.9
Annual population growth (%) (2018)	2.6
Population in 2050 under SSP2 (thousands)	22,953.4
Population in 2050 under SSP4 (thousands)	26,032.6
Urban share of population (%) (2018)	17.2
Employment in agriculture (% of total employment) (2019)	62.4
GDP	
GDP (current US\$ billions) (2018)	9.5
Annual GDP growth (%) (2018)	8.6
GDP per capita (current US\$) (2018)	772.9
Value added of agriculture (% GDP) (2018)	29
Poverty	
Poverty headcount ratio at \$1.90 a day (2011 PPP) (% of population) (2016)	55.5
Climate and disaster risk indexes	
ND-GAIN Index	
Rank (2017)	114
Score (2017)	42.6

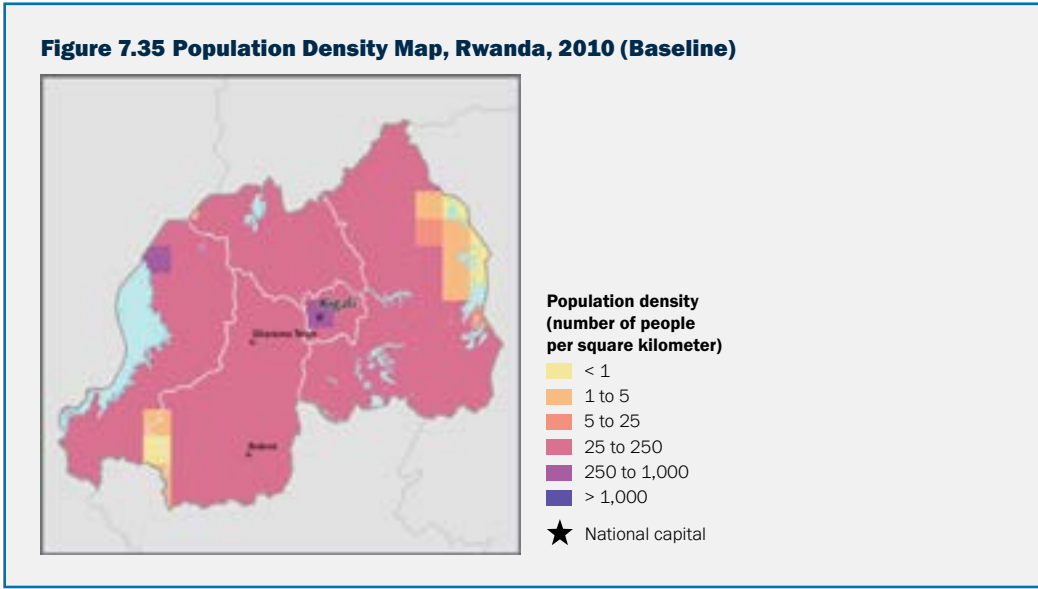
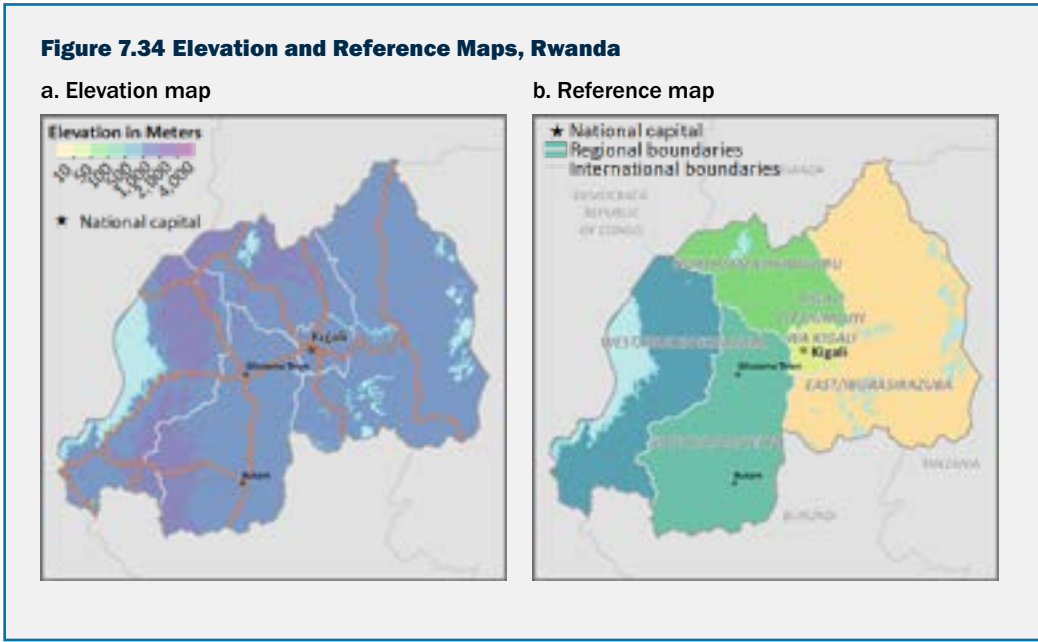
Source: WDI database<sup>64</sup>

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. For more information on ND-GAIN, see: <https://gain.nd.edu/>

**Rwanda's population was 12.3 million in 2018, and it is projected to reach 23 million to 26 million by 2050 (SSP2 and SSP4, respectively).** Annual population growth is 2.6 percent, second lowest after Kenya for the Lake Victoria Basin countries, and the fertility rate is still high (average 4.1 children per woman in 2015–20) but declining. Rwanda's population is young: half of the population was 20 years old or younger in 2020, and life expectancy was 68.4 years in 2015–20.

**Overall, the population density is high, but its distribution is not homogeneous (figure 7.34 and 7.35).** Densities are higher in Kigali City and in areas of the Western Province near the border with the Democratic Republic of Congo, and they are lower on the east and southwest, where national parks are located. These parks are major tourist destinations and contribute substantially to the national economy (LVBC 2017 and GRID-Arendal 2017).

64. See the World Bank Development Indicators (WDI) database, <https://datacatalog.worldbank.org/dataset/world-development-indicators>



Rwanda is a very rural country in which the proportion of urban population was about 17 percent in 2018.<sup>65</sup> The largest city is the capital, Kigali, with 1.1 million inhabitants in 2020.<sup>66</sup> The second largest urban area is Gisanyi in the Western Province, with a population of 137,000 in 2012.<sup>67</sup> The expansion of urban areas (e.g., Kigali) is often at the expense of agriculture and forestry land (LVBC and GRID-Arendal 2017).

65. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.  
 66. World Urbanization Prospects, 2018 (database), UNDESA, New York, <https://population.un.org/wup>.  
 67. City Population available at <http://www.citypopulation.de>.

### 7.3.2 Historical and Current Migration Patterns

**Internal migration includes rural-urban and rural-rural flows, which could be inter- and intraprovince.** Kigali City and the East Province are the only areas with positive migration balance (net migration) (table 7.10). In 2019, Rwanda's migrant population (including internal and international migrants) represented about 12 percent of the total population or 1.5 million people, most of them internal migrants (1.4 million) most of working age (16 years old and older) (NISR 2020). In addition to long-term migration, internal mobility includes high levels of temporary and circular migration (Blumenstock 2012).

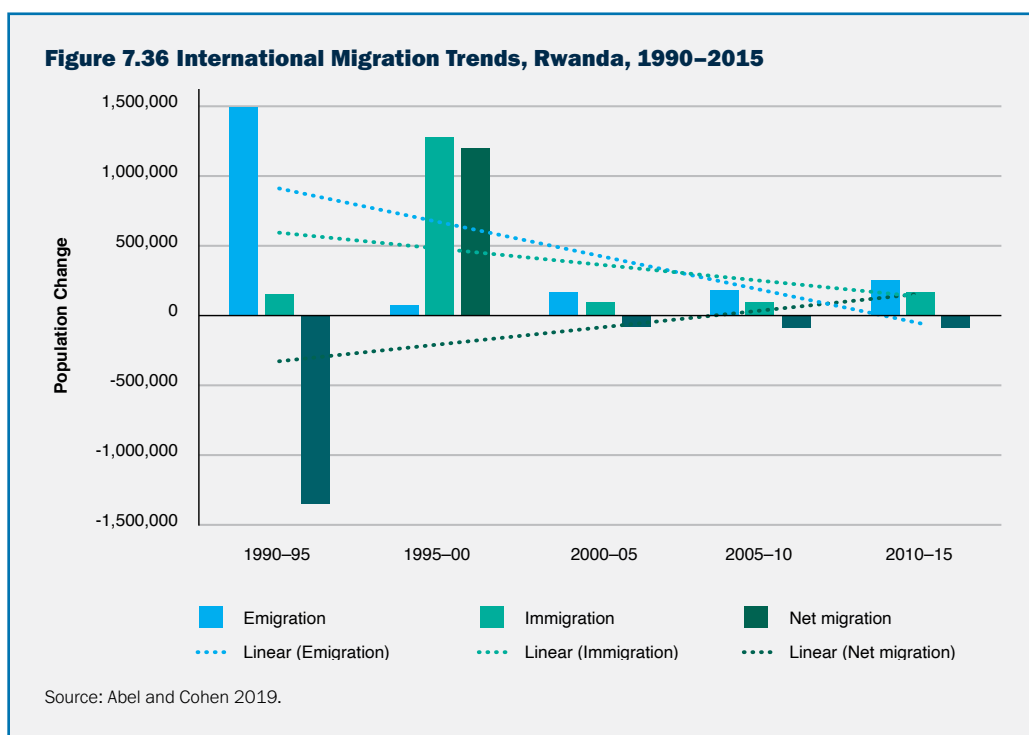
**Table 7.10 Province of Last Move and Current Residence of Internal Migrants of Working Age (Last Five Years), Rwanda, 2019**

		Province of current residence					Total
		Kigali	South	West	North	East	
Province of last move	Kigali	137,756	69,355	25,899	25,447	62,288	320,745
	South	125,599	77,108	15,214	8,167	30,049	256,138
	West	64,515	16,493	56,595	13,666	15,780	167,048
	North	40,287	4,892	8,084	27,285	39,493	120,042
	East	74,213	18,690	14,378	12,592	69,326	189,200
	Total	442,370	186,539	120,171	87,158	216,936	1,053,174

Source: NISR 2020.

Note: About one third of the migrants moved within the same province.

**International migration patterns (figure 7.36) show a sharp decline during the 2000s and a small increase in the first half of the 2010s, with small negative balances.** Main destinations for emigrants for 2010–15 were the Democratic Republic of Congo, Burundi, Uganda, the Republic of Congo, and Angola (Abel and Cohen 2019). Remittances represented a very small fraction of the GDP in 2019 (2.6 percent).



International migration stock in Rwanda represented about 0.8 percent of the total population, which is significantly lower than the world average (4.2 percent), with most migrants arriving from Uganda, Burundi, the Republic of Congo, the Democratic Republic of Congo, and Tanzania. Kigali was the province of destination of the highest number of international migrants, followed by the Southern and Western provinces (NISR 2020, 59).

#### *Conflict Mobility*

Approximately 800,000 people were killed during the genocide between April and July 1994, most of whom were Tutsi and well-educated Hutu (De Walque and Verwimp 2010). When the Rwandan Patriotic Front forces gained control of Kigali and then the remainder of the country, some 2 million Hutu fled to surrounding countries (UNHCR 2000). The impact of both the genocide and refugee flows dramatically affected the demographic profile of the country, and this has had reverberations for at least a decade (De Walque and Verwimp 2010). To this day, an estimated 270,000 Rwandan refugees remain scattered in about a dozen major African refugee host countries, including Angola, Burundi, Cameroon, the Democratic Republic of Congo, Kenya, Malawi, the Republic of Congo, South Africa, Uganda, Zambia, and Zimbabwe (Zenda 2019).

#### *Environmental Migration*

Rwanda's dependence on agriculture (in terms of GDP, employment, and subsistence farming) makes the country highly susceptible to the impacts of climate change (NCEA 2015). Nevertheless, the country's small size means that internal migration is modest, and mostly temporary. Blumenstock (2012), using cell phone records of 1.5 million Rwandans over four years, notes that, in accordance with a recent government survey, there are relatively low levels of permanent migration in Rwanda, though there are high levels of temporary and circular migration. The implication is that migration may be seasonal, associated with periods of low agricultural demand. Rwanda's relatively benign climate and trend of increasing rainfall have meant that the worst impacts of climate variability and change have largely not affected livelihoods (Mikova, Makupa, and Kayumba 2015), apart from flooding, which is exacerbated by the country's steep topography.

### 7.3.3 Climate Trends and Population Projections

#### *Climate Projections*

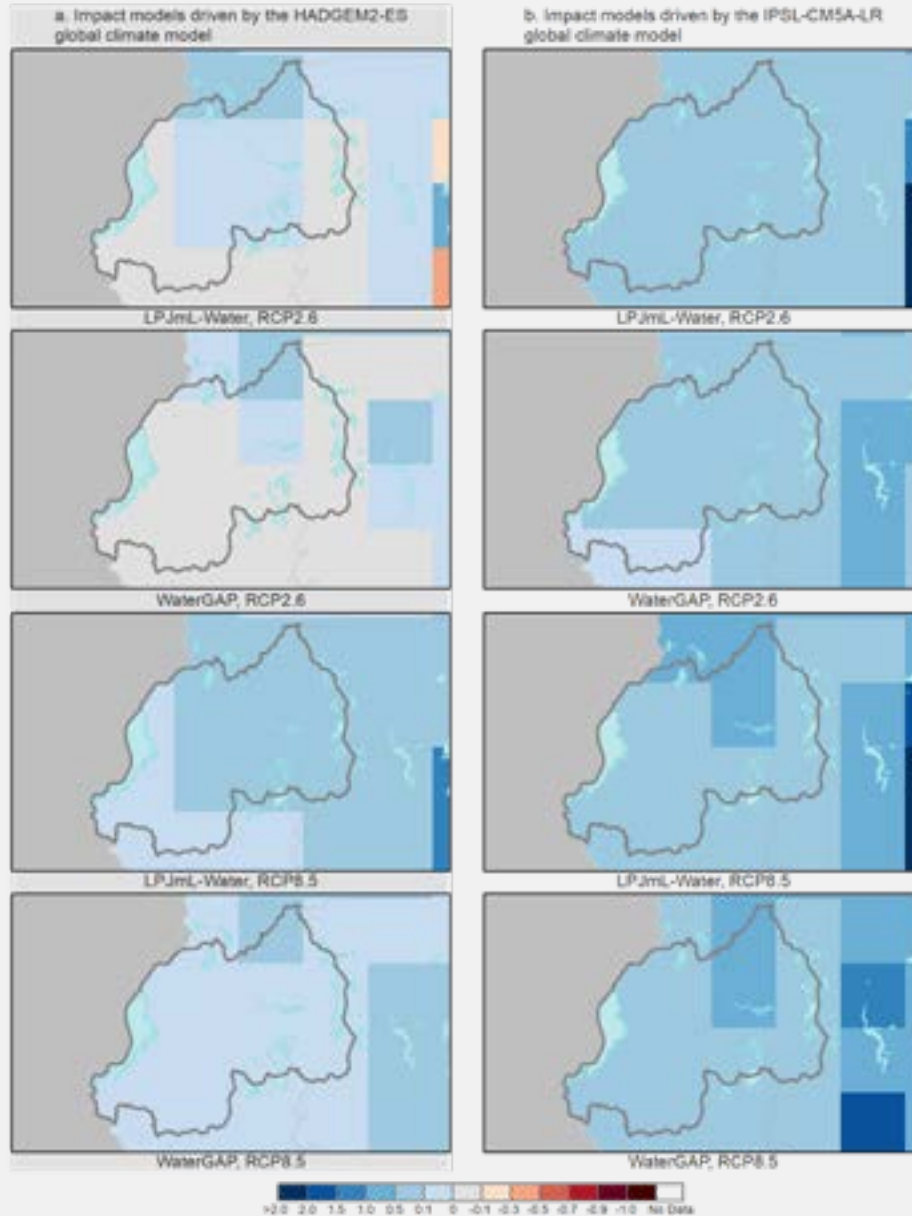
Rwanda is a landlocked country characterized by a mountainous zone 950–4,500 meters above sea level in the northwest, plateaus in the eastern central region, and lowlands in the southwest (USAID 2019). The long rainy season typically lasts from March to May, and the short rainy season from mid-September to mid-December. Temperatures are fairly moderate, with colder and wetter conditions in the northwest highlands (15°C to 17°C) and central plateau (17.5°C to 19°C), in contrast to the warmer and dryer eastern plateau (20°C to 21°C) and southwest lowlands (23°C to 24°C).

Average annual rainfall is contingent on the ENSO, with higher average precipitation coinciding with El Niño and lower average precipitation with La Niña. Weather patterns are therefore variable from year to year, with a propensity toward extreme conditions. High rainfall during some periods has led to many landslides, flooding, and erosion (MIDIMAR 2015). Severe drought has contributed to crop failure and famine. The highlands are particularly susceptible to flooding from heavy rainfalls. Periodic droughts and extensive dry periods are more common in the eastern lowlands.

**Studies of temperature changes over the past decades indicate that the average annual temperature is increasing throughout the country.** Between 1971 and 2010, mean temperature rose by around 0.35°C per decade (Araujo et al. 2016). This trend is expected to continue, with current estimates suggesting an average maximum temperature increase between 1.3°C and 1.9°C by 2050 and 2.5°C to 3.3°C by 2100 (IPCC 2014). The number of abnormally hot days is expected to increase, as are hot nights. While rainfall varies, average annual rainfall could see a 20 percent increase from 1970 through 2050. The clearest change in precipitation patterns will be a greater amount of severe rain events. Higher volume of precipitation and large storms are likely to exacerbate flood, landslides, and associated health risks.

**Panels of figures 7.37–7.39 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. Note that the coefficient for water availability in rural areas is around 2.8 times higher than that of crop production and 4.7 times that of NPP, and 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). Figure 7.37 shows that water availability is projected to increase in most regions of Rwanda, with higher increases under the IPSL climate model. There are slight declines in the southeast under RCP2.6 for the HADGEM2-ES model. Crop production changes are essentially mirror images of one another, with the LPJmL model showing substantial increases, especially in the west (Figure 7.38). The GEPIC model shows mostly slight to moderate declines of around 10 percent to 20 percent. NPP projections are provided for information purposes only, since they do not contribute to the modeling of the future population distribution.

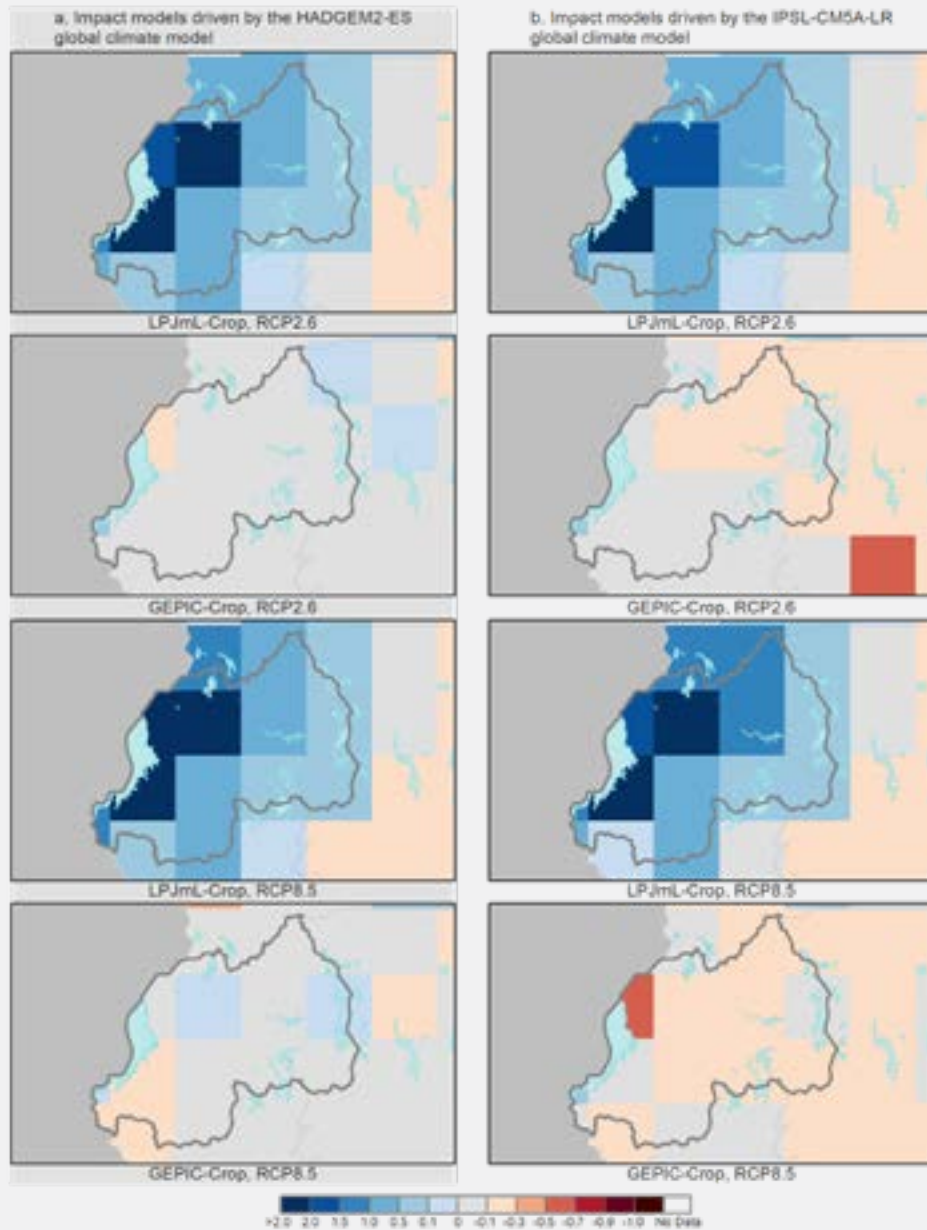
**Figure 7.37 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Rwanda, 2010–50**



Note: Data calculated against 1970–2010 baseline for water availability, from LPJmL/water and WaterGap, forced with the HadGEM2-ES climate model (panel a) and IPSL-CM5A (panel b) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline, and tan to red areas indicate drying.

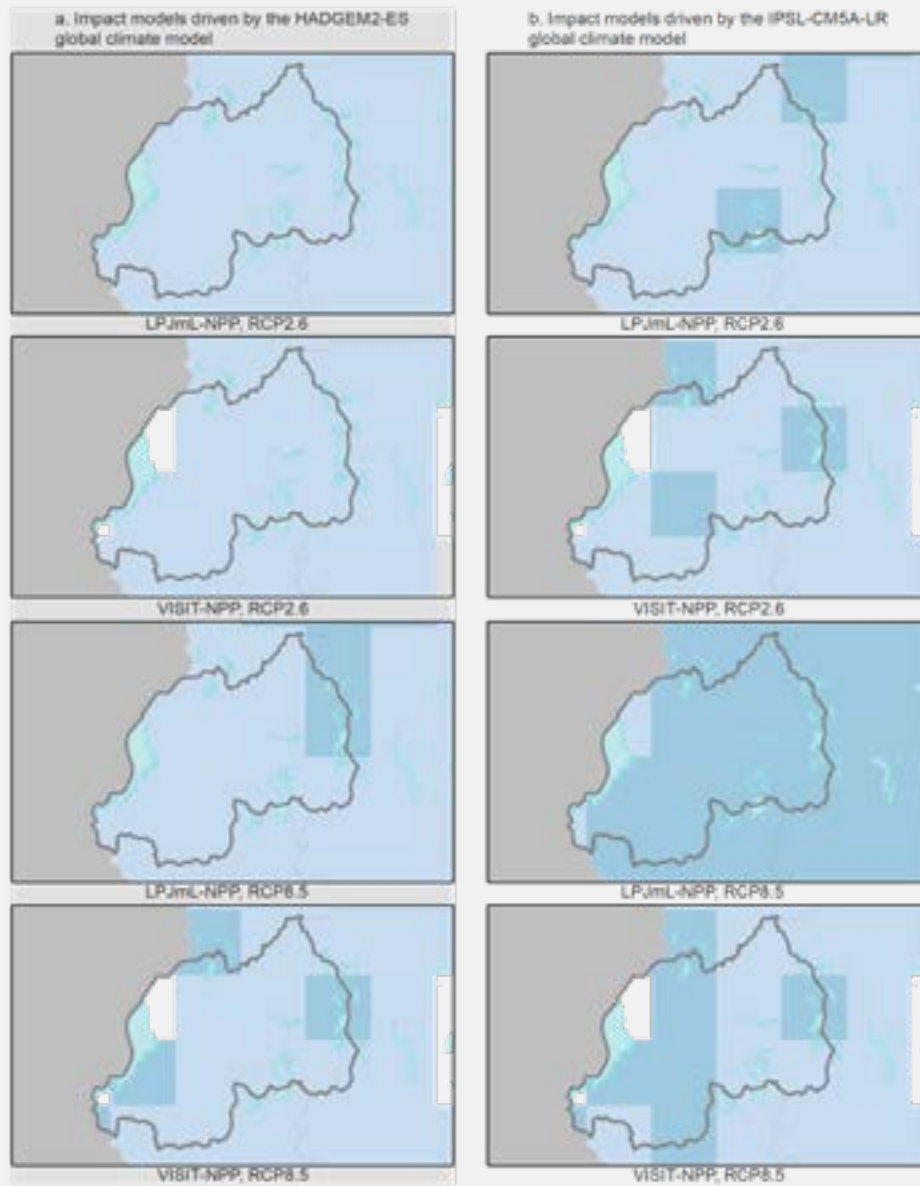


**Figure 7.38 SIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Rwanda, 2010–50**



Note: Data calculated against 1970–2010 baseline for crop production. 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.

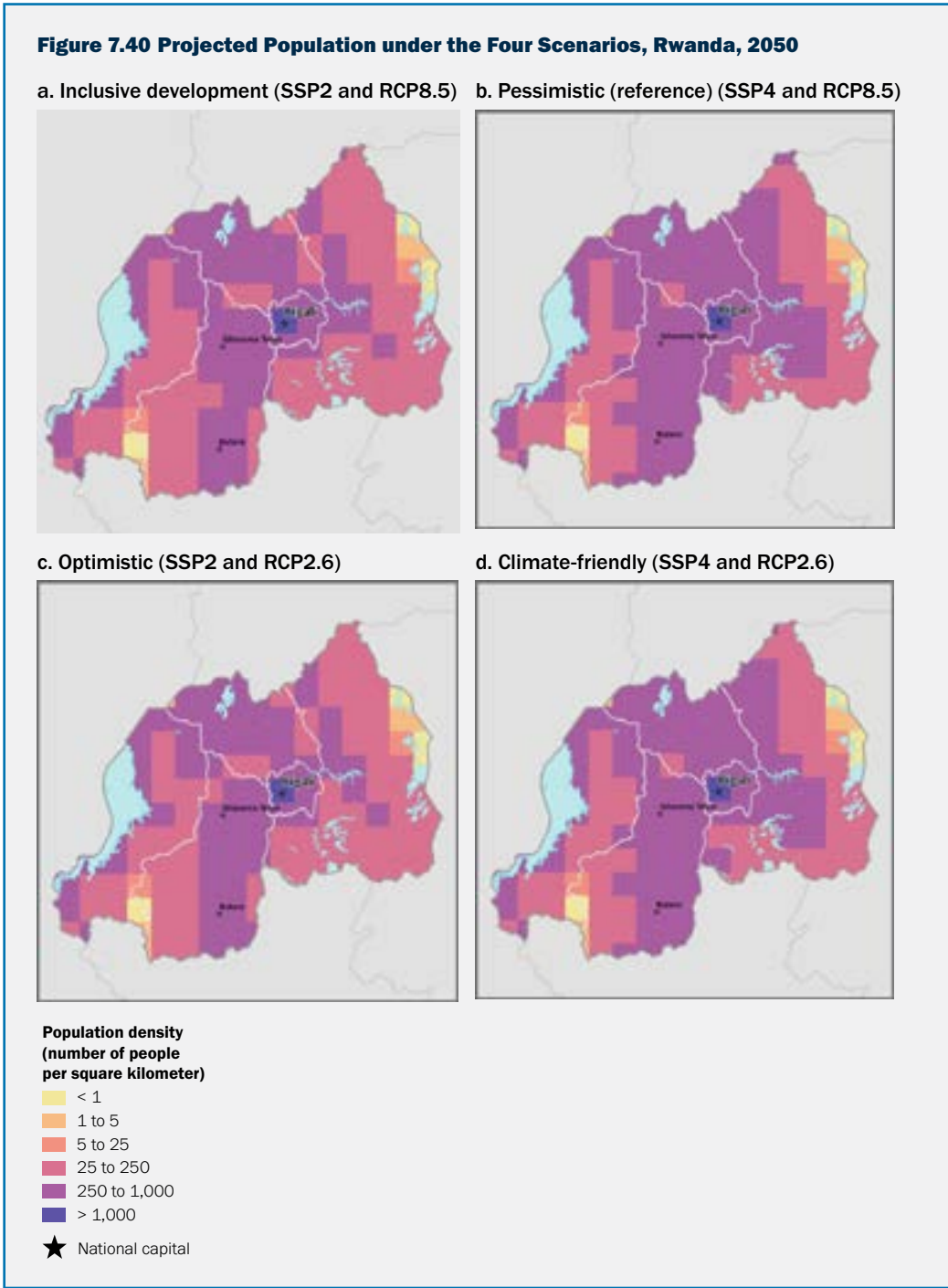
**Figure 7.39 ISIMIP Average Index Values against 1970–2010 Baseline for NPP, Rwanda, 2010–50**



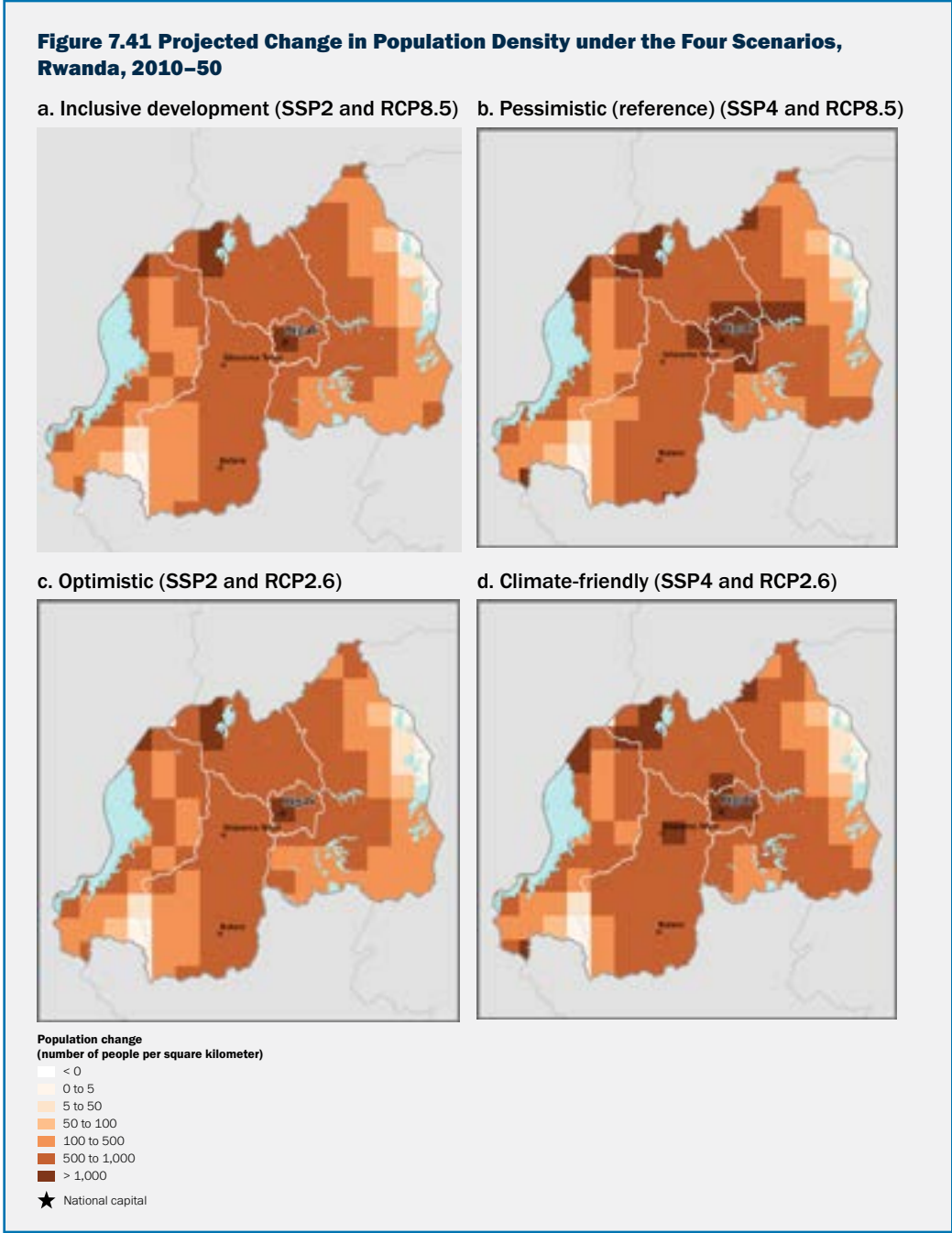
Note: Data calculated against 1970–2010 baseline for NPP. Blue areas indicate increased NPP relative to the historical baseline, and gray to tan to red areas indicate decreased NPP. NPP is only used to gap-fill crop production, and therefore is not used to model future population distribution in Rwanda. NPP = net primary productivity.

### Projected Changes in Population

**Figure 7.40, panels a–d, displays Rwanda’s projected population to 2050 for the four scenarios.** Compared with population density in 2010 (figure 7.40), there is an important increase in the areas of high density (250 people per square kilometers or more) in all the scenarios (slightly larger in the pessimistic scenario). The area surrounding Kigali (the national capital) exhibits the highest density. In contrast, the areas of low density (on the northeast and southwest) show little difference with 2010.



**Figure 7.41, panels a–d, displays changes in population density between 2010 and 2050.** The largest projected changes correspond to the Kigali area and the central region of the country, followed by the northwest. They are more pronounced in the pessimistic scenario, although patterns of change are similar across the four scenarios. Areas of no or small change coincide with areas of lower density in the northeast and southwest, where national parks are located.

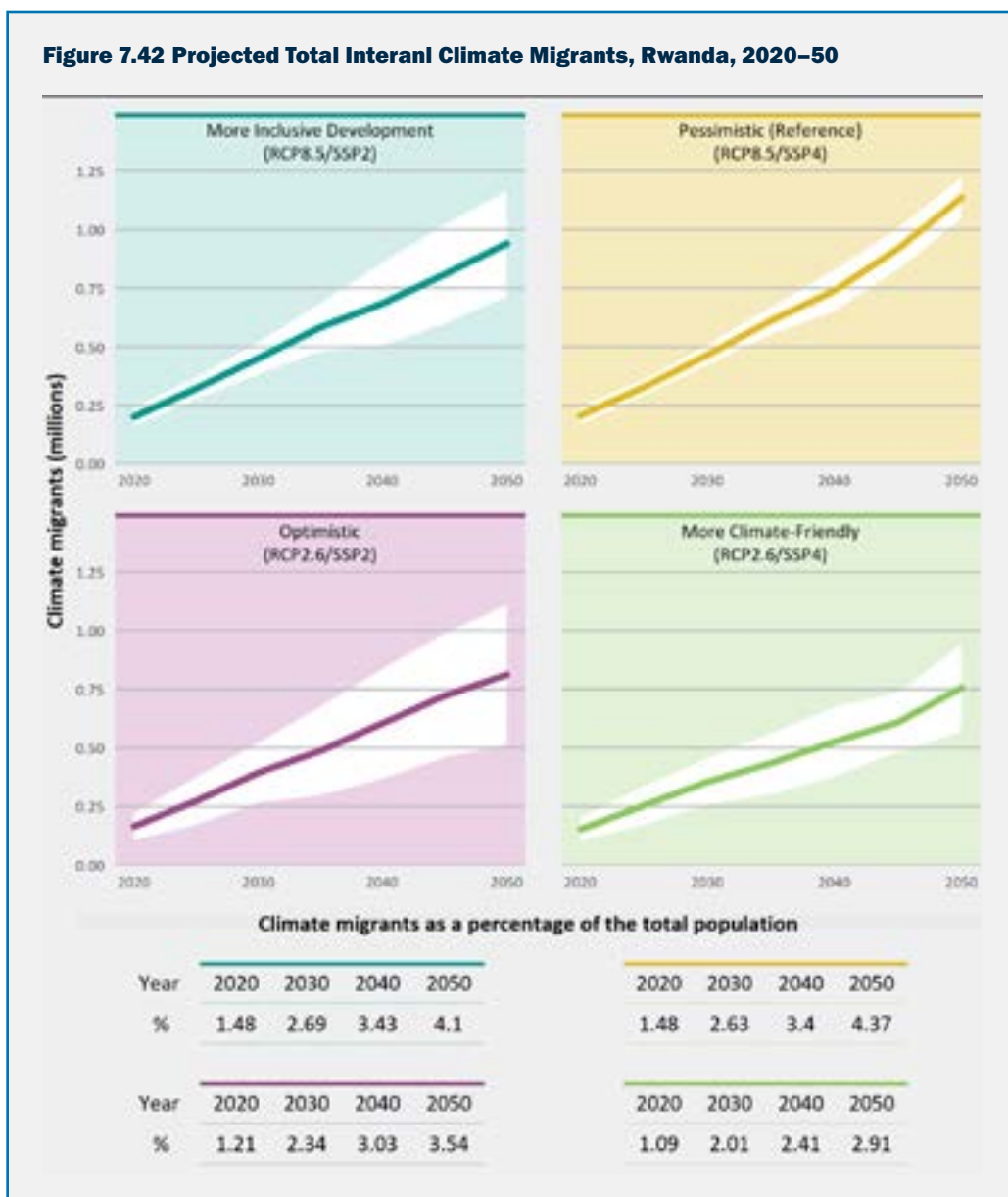


### 7.3.4 Climate Migration Futures and Trends

#### Scale and Trajectory of Internal Climate Migration

Figure 7.42, displays the estimated number of internal climate migrants in Rwanda by scenario and decade from 2020 to 2050. Table 7.11 shows the average, low, and high climate migration levels for 2050. All the scenarios show an upward trend, but the growth appears to be much faster in the pessimistic scenario and the more inclusive development scenario, both based on RCP8.5 (higher emissions). In these scenarios, climate migrants reach the largest numbers (900,000 and 1.15 million, respectively) and represent a higher proportion of the total population by 2050 (4.4 percent and 4.1 percent, respectively). The optimistic scenario and the more climate-friendly scenario present a smaller number of migrants by 2050 (800,000 and 750,000, respectively), and climate migrants represent a smaller proportion of the total population (3.5 percent and 2.9 percent, respectively).

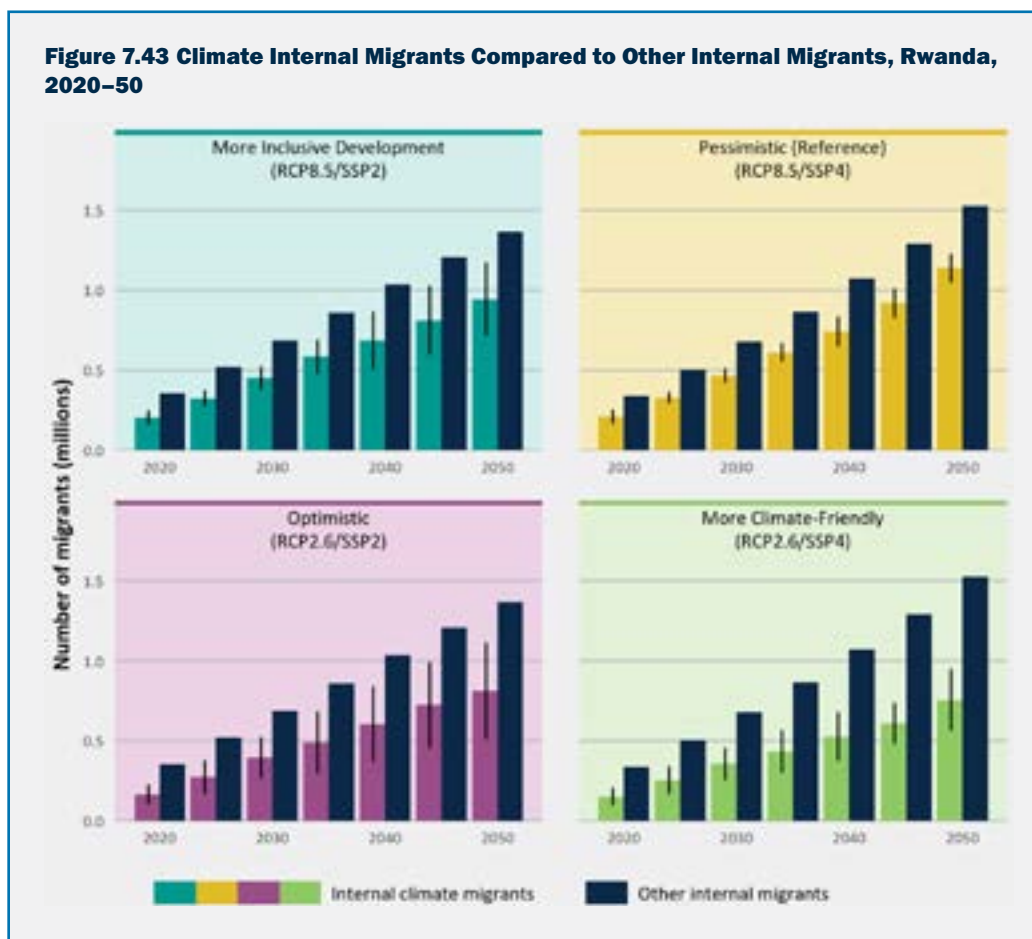
**Figure 7.42 Projected Total Interanl Climate Migrants, Rwanda, 2020–50**



**Table 7.11 Projected Total Climate Migrants by 2050, Rwanda**

Scenario	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 internal climate migrants by 2050 (millions)	1.1		0.9		0.8		0.8	
Min. (left) and max. (right) (millions)	1.1	1.2	0.7	1.2	0.6	0.9	0.5	1.1
Internal climate migrants as % of pop.	4.4		4.1		2.9		3.5	
Min. (left) and max. (right) (%)	4.0	4.7	3.1	5.1	2.2	3.6	2.2	4.8

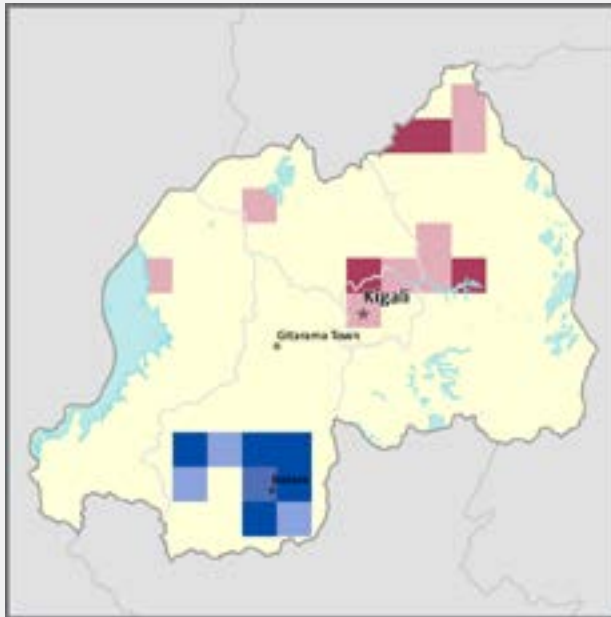
Figure 7.43, compares the number of internal climate and other internal migrants by decade and scenario. Without reaching the number of other migrants in any of the scenarios, the number of climate migrants is closer in the pessimistic scenario followed by the more inclusive development scenario. By 2050, the ratio of climate migrants to other migrants is 0.75 for the pessimistic scenario, but just 0.5 for the more climate-friendly scenario.



#### Internal Climate Migration Hotspots

Figure 7.44 displays the projected hotspots of climate in- and out-migration by 2050, and figure 7.45, panels a and b, shows hotspots for 2030 and 2040. Results for 2050 indicate that high levels of climate out-migration could be concentrated in the south of the country and correspond to areas of slight negative or no changes in water availability in the ISMIP results, which have an out-sized impact on future population distribution. High levels of climate in-migration could be in the central region close to the capital, Kigali, and in the north region by the border with Uganda and Tanzania. These areas show positive relative changes in water availability according to the ISMIP water model results. Crop production does not appear to influence future migration patterns, perhaps because of the varied patterns between LPJmL and GEPIC. This may be reducing the potential for multiple scenarios to coincide (a criteria for hotspot identification).

**Figure 7.44 Projected Hotspots of Climate In-Migration and Out-Migration, Rwanda, 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

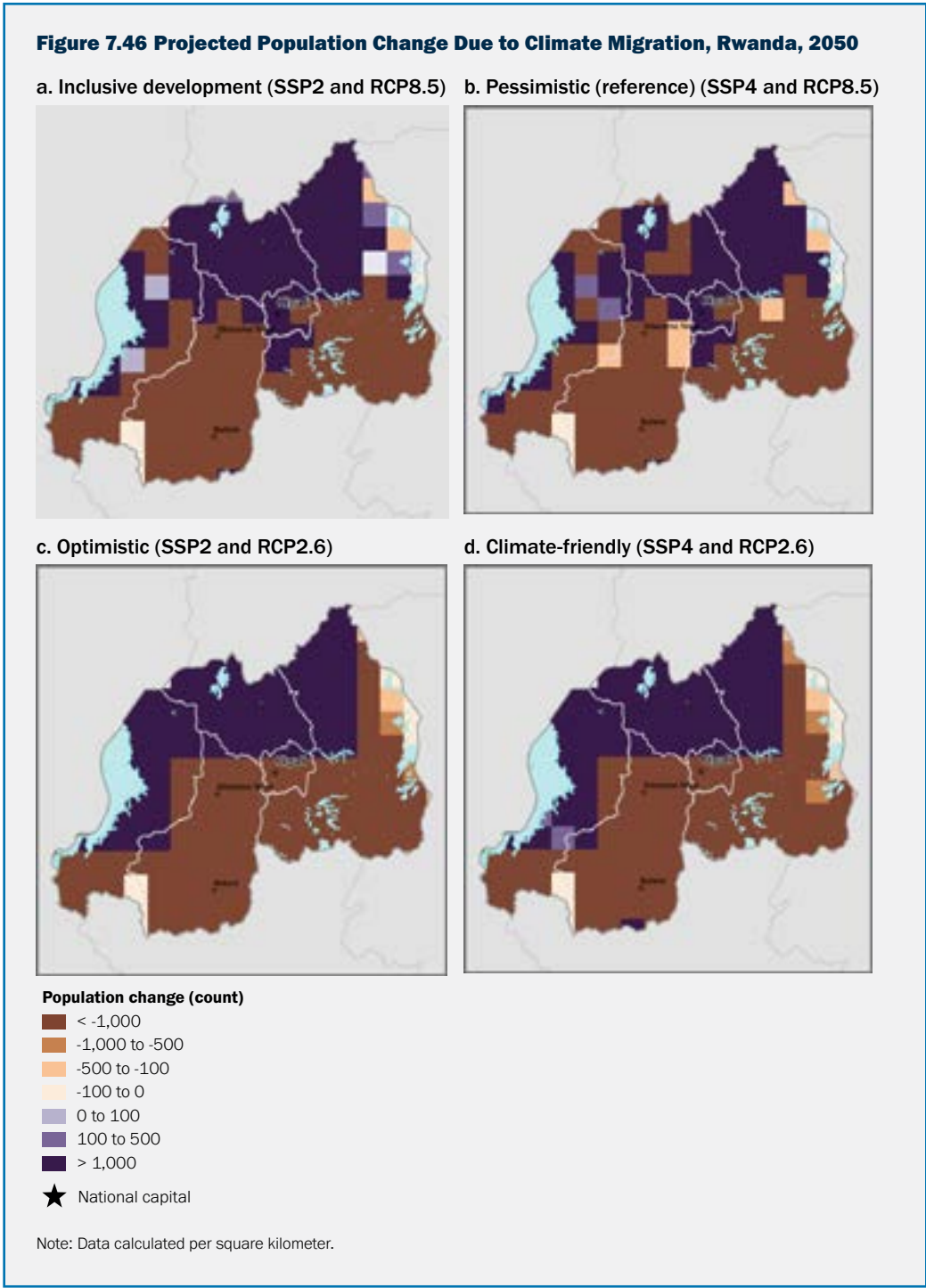
**OUT-MIGRATION**

- 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

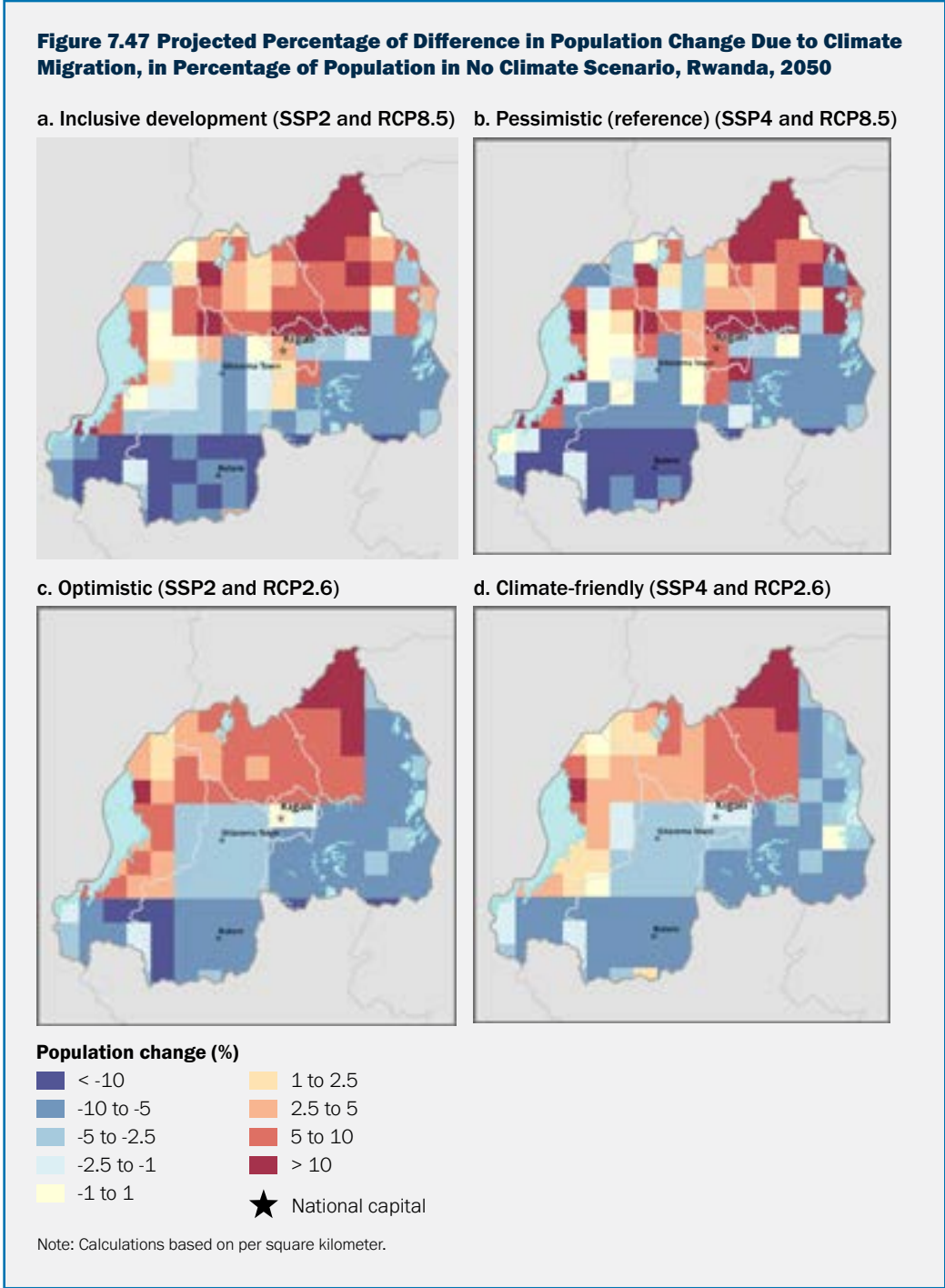
**Proactive action on climate and development could modulate the scale and trajectory of internal climate migration in Rwanda.**







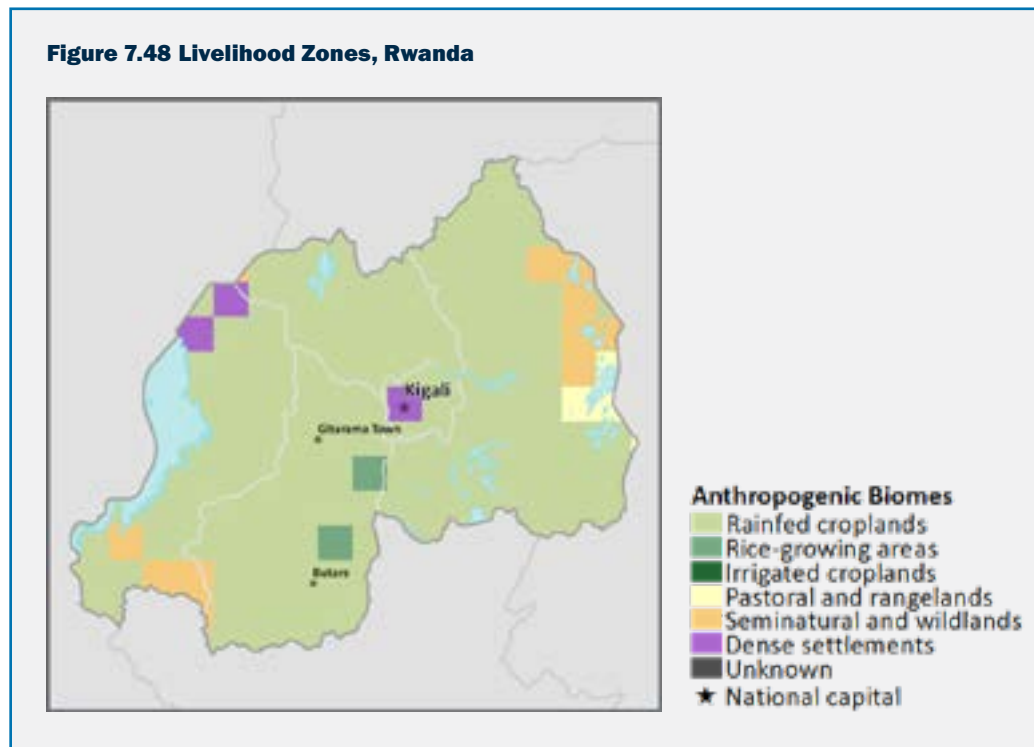
**Figure 7.47, panels a–d, displays climate migrants as a percentage of the population under the no climate impact (SSP-only) scenario in each grid cell.** This tends to highlight changes in less densely settled areas. The distribution of areas of positive and negative percent change are similar across scenarios, but the pessimistic and more inclusive development scenarios (based on RCP8.5) display the largest positive and negative percentages, which also cover a larger area in the north and south of the country.



*Climate Migration by Livelihoods*

**Figure 7.48 displays the distribution of livelihood zones in Rwanda.** Almost all the country is covered by rainfed croplands, which show positive net migration in the optimistic, more climate-friendly, and more inclusive development scenarios, but negative net migration in the pessimistic scenario. Patches of pastoral and rangelands could appear on the northeast and southwest (the location of protected areas), and these zones display negative values in all the scenarios and decades. Spots of dense settlements are visible close to the capital, Kigali, and by Gisenyi, Rubavu, and Mutura in the Western, or Iburengerazuba Province. These spots consistently show positive values across scenarios and decades.

Table 7.12 shows that net climate migration is projected to be generally negative in rice-growing and seminatural and pastoral areas and positive in dense settlements and rainfed areas, except in the pessimistic scenario, in which climate migration out of rainfed areas is high and dense settlements gain far more residents.

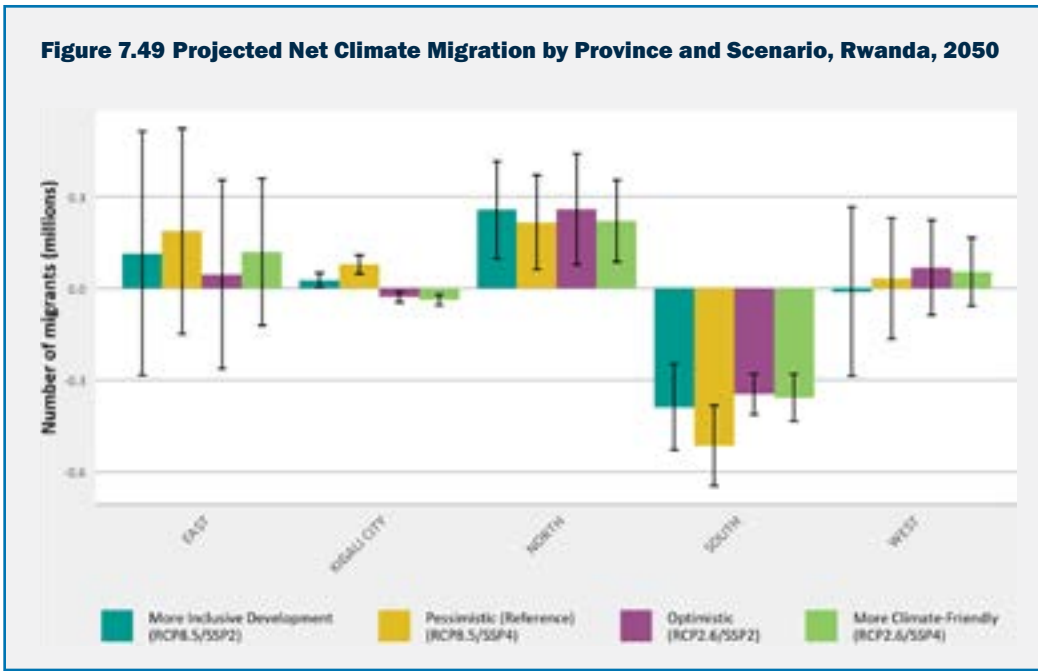


**Table 7.12 Net Climate Migration by Scenario, Livelihood Zone, and Decade, Rwanda**

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)
<b>2030</b>				
Dense settlements	4,746	17,226	5,981	30,144
Pastoral and rangelands	-1,944	-2,729	-2,599	-2,996
Rainfed croplands	18,712	6,928	20,689	-8,251
Rice-growing areas	-12,765	-11,720	-13,613	-13,161
Seminatural and wildlands	-8,837	-9,758	-10,536	-5,802
Unknown	87	54	78	67
<b>2040</b>				
Dense settlements	6,304	28,166	10,585	55,826
Pastoral and rangelands	-2,985	-4,707	-4,600	-5,115
Rainfed croplands	28,480	7,017	31,462	-25,965
Rice-growing areas	-19,806	-17,377	-21,230	-20,185
Seminatural and wildlands	-12,126	-13,185	-16,332	-4,667
Unknown	134	86	115	106
<b>2050</b>				
Dense settlements	8,159	39,593	11,659	90,246
Pastoral and rangelands	-3,989	-7,047	-6,139	-8,429
Rainfed croplands	40,676	6,662	44,486	-50,297
Rice-growing areas	-29,287	-24,758	-28,732	-30,798
Seminatural and wildlands	-15,748	-14,565	-21,425	-885
Unknown	189	115	150	162

### Climate Migration by Province

**Figure 7.49 and table 7.13 display net climate migration by scenario at the province level.** Confidence intervals are too large for the Eastern and Western provinces and make it difficult to draw conclusions. However, results indicate that the Northern Province is a net winner with positive values across scenarios, and the Southern Province displays negative values for all the scenarios by 2050. The driver is water availability increases in the north relative to the south. The city of Kigali shows mixed results: positive net migration in the more inclusive development and pessimistic scenarios, and negative net migration in the optimistic and more climate-friendly scenarios. A high median age (24) and sex ratio (114) in Kigali, when compared to a low median age (16) and sex ratio (87) in the southeast make Kigali, on balance, more attractive from a purely demographic perspective.



**Table 7.13 Projected Net Climate Migration by Scenario and Province, Rwanda, 2050**

Administrative unit	More climate-friendly (RCP2.6/SSP4)	More inclusive development (RCP8.5/SSP2)	Optimistic (RCP2.6/SSP2)	Pessimistic (reference) (RCP8.5/SSP4)
Eastern	119,931	114,670	46,905	187,637
Kigali City	-36,848	26,589	-28,316	78,546
Northern	221,398	257,803	259,785	216,872
Southern	-358,334	-388,895	-346,658	-515,618
Western	53,854	-10,166	68,284	32,563

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## Appendix A

# ISIMIP Data Inputs

The modeling team needed to choose among global climate models (GCMs) and crop, water, net primary productivity (NPP), and flood models. This appendix provides the rationale for the GCMs and models used in this effort.

### CLIMATE MODELS USED IN CROP AND WATER MODELING

Of the more than 30 GCMs used in the Coupled Model Intercomparison Project 5 (CMIP5) (Taylor, Stouffer, and Meehl 2012), five models were used in the ISIMIP Fast Track to drive the crop, ecosystem, and hydrological models. These were selected to 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 five models (McSweeney and Jones 2016; Warszawski et al. 2014). In this study, the climate model ensemble was further reduced to be applied in the population modeling framework. 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), so that at least for these regions a large range of possible future climate changes can be covered with only these two models. Further, both models are being used for producing new impact simulations within the ISIMIP2b project (Frieler et al. 2017), so that the analysis in this report could easily be updated when those new impact simulations become 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, so far 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 is an advance over using purely climate model-based indicators because they represent the actual resources (crops, ecosystem productivity, and water) relevant for human livelihoods.

#### *Crop Models*

Müller et al. (2017) evaluate 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 Fast Track, all of 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 well; both models 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.

#### *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 these case study countries. Moreover, in these studies the models have been anonymized, i.e., individual models cannot be identified. One criterion that narrowed 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, and of the models that participated, in both ISIMIP2a and the ISIMIP Fast Track, 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, on the other hand, 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 Potsdam Institute for Climate Impact Research's regional hydrological model SWIM and in WaterGAP.

#### *Ecosystem Models*

**The choice of ecosystem models follows similar considerations as that of crop and water models.** Out of four global ecosystem models (or 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 the work in 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.

## **CLIMATE MODELS USED IN FLOOD MODELING**

**Of the more than 30 GCMs that participated in CMIP5, four models (IPSL-CM5A-LR, GFDL-ESM2M, MIROC5, HadGEM2-ES) were used in the ISIMIP2b to drive the hydrological models.** These were selected to 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 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).

#### *Flood Models*

**An ensemble of 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 was evaluated for a number of river basins worldwide, including the Blue Nile (Ethiopia) Basin (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 kilometers by 50 kilometers) resolution for the whole 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 also include river routing schemes; however, none of the six GHMs used here provides 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<sup>68</sup> capable of simulating floodplain dynamics and backwater effects by explicitly 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 also been shown in details (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 are 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 are extracted for East 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.** The procedure of downscaling and mapping to observational-driven flood depth to avoid bias from the GCMs are described in detail in the supplementary text of Dottori et al. (2018), Hirabayashi et al. (2013), and Wilner et al. (2018). The annual maximum flood inundation depth at 500-meter resolution considers flood defenses in East 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 (Huizinga, de Moel, and Szewczyk 2017), a 1-meter flood depth would lead to near 40 percent damage for residential buildings in sampled African countries.** 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 or below this threshold. For each decade (2010–19, 2020–29, 2030–39, 2040–49), the occurrence of damaging annual maximum flood events are 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) ratings.
- Low (0): more than 50 percent models agreeing on no damaging flood in the decade.

**These definitions consider absolute flood depth, flood defenses in East Africa, and model agreement for each decade, although the thresholds 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 the global warming trends but also large interannual and decadal climate variations.

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68. See CaMa-Flood: Global River Hydrodynamics Model at <http://hydro.iis.u-tokyo.ac.jp/~yamada/cama-flood>.



Credit: Sarah Farhat / World Bank

Sarah Farhat / World Bank

## Appendix B

# Population Gravity Model and Coefficients

This appendix provides technical details on the population gravity model, and describes the coefficients derived from the historical population distribution data, which help explain the drivers of future climate migration.

### TECHNICAL DETAILS OF THE MODEL

The value (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  $\alpha$  and  $\beta$  parameters for the urban and rural populations are necessary, and (equation 3.2) must be calibrated. Two separate procedures are carried out for the urban and rural population distributions. As mentioned in chapter 3, 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  $\alpha$  and  $\beta$  parameters capture broad patterns of change in the distance-density gradient, 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 been shown to accurately capture observed density gradients throughout the world (Bertaud and Malpezzi 2003). To estimate  $\alpha$  and  $\beta$ , 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  $\alpha$  and  $\beta$  that minimize the sum of absolute deviations (equation B.1):

$$S(\alpha, \beta) = \sum_{i=1}^n |P_{i,t}^{mod} - P_{i,t}^{obs}| \quad (\text{B.1})$$

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  $\alpha$  and  $\beta$  estimates.

In this modified version of the population potential model, the index 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 and the different sectoral impact, flood risk, demographic, and conflict indicators are estimated (the indicators are hypothesized to affect population change). When  $\alpha$  and  $\beta$  are estimated from historic data (e.g., observed change between 2000 and 2010), a predicted population surface is produced that reflects optimized values of  $\alpha$  and  $\beta$ , 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 () (equation B.2):

$$\Delta P_{i,t}^{obs} = A_i * \Delta P_{i,t}^{mod} \quad (B.2)$$

where  $P_{i,t}^{obs}$  and  $P_{i,t}^{mod}$  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):

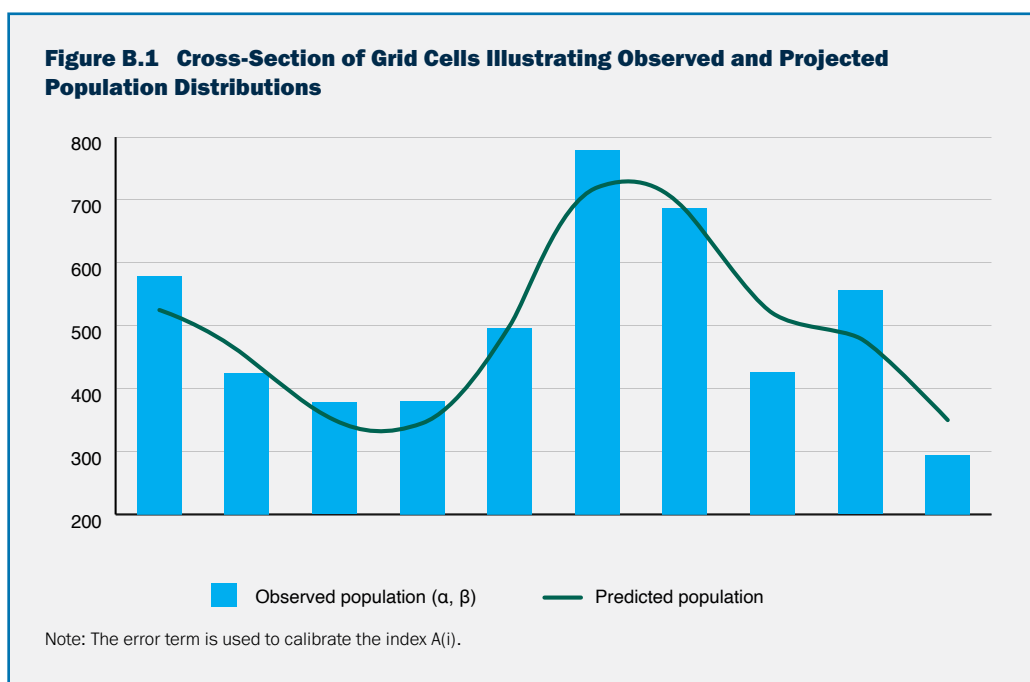
$$A_{i,t} = \rho W A_{i,t} + \beta_1 C_{i,t} + \beta_2 H_{i,t} + \beta_3 N_{i,t} + \beta_4 F_{i,t} + \beta_5 M_{i,t} + \beta_6 S_{i,t} + \beta_7 K_{i,t} + \varepsilon_{i,t} \quad (B.3)$$

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 make up the set of explanatory variables that go into producing index . Note that for any grid



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cell in which  $C$  (crop yield) is a non-zero value, the value of  $N$  (NPP) is automatically set to zero, so that only one of the two variables is contributing to the index. Finally, is the spatial autocorrelation coefficient and  $W$  is a spatial weight matrix. From this procedure, a set of cell specific  $\alpha$  values is estimated for both urban and rural population change.



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  $A_t$ . Finally, to produce a spatially explicit population projection, estimates of  $\alpha$  and  $\beta$  are adjusted to reflect the Shared Socioeconomic Pathways (SSPs) to produce estimates of the agglomeration effect, to which the spatio-temporally variant estimates of for the RCPs described above are applied. Finally, exogenous projections of national urban and rural population change are incorporated and the model applied as specified in equation 3.2.

**As a result 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 (1, equation 3.2) are excluded, because the value of in these cells (0), renders the observed value of inconsequential. Second, the rural and urban distributions observed 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 (e.g., 100 persons) is actually quite large relative to total population within in the cell (e.g., large percent error). The value of 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 effect 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, in fact, they are the result of a definitional change. In most cases these exclusions eliminate 5 percent to 10 percent of grid cells.

## 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 1990–2000 and 2000–10 for each of the potential drivers of spatial population change. The coefficients are derived from an equation that includes each of the potential drivers of migration described in chapter 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. We do not include crop productivity and NPP in the calibration for urban populations because these would not be hypothesized to have an impact in those areas (their populations are not directly dependent on cropping or animal husbandry).

The coefficients in table B.1 represent the average of the coefficients across the two decades for Tanzania, the only country that had matching population and population growth rates at the same administrative level across the three time steps from 1990 to 2010.<sup>69</sup> Note that sea level rise (in coastal Kenya and Tanzania) is not considered a driver of migration, but is inserted as a spatial mask in the modeling work to move populations out of inundated areas.

**Table B.1 Model Coefficients for the Lake Victoria Basin**

Predictor	(Parameter) coefficient		Units
	Urban	Rural	
Crop production	n.a.	0.793548	5-year deviation from historic baseline
Water availability	1.303542	2.261628	5-year deviation from historic baseline
Net primary productivity <sup>a</sup>	n.a.	0.477869	5-year deviation from historic baseline
Median age	-0.00534	0.002636	Median age of the population in years
Sex ratio	0.001975	-0.00424	Males/females
Conflict-related fatalities	-0.00465	-0.00027	Number of recorded fatalities
Flood risk	0.218818	0.020851	5-year likelihood of flood event

The coefficients are unstandardized and cannot be directly compared except for the ISIMIP crop, water, and NPP values, since 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 -1 to +2, whereas the range for median age is roughly 12-30, and for sex ratio the range is 55-130. 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 nonclimate variables plus flood risk, while table B.3 provides examples of the multiplication of the minimum and maximum values times the rural coefficients.<sup>70</sup> Water availability has by far the biggest absolute range in values (6.785), followed by crop production (2.381) and net primary productivity (1.434). The largest of the nonclimate variables, sex ratio, has a value of almost 1. The impact of the other variables (conflict and

69. 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.

70. For example, for median age, the minimum value of 12.5, when multiplied by the rural coefficient of 0.002636, yields a value of 0.033, while the maximum value of 28.6, when multiplied by the same coefficient yields a value of 0.075.



flood risk) is minimal compared to the ISIMIP variables and the sex ratio.<sup>71</sup> The coefficient values in Table B.3 are used to calculate the “local characteristics” parameter  $A_i$  that affects the relative attractiveness or “potential” of a grid cell, in combination with the agglomeration effect, for the allocation of population in each time step (Equation 3.2).

**Table B.2 Descriptive Statistics for Lake Victoria Basin for Each Data Layer**

	Min.	Max.	Mean	SD
Median age	12.5	28.6	16.7	2.1
Sex ratio	55.5	284.4	103.7	28.4
Conflict-related fatalities	1.0	295.0	9.6	10.6
Flood risk	0.0	4.0	1.4	1.2

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	0.793548	-0.794	1.587	2.381
Water availability	-1	2	2.261628	-2.262	4.523	6.785
Net primary productivity	-1	2	0.477869	-0.478	0.956	1.434
Median Age	12.5	28.6	0.002636	0.033	0.075	0.042
Sex ratio	55.5	284.4	-0.00424	-0.235	-1.206	0.971
Conflict-related fatalities	1	295	-0.00027	0.000	-0.080	0.079
Flood risk	0	4	0.020851	0.000	0.083	0.083

71. 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 nonclimate impact variables.



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## Appendix C

# ISIMIP Projections to 2050–2100

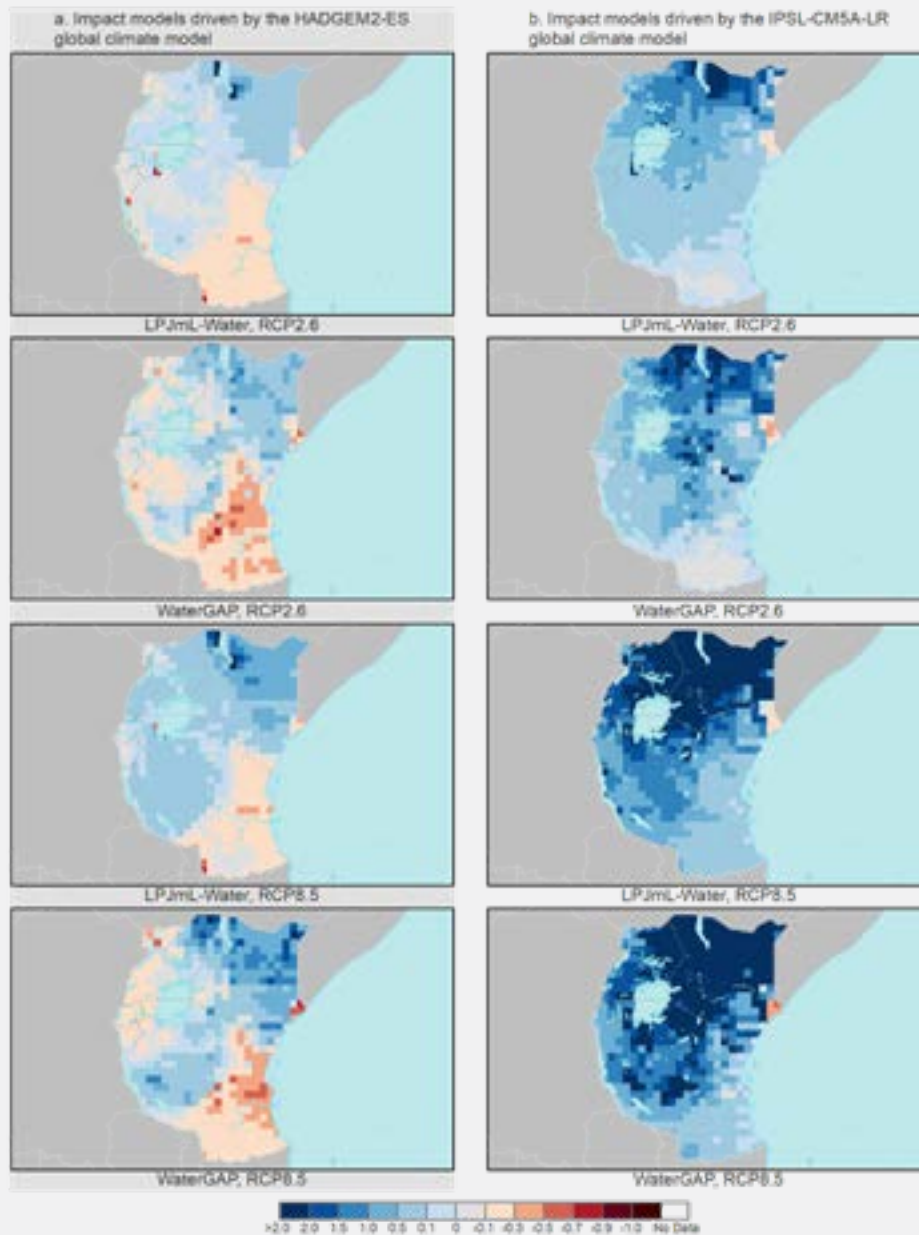
This appendix presents the projections for the water, crop, and ecosystem models out to 2050–2100 using the index defined in equation 3.1, in which the historical baseline value is subtracted from the projected value and then divided by the historical baseline value. Positive index values are capped at 2, which represents a tripling of the baseline value (whether it be water availability, crop production, or ecosystem productivity).

**Figure C.1, shows that water availability will continue some of its earlier trajectory.** The Hadley model (HADGEM2-ES) shows drying in the south of the Lake Victoria Basin (LVB) region and wetting in the north. The IPSL-CM5ALR model shows mostly a wetting pattern across the region, but with modest drying in southern Tanzania under the LPJmL-water model.

**The water model runs are highly consistent across the two GCMs (figure C.2).** A number of models show strong declines in crop productivity in northeastern Kenya and in western Tanzania and Uganda. The LPJmL Crop model shows a strong increase in water availability across all model runs in the southeastern corner of Kenya near Lake Victoria.

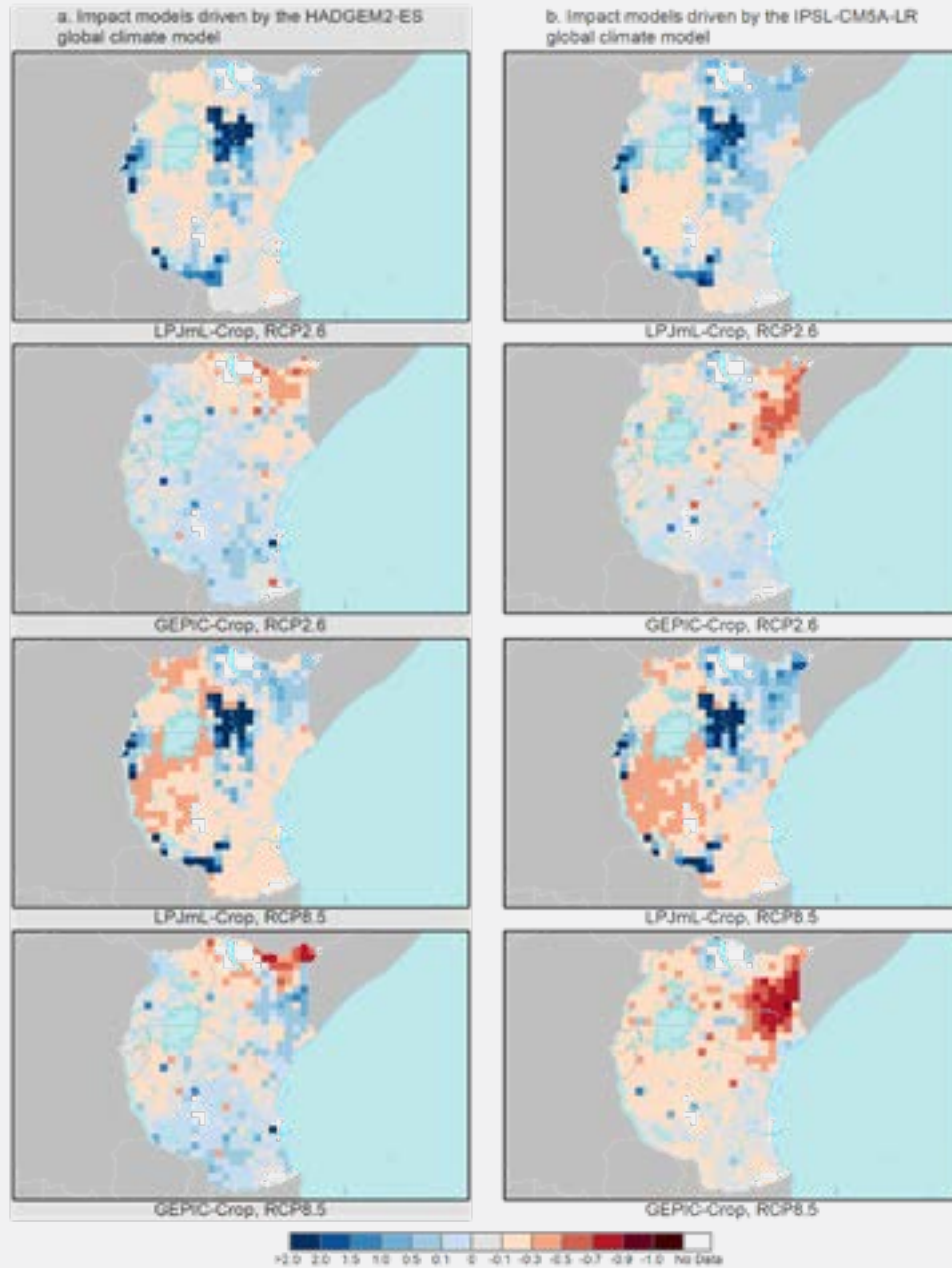
**Net primary productivity (NPP) models to the end of the century show mostly increases in NPP except for modest areas of decline along the eastern coastal areas that vary in intensity and location by model.**

**Figure C.1 ISIMIP Average Index Values against 1970–2010 Baseline for Water Availability, Lake Victoria Basin, 2050–2100**



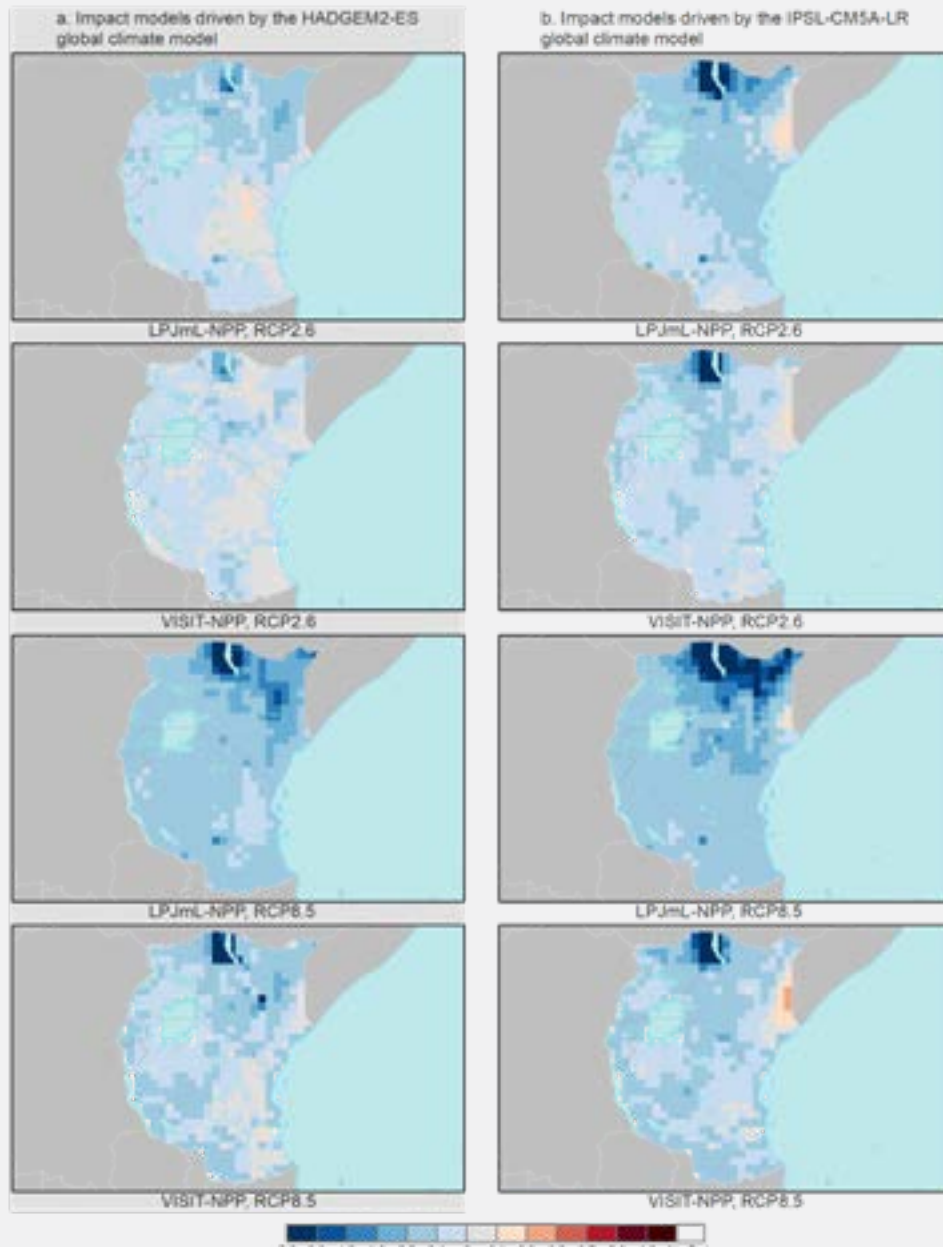
Note: Data calculated against 1970–2010 baseline for water availability, from LPJmL/water (panel a) and WaterGAP (panel b), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5. Blue areas indicate wetting relative to the historical baseline,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

**Figure C.2 ISIMIP Average Index Values against 1970–2010 Baseline for Crop Production, Lake Victoria Basin, 2050–2100**



Note: Data calculated against 1970–2010 baseline for crop production, from LPJmL/crop (left) and GEPIC (right), 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.2 ISIMIP Average Index Values against 1970–2010 Baseline for Ecosystem NPP, Lake Victoria Basin, 2050–2100**



Note: Data calculated against 1970–2010 baseline for ecosystem NPP, 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.



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## Appendix D

# Comparison Between the Original Groundswell and Lake Victoria Basin Results

Comparison of the estimated number of climate migrants reported in the original Groundswell report (Rigaud et al. 2018) with the results for the custom modeling for the Lake Victoria Basin (LVB) countries in this report reveals some commonalities and differences for three out of four scenarios (there was no optimistic scenario in the original Groundswell report) (table D.1). Similar to the original Groundswell model, trajectories of climate migration are highest under the high end of the pessimistic (reference) scenario, with a total 38.5 million climate migrants by 2050. The high end of the inclusive development scenario is a close third, with 30.6 million climate migrants, just after the climate-friendly scenario, with 33.6 million climate migrants. Also, the hotspots of in- and out-migration generally occur in the same locations. Yet overall, estimates for the Lake Victoria Basin model are higher than estimates for the Groundswell model. This section provides explanations for these differences.

**The enhanced modeling applied in the Lake Victoria Basin study differs in several important ways (see chapter 3) from the modeling approach developed for the first Groundswell report.** As such, it stands to reason that the results of this study might vary from the original Groundswell report. It is common in modeling for results to diverge as new features are captured. For example, the climate modeling community has noted higher variance across model runs in the recently released CMIP6 global climate models as new features of the climate system are captured. As Eyring et al. note (2019, 102):

“The latest generation of climate models feature increases in spatial resolution, improvements in physical parameterizations (in the representation of clouds, for example) and inclusion of additional Earth system processes (such as nutrient limitations on the terrestrial carbon cycle) and components (such as ice sheets). These additional processes are needed to represent key feedbacks that affect climate change, but are also likely to increase the spread of climate projections across the multimodel ensemble.”

**Thus, models of increasing complexity often demonstrate increased variability relative to simpler models, because more moving parts and interactions may drive results in disparate directions.** To better contextualize the results of the Lake Victoria Basin study, we will explain ways in which the outcomes projected here are both similar to and different from the Groundswell study, and the mechanisms through which differences may occur.

**In general, the Lake Victoria Basin and Groundswell studies project very similar geographic patterns of climate migration, and thus, similar hotspots of in- and out-migration.** These similarities, given the different modeling approaches, suggest that these results are robust, and should be taken with a fair degree of confidence. Moreover, the relative magnitude of projected climate migration across the scenarios common to Groundswell and the Lake Victoria Basin study are similar as well, suggesting that the pessimistic scenario will produce the most climate migration. The optimistic scenario, featuring low emissions and a more favorable development context, produces the lowest levels of climate migration. However, the studies do not agree on the magnitude of projected climate migration: the Lake Victoria Basin study projects levels four to five times higher under each of the comparable scenarios.

**Differences in the magnitude of projected climate migration, that is, the total number of projected climate migrants, between studies may be because of changes in the Lake Victoria Basin modeling relative to the original Groundswell model.** However, there is nothing about the Lake Victoria Basin model that will inherently lead to higher numbers. The Lake Victoria Basin study approach was also applied, for example, to Ethiopia and 16 West African countries. In the case of the former, the model projected more climate migrants than the original Groundswell approach; however, in West Africa the enhanced model projected climate migration of a lesser magnitude (in both cases geographic patterns and the relative magnitude of migration across scenarios were fairly stable). Here, the increase in magnitude relative to Groundswell can be attributed to four broad factors: (i) the higher spatial resolution of the Lake Victoria Basin model, (ii) the higher temporal resolution of the Lake Victoria Basin model, (iii) the addition of demographic variables in the Lake Victoria Basin modeling, and (iv) the relatively short historic data record against which to estimate model parameters.

**The Lake Victoria Basin model is applied at 1-kilometer (0.5 arc-minute) resolution, while the original Groundswell model was applied at a 15-kilometer (7.5 arc-minute) resolution.** The difference in spatial resolution can lead to disparate results through two primary mechanisms. First, models calibrated at different resolutions (even if the input data are similar) may yield different parameter estimates. That is, the strength of the signal on the variables of interest may be different because the model may pick up on patterns at 1-kilometer resolution that are muddled at the 15-kilometer resolution, or vice versa. Relative to the original Groundswell model, the signal on the water stress variable was considerably stronger, which in this case, contributed to a higher number of projected climate migrants.

**The second mechanism relates to the resolution at which the model is applied, and that at which migration is measured.** Despite application at different resolutions, in the Lake Victoria Basin model results were aggregated to 15 kilometers for purposes of estimating the number of migrants. However, this is done after intercell migration is projected by the model (i.e., the final results are aggregated). Because potential migrants have more possible destinations in a higher resolution model, it is possible that the higher resolution model will predict either more or fewer migrants as a function of which cells are most and least attractive, and how far those cells are from one another.

**The temporal resolution of the model can have a similar amplifying or dampening effect on the projected number of climate migrants.** Because the Lake Victoria Basin model is applied in five-year time steps as opposed to 10-year (as in the Groundswell model), there is more detailed information regarding the changing conditions that might lead someone to move (or not). For example, if water stress, when measured over a 10-year period, does not appear to deviate much from the historic baseline for a given location, then the model will not predict much movement in or out of that location as a function of water

stress. However, if in reality there were a particularly dry five-year period followed by a wet five-year period in this location (which cancel one another out in the 10-year data), there may have been movement out of the region initially, followed by return migration or movement by others into the region later. The coarser temporal model will miss this movement, while the higher resolution model will capture it.

**Table D.1 Comparison of Model Results for Groundswell and Lake Victoria Basin modeling work for Lake Victoria Basin countries by 2050**

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 LVB	Projected internal climate migrants in Groundswell Africa LVB	Internal climate migrants in Groundswell Africa LVB (SD)	Difference in projected number of internal climate migrants between the original Groundswell and Groundswell Africa LVB (Groundswell Africa LVB-original Groundswell)
Burundi	Optimistic	-	-	-	16,810,184	586,741	387,048	-
Burundi	More climate-friendly	21,471,620	89,312	56,901	18,099,239	493,874	292,607	404,561
Burundi	More inclusive development	19,882,568	122,417	56,289	16,810,184	551,565	400,402	429,148
Burundi	Pessimistic (reference)	21,510,653	124,953	67,323	18,099,239	629,321	378,104	504,368
Kenya	Optimistic	-	-	-	78,055,622	4,221,245	1,295,917	-
Kenya	More climate-friendly	96,303,160	695,815	243,602	91,674,704	4,913,378	1,787,385	217,562
Kenya	More inclusive development	81,996,237	1,010,947	185,178	78,055,622	4,320,894	842,519	3,309,947
Kenya	Pessimistic (reference)	96,280,481	1,281,636	516,969	91,674,704	5,872,851	1,760,866	4,591,215
Rwanda	Optimistic	-	-	-	22,953,347	812,653	304,841	-
Rwanda	More climate-friendly	30,019,189	175,366	104,381	26,032,569	756,594	190,675	581,227
Rwanda	More inclusive development	26,526,152	247,587	104,682	22,953,347	942,204	231,139	694,617
Rwanda	Pessimistic (reference)	30,004,920	188,660	47,699	26,032,569	1,136,773	90,517	948,113
Tanzania	Optimistic	-	-	-	102,253,936	9,781,741	3,382,959	-
Tanzania	More climate-friendly	123,952,110	1,491,249	907,081	119,048,184	11,433,170	4,278,700	9,941,921
Tanzania	More inclusive development	106,694,062	2,796,693	797,939	102,253,936	11,185,512	2,756,064	8,388,820
Tanzania	Pessimistic (reference)	123,954,637	2,677,400	808,312	119,048,184	13,394,939	3,305,488	10,717,539
Uganda	Optimistic	-	-	-	93,253,351	7,089,913	691,976	-
Uganda	More climate-friendly	114,738,215	1,400,628	1,003,919	112,336,667	8,647,304	938,452	7,246,677
Uganda	More inclusive development	95,383,646	1,951,039	1,005,618	93,253,351	8,810,974	679,506	6,859,935
Uganda	Pessimistic (reference)	114,723,428	2,179,599	1,072,572	112,336,667	10,870,185	1,193,479	8,690,586
LVB	Optimistic	-	-	-	313,326,440	22,492,294	3,720,938	-
LVB	More climate-friendly	386,484,294	3,852,370	2,315,884	367,191,364	26,244,319	4,743,910	22,391,949
LVB	More inclusive development	330,482,665	6,128,682	2,149,707	313,326,440	25,811,148	2,996,865	19,682,466
LVB	Pessimistic (reference)	386,474,119	6,452,248	2,512,875	367,191,364	31,904,069	3,949,993	25,451,820

Note: GS = Groundswell; LVB = Lake Victoria Basin.

**A third (and likely most important) potential source for variation in the projected total number of climate migrants is the introduction of the demographic variables to the Lake Victoria Basin model.**

Introducing complexity into any model potentially increases the variability in outcomes, because for every new variable there are an increasingly large number of complex interactions driving outcomes. Here, the demographic variables (age and sex distribution by grid cell) introduced in the enhanced model affect the results through their relationship with population change (as derived through the spatial autoregressive calibration) and their interaction with the climate drivers. Thus, the degree to which additional demographic variables will affect estimates of climate migrants depends on whether the projected impact of age and sex structure on migration runs counter to or aligns with the direction of movement driven by climate, and on the degree to which the impact of age and sex structure either mitigates or enhances the signal (coefficients from calibration) on climate effects. Through the course of the Lake Victoria Basin modeling, and previous modeling of Ethiopia and the West Africa Coastal Areas (WACA) region, we have found inconsistency in the impact of demographic characteristics of the population of future outcomes. In the WACA region, the signal on the demographic variables was strong, which mitigated or dampened climate migration. In the Lake Victoria Basin and Ethiopia the opposite was true, and including demographic variables has amplified the impact of climate. These results demonstrate how added complexity can lead to increasingly disparate outcomes.

**A final potential source of inconsistency in the total number of climate migrants between the Groundswell and Lake Victoria Basin modeling relates to the short historic period for which we have data to fit the model.**

Given only a small sample of countries for which multiple censuses and data points may fit a model, the exercise is vulnerable to the impact of outliers, or short-term aberrations in the historic data. As seen in table D.2, the parameter estimates from the calibration in the original Groundswell report vary by country in the Lake Victoria Basin because different countries were used for calibration in different parts of East Africa. The estimates are also far lower, particularly for water availability, than the parameters in the Lake Victoria Basin model (Table 3.7). Unfortunately, there is little that can be done to combat this problem, and the results must be considered within the context of the existing data constraints.

**While these results may not be considered desirable from a policy communication perspective, this reflects the reality that this is partly a research project and partly a policy project.** The research part means that we are testing different approaches and sometimes the results are unanticipated.

**Table D.2 Coefficient Values for the Lake Victoria Basin Countries, Groundswell Modeling**

	Urban		Rural	
	Crop	Water	Crop	Water
Burundi	0.023303	0.037088	0.096555	0.890003
Kenya	0.016749	0.033076	0.067242	0.570891
Rwanda	0.023303	0.037088	0.096555	0.890003
Tanzania	0.023303	0.037088	0.096555	0.890003
Uganda	0.016749	0.033076	0.067242	0.570891

Source: Rigaud et. al. 2018.



