COUNTRY NOTE

CLIMATE MIGRANTS

DOMINICAN REPUBLIC

FOREST CARBON PARTNERSHIP

WORLD BANK GROUP

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ABBREVIATION LIST

1km	1 kilometer
DR	Dominican Republic
ENI	National Immigrant Survey
ERP	Emissions Reduction Program
GCM	General Circulation Model
GDP	gross domestic product
GHG	greenhouse gas
GPW	Gridded Population of the World
HTI	Haiti
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
IUCN	International Union for the Conservation of Nature
km	kilometer
LAC	Latin America and the Caribbean
NDC	Nationally Determined Contributions
NPP	Net Primary Productivity
RCP	Representative Concentration Pathways
SLR	sea level rise
SSP	Shared Socioeconomic Pathways

KEY DEFINITIONS
RELATING TO THIS COUNTRY NOTE

Climate migration
The movement of people from one country, region, or district to settle in another, largely as a result—directly or indirectly—of the slow onset of impacts on their livelihoods brought about by climate change in the form of natural degradation (such us shifts in water availability, crop productivity, ecosystem productivity) or other factors (such as sea level rise).

Human mobility
As an umbrella term, it covers all aspects relating to the movement of people, regardless of why, whether or not the movement is voluntary or forced. The term not only relates to the involuntary internal and cross-border displacement of populations, but also to the voluntary, the latter of which usually is planned and consented to.

Internal migration
Refers to the movement of people within a State involving the establishment of a new temporary or permanent residence. Internal migration movements can be temporary or permanent and include those who have been displaced from their habitual place of residence such as internally displaced persons, as well as persons who decide to move to a new place, such as in the case of rural–urban migration. The term also covers both nationals and non-nationals moving within a State, provided that they move away from their place of habitual residence (IOM Glossary of Migration). The operational definition for this study also makes explicit that internal migrants are those that change municipalities of residence.

Out-migration and In-migration
Out-migration relates to migrants who depart from a specific location (also called emigrants), while in-migration refers to those moving into a particular destination (also called immigrants). The general term, "migrant," defines both immigrants and emigrants, depending on the location taken into consideration.

International or cross-border migrant
Any person who is outside a State of which he or she is a citizen or national, or, in the case of a stateless person, his or her State of birth or habitual residence. The term includes migrants who intend to move permanently or temporarily, and those who move in a regular or documented manner as well as migrants in irregular situations (IOM Glossary of Migration).

Slow-onset processes and rapid-onset events
For the purpose of this Country Note, the definitions from Germanwatch (2021) are applied: (i) Slow-onset processes are "(...) a phenomena caused or intensified by anthropogenic climate change that take place over prolonged periods of time — typically years, decades, or even centuries—without a clear start or end point." For example, changes in precipitation patterns or volume over the years or sea level rise. (ii) rapid-onset events are "single, discrete events with a clearly identifiable beginning and/or end and that occur or reoccur in a matter of days or even hours at a local, national, or region scale." For example, cyclones or floods, which climate change can also modify its frequency or intensity.

KEY MESSAGES

1

Climate-induced migration in the Dominican Republic (DR) as a result of changes in the availability of water, sea level rise, and crop and ecosystem productivity exhibits distinct patterns in internal versus cross-border movements.

2

Internal climate migration is strongly focused on the migration of people from rural to urban areas; and sometimes urban to urban migration, partly due to reduced agricultural outputs, decreased capacity for pastoralism, and water stress, particularly in irrigated cropland areas.

3

Santo Domingo, the DR's capital, is projected to become a net receiver of internal climate migrants by 2050. This may change by 2100, however, with the city's center (Distrito Nacional) transforming, instead, into a net sender of climate migrants due to the foreseen increase in population density, combined with water stress, which would push people to move outward and into the city's suburban districts. In Santiago, the country's second largest city, it is anticipated that it will face increased water stress and is projected to be a net sender of climate migrants by 2050.

4

The cross-border flow of Haiti's climate migrants into the DR is projected to settle in urban, agricultural, and border areas, with those in Dominican cities representing a higher absolute numer. In relative terms, however, they represent a higher share of the local population in border areas which are currently lagging in terms of infrastructure and human development, potentially elevating tensions among host and migrant communities who compete for already limited resources.

5

Many climate migrants leave their community of origin as a result of climate change and natural degradation impacts on their agricultural productivity, while others find ways to adapt within their communities by, for example, diversifying into forestry and agroforestry. Agroforestry allows forest conservation and land recovery; it also provides farmers an income source throughout the year. Nevertheless, those farmers on already low incomes may struggle to transition into forestry and agroforestry, since these require more time and investment than traditional cash crops. Some emigrants have considered returning to their original communities and would do so, were economic conditions more favorable. Certain policies have assisted farmers to overcome these barriers, such as the provision of plants and the support to establish plant nurseries through local associations. There are other policies, as well as climate adaptation strategies, which relate to the use of production technologies and technical support, although reportedly with less success. Some emigrants have considered returning to their original communities and would do so, were economic conditions are more favorable.

6

The findings of this Country Note call for the DR to ensure more effective integration of climate and migratory policies, as well as ensuring these are aligned with broader national objectives for green, resilient and inclusive development. Policy recommendations may be framed in three main pillars: (i) Having a coherent legal and institutional framework for climate and migration policies; (ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process; and (iii) Climate adaptation and mitigation focused on preparedness and anticipatory action. A territorial approach that contextualizes policy solution and considers multiple sectors, such as agriculture and forestry, water management and urban planning, will also ensure the success of key policies in these areas.

EXECUTIVE SUMMARY

The Dominican Republic (DR) is vulnerable to climate change and has a high rate of natural degradation. The effects of climate change include not only rapid-onset events, such as hurricanes and floods, but also slow-onset processes, such as decreased water availability, sea level rise (SLR), and land degradation. Comparative studies demonstrate that the country is ill prepared to confront these anticipated climate change effects. Deforestation and land degradation also are significant in the DR, especially in the northwest and southwest regions, threatening ecological processes, resilience, emission mitigation, and the productivity of forestry and agriculture.

The DR shows evidence of significant human mobility flows of (i) internal migration, mainly rural to urban; and (ii) international cross-border migration, especially from Haiti. The most recent data on internal migration from the DR's 2010 National Population and Housing Census (GoDR, 2010)—referred to as the 2010 Census going forward—shows that the rate of immigration into large cities (Santo Domingo, Santiago, Higüey) is high. While internal out-migration trends are less clear spatially, border areas appear to be places of high expulsion. In terms of international migration—despite the larger number of people emigrating from the DR compared to those who have immigrated—immigration flows are nevertheless sizeable. According to the National Immigration Survey 2017 (ENI for its Spanish acronym; GoDR, 2018). International migrants born outside the DR account for 5.6 percent of total population (one of the highest rates in the Latin America and the Caribbean [LAC] region) and approximately 8.1 percent of the total labor force. The largest migrant groups are those originating in Haiti (87.2 percent) and Venezuela (4.5 percent). The most common places of arrival are Santo Domingo and Santiago, although Haitians represent a larger proportion of the population in the border provinces (8 percent).

Given this context, the DR is an important place to study migration induced by the impacts of climate change and natural degradation. In this report, climate migration refers to migration that can be attributed largely (directly or indirectly) to the slow-onset impacts of climate change on livelihoods through natural degradation such us shifts in water availability, crop productivity, ecosystem productivity, or to factors such as sea-level rise.

Given climate impacts on migration can be direct or indirect (e.g., climate impacting livelihoods and that in turn triggering migration), we do not conceptualize it as mutually exclusive to other types of migration, like labor migration. Furthermore, climate migration is conceptualized as a valid adaptation strategy to the consequences of climate change and natural degradation.

This Note builds upon previous studies undertaken regarding climate migration in the DR, and combines a quantitative modeling approach with a qualitative case study.
The quantitative modeling applied new methods to predict the number of internal climate migrants in the DR by 2050 and 2100, as well as their place of origin and destination, showing trends and producing a novel dataset of internal climate migration. It also estimated the share of climate migrants potentially coming from Haiti into the DR, their projected destinations, and calculating by how Haitians' migration patterns could change as a result of various climate scenarios. The study used variations from a modeling methodology originally developed for a World Bank flagship publication, Groundswell: Preparing for Internal Climate Migration (Rigaud et al. 2018).[1] The qualitative case study relies on in-depth interviews held with internal climate migrants who had been involved in agriculture. While the quantitative method provides a country-level view and estimates of climate migrants, the case study allows to deepen into the motivations behind their decision to migrate, the experiences during their journeys, and their expectations.
The interviewed emigrants had originated from the border municipality of Restauración in Dajabón Province, a location where agriculture and forestry activities are essential to their livelihoods and where natural degradation is a key issue.
Even though there are many climate migrants that are not related to agriculture or this location, the case study concentrated in these because of the presence of poor and excluded groups and their relevance for existing environmental programs.

The DR's internal climate migration significantly relates to rural-to-urban migration and, in some cases, to substantial urban-to-urban migration. In terms of the former, the combination of reduced agricultural outputs, capacity for pastoralism, and water stress (particularly in irrigated croplands) is driving people into the urban areas. There are differences, however, within the projected impacts of climate change on urban areas, many of which rely on nearby agricultural lands (i.e., worsening agricultural conditions will impact not only the rural economy but also urban). Cities such as Santiago, expected to experience increased water stress, is projected to be a net climate out-migration hotspot (although the city may still grow its population regardless); on the other hand, the urban fringe of Santo Domingo continues to grow substantially under all scenarios. Interestingly, estimates indicate that the Distrito Nacional (central district) may become a net receiving point for internal climate migrants by 2050, originating from various points of departure within the country. Toward 2100, however, the center may become a net climate out-migration site as a result of increased population density combined with water stress, thus driving climate migrants to move to the suburban strip of Santo Domingo.

It was estimated that a large share of migrants, both internal and cross-border from Haiti into the DR, will be driven by climate change, and the number and share will continue to increase through the end of the century. During the period 2020-2050, depending on future scenarios, between 149,000 and 368,000 people could potentially migrate internally as a result of climate change (1.2-2.8 percent of the DR population and 30-74 percent of internal migrants during the period 2005-2010), and 234,000 to 473,000 additional internal climate migrants in the second half of this century (2050 to 2100; 1.9-5.3 percent of the DR population). Similarly, depending on the scenario, between six and 20.1 percent of cross-border migrants from Haiti to the DR will be driven by climate change by mid-century, and between 11.2 and 28.1 percent in the second half of the century. Pessimistic scenarios (regarding both socio-economic and climate outcomes) would result in higher numbers of climate and other migrants. While estimating these numbers accurately and precisely is difficult and hold much uncertainty of the future (e.g., assuming there is no change in border policy or in Haiti's fragile economic and political situation), these estimates nevertheless do convey the message that climate change, indeed, could displace a large number of people into and within the DR, in the absence of adequate and timely policy measures, and brings important details on the spatial distribution of these migrants. These estimates should be used in conjunction with other data sources and knowledge to inform policymaking.

The DR's internal climate migration significantly relates to rural-to-urban migration and, in some cases, to substantial urban-to-urban migration. In terms of the former, the combination of reduced agricultural outputs, capacity for pastoralism, and water stress (particularly in irrigated croplands) is driving people into the urban areas. There are differences, however, within the projected impacts of climate change on urban areas, many of which rely on nearby agricultural lands (i.e., worsening agricultural conditions will impact not only the rural economy but also urban). Cities such as Santiago, expected to experience increased water stress, is projected to be a net climate out-migration hotspot (although the city may still grow its population regardless); on the other hand, the urban fringe of Santo Domingo continues to grow substantially under all scenarios. Interestingly, estimates indicate that the Distrito Nacional (central district) may become a net receiving point for internal climate migrants by 2050, originating from various points of departure within the country. Toward 2100, however, the center may become a net climate out-migration site as a result of increased population density combined with water stress, thus driving climate migrants to move to the suburban strip of Santo Domingo.

In contrast, Haitian climate in-migration into the DR projects a different trend. The border regions, El Cibao, and Higüey would receive proportionally more climate migrants from Haiti than from within country, while Santo Domingo province would receive proportionally less (although high numbers in absolute terms). Patterns of Haitian in-migration would also shift slightly due to climate change, with both El Cibao and the area of the Cordillera Central receiving proportionally more climate migrants than in the past. Meanwhile, Santo Domingo continues to receive a smaller portion over time. Together, the likely pattern is one of internal emigration from agricultural and pastoral regions by the Dominican population fueling urban growth, while these same regions will presumably experience an influx of labor migrants from Haiti, many of whom may be driven by Haiti's climate change impacts. It is worth noting that general patterns of internal climate migration, on the one hand, more strongly follow changes in environmental conditions within the DR. On the other hand, however, migrants from Haiti, while reacting slightly to the environmental situation in the DR, seem more driven in choosing their destination by existing social networks and the potential for rural labor opportunities.

Internal emigrants who were interviewed in Restauración, most of whom worked in the agriculture, perceive that changes in precipitation and land degradation are impacting agricultural productivity—one of the main livelihoods in the area—causing people to migrate as an adaptation strategy. The main reasons to emigrate, they stated, were the lack of employment, low agricultural productivity, and the pursuit of better education opportunities. However, when inquired about the root causes of these drivers, participants recognized how natural degradation and climate change played a role in the intention to migrate through loss of agricultural productivity, showing an indirect impact of climate and natural degradation. Interviewees were able to relate the changes in hydrological factors (e.g., precipitation) to changes in the sowing and harvest seasons, both of which can result in an unpredictable loss of production on rain-fed farming systems. Likewise, low soil productivity, caused by deforestation, forestry intensification, and water stress, is perceived as the source of lower yields. Farmers have reported applying various strategies to adapt to productivity loss, such as rotating between lands and soil treatment; these, however, have proved less successful. Faced with these challenges on their livelihoods, migration to seek better economic opportunities appears as the main adaptation strategy to improve their living conditions.

While many emigrated as a result of low agricultural production and productivity, others found ways to adapt within their communities, for example, by diversifying activities into forestry and agroforestry. Agroforestry allows forest conservation and land recovery; it also provides the potential for farmers to be able to rely on a source of income throughout the year. Thus, some emigrants have considered returning to their original communities and would do so, were economic conditions more favorable; from the interviews, in fact, some reportedly were returning to work in forestry. Despite the potential of forestry and agroforestry, there might also be additional challenges that low-income farmers may experience in their efforts to undertake these economic activities; as they require more time and resources than for cash-crops.

Certain policies (e.g., provision of plants, support to establish plant nurseries through local associations), however, have assisted farmers to overcome such obstacles.

Other adaptation strategies and policies include the use of production technologies and technical support, although these reportedly with less success.

The above results call for a more integrated migration, climate, and development policy. As in many other countries and within various development organizations, climate change and human mobility are treated as distinct policy areas. As evidenced in this study, the two are inextricably related, with a growing body of literature calling for more cross-sectoral policies. On the one hand, recognizing migration as a valid adaptation strategy could support people to deal with the effects of climate change (especially to those trapped because of insufficient resources to even migrate), and support a planned, safe and dignified movement that increases the positive impacts while reducing the negative ones. On the other hand, migration policies that take into account the current relevance of Haitian workers for the DR labor market—particularly in terms of agriculture – could support the creation of programs that will incentivize large and small farmers to apply environmentally sustainable practices while, at the same time, ensure the supply of agricultural labor from which Dominicans seem to be exiting. Such integration, thought through an adaptation framework, will help to improve the effectiveness of two seemingly distinct yet interconnected sectoral policies. Furthermore, these should align with broader national objectives for green, resilient and inclusive development. A territorial approach considering multiple sectors, such as agriculture and forestry, water management and urban planning, will allow a holistic response to climate migration.

Recommendations to address current and future climate-driven migration in the DR are based on three pillars, in line with the key findings of the World Bank's World Development Report 2023 (World Bank 2023) and the policy response framework outlined in the special focus on migration in Migration and Development Brief No. 37 (Ratha et al. 2022).

The following table includes specific recommendations, along with the three pillars:

Table 1.
Summary of Policy Recommendations to Address Climate Migration in the Dominican Republic

PILLAR	POLICY RECOMMENDATIONS
(i) Coherent legal and institutional framework	Support technical roundtables among the National Climate Change Council, the National Migration Council, Ministry of Agriculture, Ministry of Labor, Ministry of Environment, Ministry of Interior and Ministry of Economy, Planning and Development to better integrate environmental, agricultural, and migratory policies in the country. Provide technical advice and facilitate knowledge exchanges with small-island states in Latin America and in other regions, including through regional platforms. For instance, through the Greater Caribbean Climate Mobility Initiative (GCCMI) and similar regional platforms. Create clear and established legal frameworks to support climate-induced migration pathways at the national level. Mobilize international technical, institutional, and financial support to provide regional responses to facilitate safe and planned cross-border climate migration. Support the professionalization and reduce turnover of migratory civil servants with a dedicated module or seminar on climate-induced migration as part of the curriculum of the National Migration Institute´s Master's degree in Migration and Development in the Caribbean. Promote further research, analytical work, and data generation and collection on these issues.

PILLAR	POLICY RECOMMENDATIONS
(ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process	Develop early warning systems to enable prior planning for slow and rapid human mobility flows in response to climate change impacts and natural degradation. Planned relocation may imply the voluntary movement of people to other cities or areas within a country. In line with Law No. 368-22 on Territorial Development, Land Use, and Human Settlements, greater attention is needed to ensure that affected persons are involved fully in decisions regarding their relocation. Codesign and implement climate-induced relocation plans with local communities. Lessons learned from the DR's Lake Enriquillo experience can be a starting point.[1] Boost national and international resource mobilization to finance subsidies and enable safe and planned migratory pathways for internal and cross-border climate migrants. Support climate-informed territorial development and planning instruments and socio-environmentally sustainable investments that address rural-urban corridors and the unique challenges or border areas. Prepare and update local development and climate action plans to allow the mobility of people, identify their destination, and ensure appropriate preparations and key services for arrival at destination (e.g., health, education, and housing). For instance, support the continuity and adequacy of educational process for internal migrants.

PILLAR	POLICY RECOMMENDATIONS
(iii) Climate adaptation and mitigation focused on preparedness and anticipatory action	Periodically update territorial planning instruments at the Dominican Republic's (DR) Ministry of Economy, Planning, and Development (Ministerio de Economía, Planificación y Desarrollo, MEPYD) to take into account predicted climate migration flows. Invest in the adaptation of rural and border communities and other out-migration hotspots, to enable potential migrants to stay in place, where viable, are also important. National planning instruments at MEPYD, such as the regional development strategy for border areas "Mi Frontera RD" already integrate climate and migration policy and can serve as reference for other planning instruments in the country. Prioritize strategies aimed at supporting livelihoods and addressing the risk of displacement caused by climate change in areas adjacent to protected zones. The Emissions Reduction Program (ERP) in the DR may constitute an avenue for future preparedness in green and sustainable sectors. The program may provide technical and financial support in favor of national efforts. This program could be leveraged to reverse unsustainable practices in the forestry and agriculture sectors that are factors that influence the decision to migrate. Address the barriers to enter the agroforestry field through incentivization and subsidy programs, and promote green jobs in the forestry sector. Provide technical and technological support to increase agriculture and land productivity, irrigation, as well as water management to address factors that influence the decision to migrate. Enhance waste management to reduce environmental pollution and health risks, especially in water and sanitation sectors, ensuring equitable access to clean resources, and supporting public health and environmental preservation.

PILLAR	POLICY RECOMMENDATIONS
(iii) Climate adaptation and mitigation focused on preparedness and anticipatory action	Minimize the use of harmful chemicals by large agricultural producers to reduce the speed of soil and water degradation and its subsequent impacts on climate-induced migration from rural areas. Improve urban-rural corridors and increase awareness of the importance of sustainable agricultural practices among rural and urban youth. Strengthen technical assistance for preparedness as a critical measure in cities expected to receive an influx of migrants over the next few decades. Invest in infrastructure and employment in cities (e.g., Santo Domingo, Santiago, Higüey), as well as in sustainable areas. Additional research is needed in this area. Likewise, given water stress and sea-level rise pressures on cities, climate resilient urban planning is needed to ensure cities are able to accommodate growing numbers of people under conditions of climate stress, including resilient infrastructure, housing, and services, with social inclusion and cohesion considerations.

[1] The Government of the DR has relocated many affected by a rise in water levels in Lake Enriquillo to the new town of Boca de Cachón, a US$24 million community built by the government to house people on the verge of losing their homes to the lake.

BACKGROUND AND OBJECTIVES

This report aims to introduce climate migration in the policy debate of the DR by presenting key findings based on quantitative and qualitative analyses. While the country has undertaken many efforts to develop policies and institutional arrangements relating to migration and climate change, the interaction between the two in the policy discussion remains siloed. For example, the topic of migration does not appear in the Dominican Republic's (DR) top climate change strategies, namely the Nationally Determined Contributions (NDC) and the National Adaptation Plan. Neither does climate change appear prominently in any migration policy, except for that caused by natural hazards (e.g., earthquakes and hurricanes).

While extreme weather events and disasters caused by natural hazards are the most visible climate change manifestations, other effects of climate change and environmental issues, such as deforestation and slow-onset processes (e.g., natural degradation, reduced water availability), may have more profound consequences. Hazards such as cyclones, floods, landslides, and droughts are more prominently discussed in the context of climate change and its impacts on migration.

Evidence, however, suggests that slow-onset natural processes (e.g., sea level rise, land degradation, and changes in precipitation and water availability) may have larger impacts on livelihoods and on migration (Germanwatch 2021). At the same time, detrimental and unsustainable natural resource management and agriculture practices, as well as deforestation, also are discussed as paths through which humans further contribute to natural degradation and climate change; these also are recognized as areas that could hold important mechanisms to adapt and mitigate the consequences.

Through this Country Note, the World Bank aims to contribute to a better understanding of climate-induced human mobility in the DR. Taking advantage of the Emissions Reduction Program (ERP) preparation,[2] the World Bank's Inclusion Global Practice has carried out this study to provide initial evidence on the relationship between climate-induced migration, natural resource degradation, and agriculture practices with forestry impact. The study applied qualitative and quantitative research methods, detailed throughout this report. This study also created a new granular raster dataset as a public good to support further research on climate migration.

This study discusses climate-induced migration, including the drivers as a result of natural degradation. Following the World Bank flagship report, Groundswell: Preparing for Internal Climate Migration (Rigaud et al. 2018)—referred forthwith as Groundswell—this note will refer to climate change-induced migration, or climate migration, to discuss migration that is largely linkable to the impacts of climate change (directly or indirectly), particularly through natural degradation and slow onset processes (such as water availability, crop productivity, ecosystem productivity, and sea-level rise).

The study applies quantitative modeling to predict the number of climate migrants in the DR by 2050 and 2100, as well their origin and destination. The study uses a modeling methodology that was initially developed for Groundswell, referred to above. Estimates of climate migrants and their origin and destination are developed for different regions of the world. Given the methodological challenge to include Small Island States in the modeling, however, the Caribbean region was not included in these initial estimates; hence, this study produces estimates of internal migration for the DR. Additionally, given the prominence of international migration from Haiti into the DR, this analytical work will include for the first time, additional modeling to calculate the share of international climate migrants and their destinations, focusing specifically on those originating in Haiti.

This study also uses a qualitative methodology to document a case study of the decision-making process of climate migrants related to the agriculture sector from the municipality of Restauración in the Province of Dajabón. While the quantitative modeling will provide a general view of future migration flows caused by different drivers related to climate change and natural degradation, the qualitative study will delve into the decision-making and migration process, critical to formulate effective policies and support these populations. Slow-onset processes and natural degradation are likely to directly affect those people whose livelihoods depend on natural resources. As such, a World Bank team interviewed a number of emigrants who were involved in the agriculture sector; the objective was to learn how climate and natural variables impacted the livelihoods of interviewees and their decision to migrate. While there are many other climate migrants that are not related to agriculture (e.g., urban-to-urban, driven by sea-level-rise, etc.), the team selected this sector because of presence of poor and excluded groups and its relevance for existing environmental programs. The team focused on emigrants from a single municipality, Restauración, to obtain a more comprehensive understanding. The municipality not only has a population dedicated to forests and agricultural activities, but also holds a history of internal and international migrations. The study delves into the decision to migrate, the process of migration, and the adaptation efforts that may have supported the decision.

[2] The ERP and the framework by the UNFCCC Conference of the Parties (Reduce Emissions from Degradation and Deforestation (REDD+), aim to improve the quality of life in rural communities in the DR and increase the resilience of ecosystems against the impacts of climate change, and promote activities such as agriculture and sustainable forest management, forestry, and coffee and cocoa agroforestry, among others.

The report is structured as follows: It (i) describes the context and relates to previous studies on climate change, natural degradation, migration, and climate migration in the DR; (ii) summarizes the methodology and results from the quantitative modeling exercise; (iii) documents the case study of Restauración, describing the context of the municipality and the methodology and results of interviews; and (iv) discusses the implications for climate change and migration policy.

CONTEXT:

CLIMATE CHANGE, NATURAL DEGRADATION, AND MIGRATION

Climate Change and Natural Degradation Vulnerability

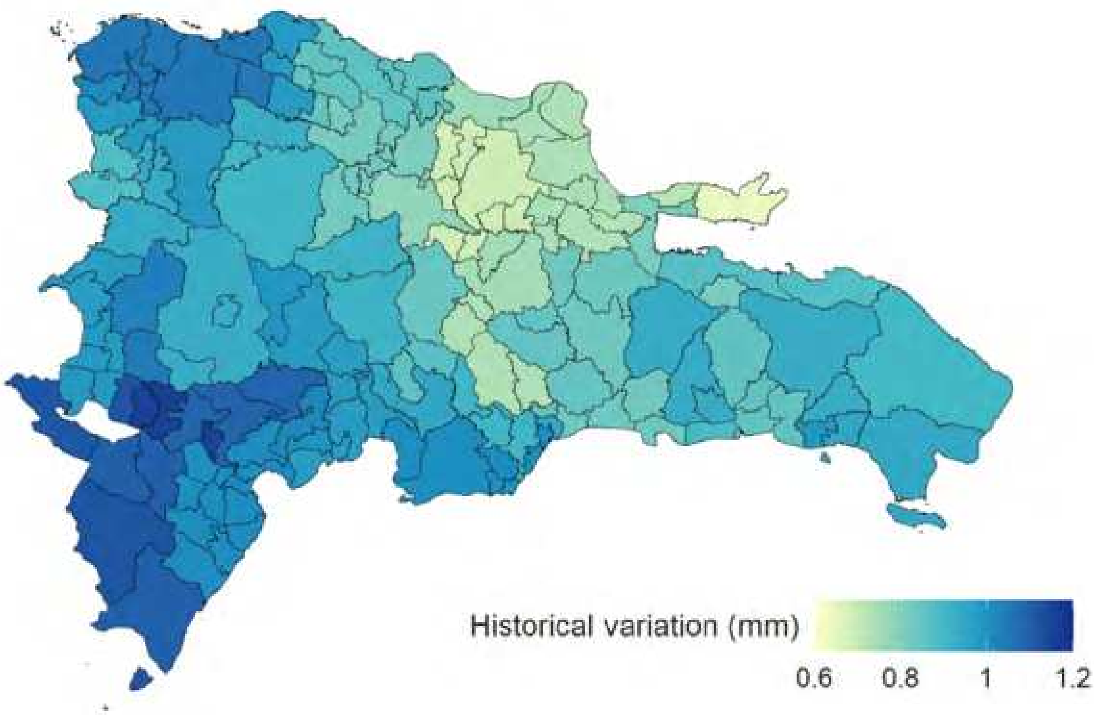
The DR is vulnerable to natural hazards and climate change. It has a high risk of floods, landslides, cyclones, and fires, and a considerable risk of earthquakes, droughts, and extreme heat (GFDRR 2023). The DR is the tenth most impacted country across the globe that has suffered from climatic phenomena between 1997 and 2016, based on the Global Climate Risk Index (CRI) 2018 (Eckstein, Künzel, and Schäfer 2018).[3] In particular, climatic events and their impacts are expected to be aggravated by climate change, including rising temperatures, changing precipitation patterns, and an increase in their frequency and intensity. Comparative studies demonstrate that the country is not adequately prepared to confront such effects (Notre Dame Global Adaptation Initiative 2023).

These climate change impacts include rapid-onset events (e.g., cyclones and extreme rainfall) and slow-onset processes (i.e., related to sea-level rise, land degradation, reduction on water availability). Sea level rise is one of the most significant threats to small islands and atolls with low-lying areas.

From the historical data (WHO and UNFCCC, 2021), future projections indicate that total annual precipitation by 2050 may decrease by 15 percent, on average, throughout the DR, with precipitation in the southern and western regions mostly decreasing. The start and end dates of the dry and rainy months may shift, with the weather patterns becoming more intense. Freshwater resources for human and agricultural use are expected to decrease up to 25 percent by 2050, as will decrease the overall water quality. These impacts are predicted to be heterogeneously distributed across the country. Figure 1 illustrates the uncertainty of precipitation across the DR's municipalities, with the darker colors representing higher variability between 2011 and 2015 compared to the historical trend (1950-1999). As such, it is increasingly more difficult to predict future seasons and water availability. These are expected to impact vulnerable populations, such as the farmers of rainfed agriculture in the border area of the DR.

[3]Publisher: Germanwatch. Subsequent Germanwatch rankings position the DR as less impacted, since the relevant events in 1997 and 1998, such as Hurricane George, are no longer considered.

Figure 1: Precipitation Variability in 2011-2015. Compared to Historical Trend 1950–1999: Dominican Republic.

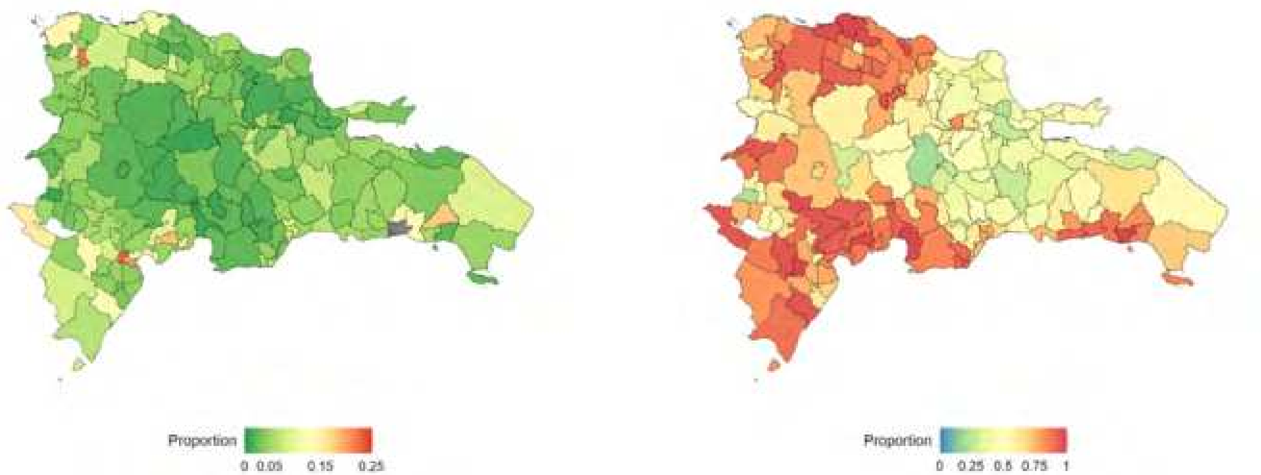


Source: World Bank staff, using data from Terrestrial Precipitation 1900-2017 Gridded Monthly Time Series v 5.01.
Notes: Comparison period is historical precipitation average from 1950–1999.

Forest and land degradation is also high in the DR, especially in some areas, threatening the ecological process, resilience, emission mitigation, and productivity of forestry and agriculture activities. Forests, especially primary forests, have the capacity to absorb carbon and contribute to meeting emission reduction goals. On the other hand, soil degradation, deforestation, and land use changes generate emissions, compromise future economic activity, and increase vulnerability to extreme natural hazards. Despite the country's efforts to regain forest cover,[4] deforestation continues to be relatively high in comparison with other countries in the LAC region,[5] and is one of the main environmental issues in the DR, given the fact that deforested areas are more susceptible to desertification and drought which, in turn, reduces land productivity. Figure 2 illustrates two maps denoting the rate of deforestation and the proportion of land that are declining in terms of productivity in the period 2011-2015; it also indicates that these issues are more prominent in the southwest, northwest, and east of the DR. As such, Agriculture, Forestry and Other Land Use (AFOLU) activities are extremely important in the mitigation and adaptation country plans, as recognized in the 2020 country's NDC.

[4] Since the formulation in 1986 of the Tropical Forest Action Plan for the DR (PAFT-RD), the country has developed numerous strategies to increase the country's forest cover, such as the Plan Nacional Quisqueya Verde (PNQV); Sistema Nacional de Áreas Protegidas (SINAP); Proyecto de Desarrollo Agroforestal de la Presidencia (PAP); Agroforestal system with coffee in shade (CAFÉ); and Programa Megaleche (silvopastoral system and conservation of forests on livestock farms). Many of these projects are part of the ERP.

Figure 2: Proportion of Tree Cover Lost (left) and Land that Has Declined in Productivity (right): Dominican Republic (2011-2015)



Sources: World Bank staff, using (i) Hansen et al. 2013; and (ii) Land Productivity Dynamics LPD - MODIS (derived from NDVI product of MODIS/Terra Vegetation indices 16-Day L3 Global 250m SIN Grid V006).
Notes: (Left) The grey municipality refers to San Pedro de Macorís, which had an unusually large tree cover loss rate of 0.48, possibly an error of measurement due to the small size of the forest cover. The denominator is the forest extent relating to 2000, which is the only available in the Hansen dataset. (Right) The proportion of land categorized as "Declining" in terms of productivity. The other categories in the dataset are "Non vegetated area," "Early sign of decline," "Stable but stressed," "Stable," and "Increasing." The denominator is the municipality's total hectares.

To prevent natural degradation, it is essential to comprehend the practices of the agriculture sector, and their causes, effects, and potential alternatives. Along with illegal logging, one of the main causes of forest loss is cattle ranching on a commercial scale, expansion of the agricultural frontier (GoDR, 2019), and unsustainable agricultural practices. One of these practices is the recurrent burning of forest (tumba y quema) for agriculture and livestock use and/or for the production of charcoal, which leaves the surface of the land uncovered for prolonged periods of time, becoming prone to water runoff, soil degradation, and a reduced ability to retain moisture. This, in turn, causes the surrounding areas, along with the agriculture practiced in those areas, to become vulnerable, particularly where there are steep slopes. Likewise, lack of land ownership of many farmers intensifies these practices since reduces the incentives to invest in land sustainability due to low opportunity cost. However, these practices are also common in large commercial agricultural producers,[6] especially in their initial stages.

[5] Based on the data from Global Forest Watch (2023), World Bank staff calculates that the DR is 10th in the LAC region to have faced the highest tree cover loss rate (as a percentage of forest cover in 2010) between 2011 and 2021. If calculated in terms of total area loss in lieu of a percentage rate, however, larger countries show having experienced greater loss, with the DR placed in this case as 17th. The calculation does not include reforestation.

Migration in the Dominican Republic

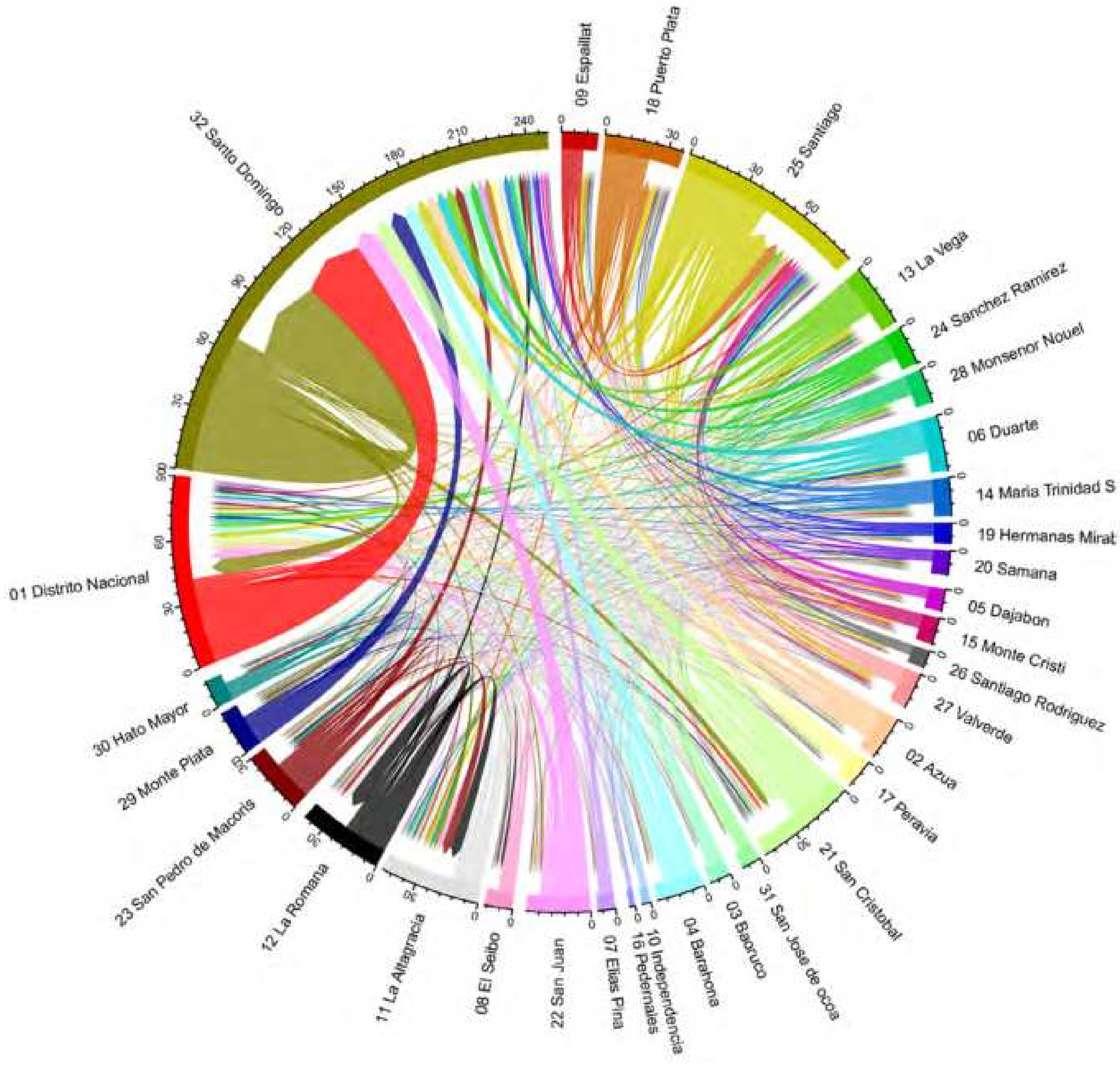
The DR population has a long history of internal migration. Notable patterns of territorial mobility in terms of volume and magnitude occurred in the 1950s, with the number of migrants having tripled by the 1980s. The main regional attraction areas during this approximate 30-year period were the (i) north macroregion of the country, given its successful agricultural production of export items such as coffee, cocoa, tobacco, and rice; (ii) southeastern region due to the sugarcane plantations; and (iii) capital city of Santo Domingo, the seat of political power (Ariza and Lozano 1993).

The 1960s and 1970s were years of high rural-urban mobility. The Cibao area, in particular, began to lose its attraction compared with the capital's National District. Other provinces experienced a retreat in population as a result of lower agricultural production, economic concentration of resources, and rapid urbanization. During this period, 54 percent of urban growth reflected rural-urban displacement, slowing gradually in the 1970s and 1980s (Jiménez 1992). It was not until the 1990s when the Northwest Cibao region (including Montecristi, Dajabón, Santiago Rodríguez, and Valverde) recorded the highest emigration rate. Likewise, the border zone provinces—the poorest parts of rural DR, with extreme poverty twice as high compared with the rest of the country (UNEP 2013)—also recorded a high emigration rate. Many Dominicans sold or leased their lands in these provinces, ultimately moving to the cities.

The most recent internal migration data emerges from the 2010 Census (GoDR 2010), which reflects a continuing high arrival of people into cities such as Santiago or Santo Domingo. According to the Census, 497,470 people (5.3 percent of the population in 2010) moved across municipalities between 2005 and 2010, and 404,854 (4.3 percent in 2010) from province to province. Figure 3 reflects the emigration flow between provinces around the country within this period (see Appendix 1 for a map of DR provinces and Appendix 2 for a similar graph at the municipality level). The most notable trends are high internal immigration to the cities, especially within the Province of Santo Domingo (182,828), Distrito Nacional (48,882), and the Province of Santiago (44,700), particularly within the municipality of Santiago (31,051). Santo Domingo Province and the Distrito Nacional form part of Santo Domingo's metropolitan capital area, while the city of Santiago is the second largest in the country. The three areas experienced 55 percent of internal mobility between 2005 and 2010. The migration map by municipality (Figure 4), also illustrates that in the East, the Higüey municipality in Altagracia Province has high internal immigration (30,336), likely because of the attraction of the third largest city and employment opportunities in livestock production and tourism from the Punta Cana and Bávaro beach areas.

[6] A study indicates that the DR has an extreme concentration of land held by various companies and individuals. Only 50 major producers control more than 1,000 hectares each; 200 families control approximately 600,000 hectares (equivalent to 50 percent of the country's arable land), and only 40 percent of privately owned land is titled (Ovalles, 2011).

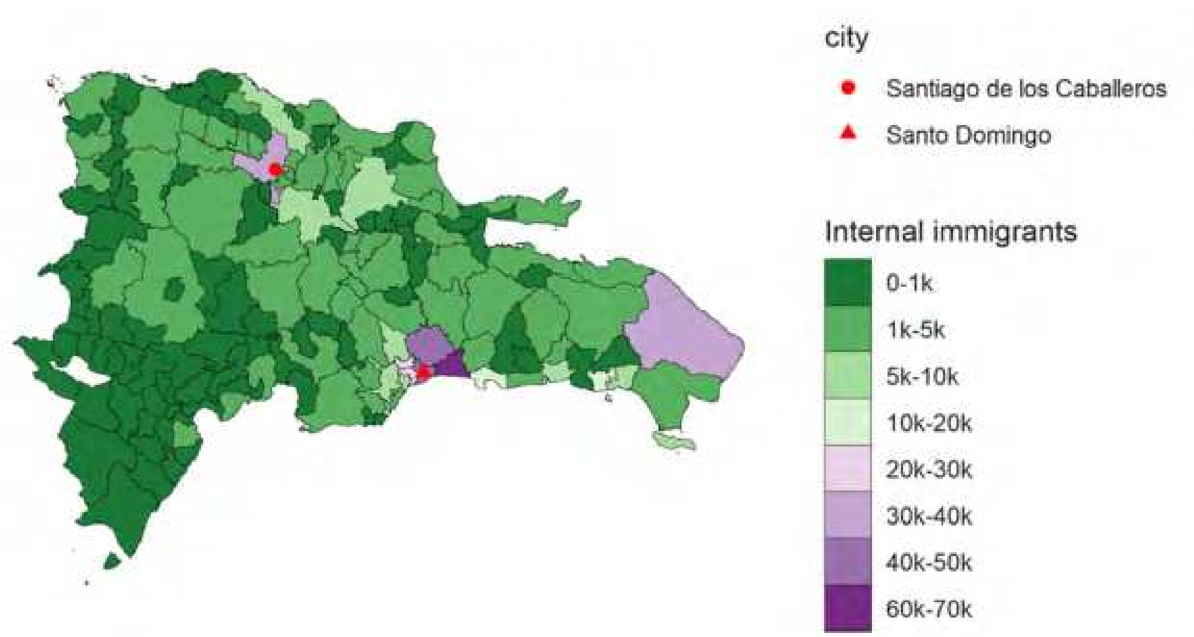
Figure 3: Internal Out-Migration and In-Migration between 2005 and 2010, by Province: Dominican Republic



Sources: World Bank staff, based on data from the National Population and Housing Census 2010 of the Dominican Republic (GoDR 2010).

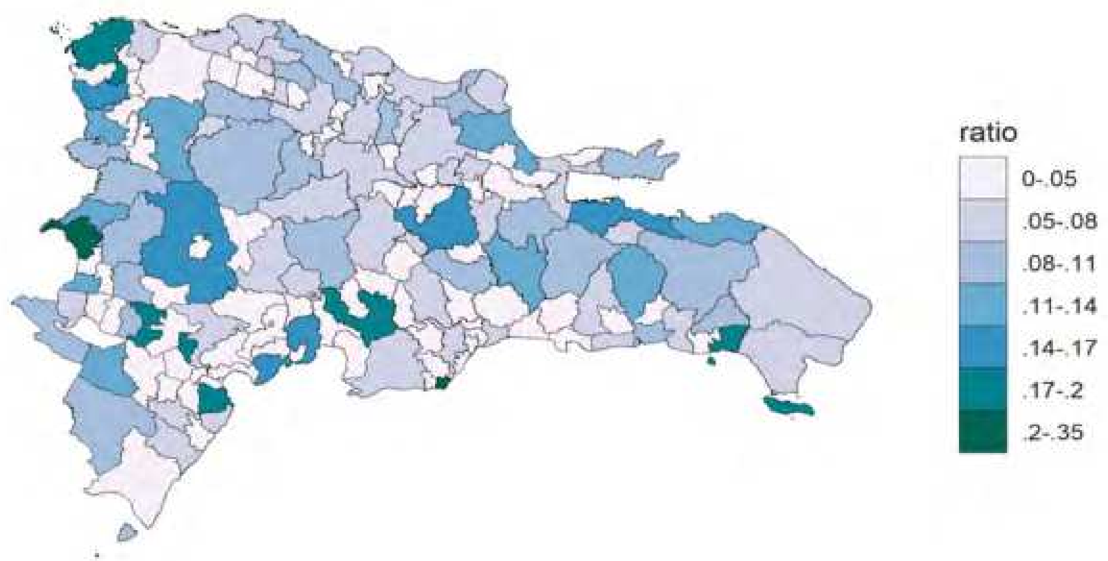
Notes: The graph was created based on the 2010 Census survey (GoDR 2010) question regarding the name of the municipality in which the person (five years and older) was living in 2005. Each tick mark represents 6,000 people; the number represents those who, in 2005, were living in another municipality within the DR; and arrows in the same province represent those who have moved between municipalities within the same province.

Figure 4: Internal In-Migrants between 2005 and 2010, by Municipality: Dominican Republic



Sources: World Bank staff, based on data from the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010).
Notes: k = thousands. The graph was created based on a census question regarding the name of the municipality in which the person (five years and older) was living in 2005. The number represents those who, in 2005, were living in another municipality within the Dominican Republic

Figure 5: Ratio of Out-Migration over People Staying between 2005 and 2010, by Municipality: Dominican Republic



Sources: World Bank staff, based on data from the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010).
Notes: The graph was created based on a Census question relating to the name of the municipality in which a person (5 years and older) was living in 2005. The ratio represents those who were living in a municipality in 2005 and had left it by 2010, against those who had remained from 2005 to 2010, inclusive. The data prevented the computation of the population size in 2005.

Internal out-migration trends are spatially less clear, although there are some notable trends. Of the four provinces with the highest internal immigration in 2010 (Santo Domingo, Distrito Nacional, Santiago and Altagracia), Santiago has a more balanced number of people who emigrated in 2005 and immigrated in 2010; this suggests that, for many, it may have been an intermediate and temporary destination. Conversely, the Province of Santo Domingo shows a clear growing trend of immigration (more immigrants than emigrants), as well as a large number of migrants who moved from municipality to municipality within the province or to Distrito Nacional. Aside from these four provinces, the others had more internal emigrants in 2005 than immigrants in 2010. San Juan, for instance, had 17,135 more internal emigrants than immigrants, suggesting a considerable reduction in population. San Cristóbal also has a large number of emigrants. With regard to the ratio of people emigrating versus those staying in 2005, there is no clear spatial pattern at the municipal level (Figure 5), except for a high ratio in a number of border municipalities.

The DR also has a large inflow of international migrants, especially from its neighbor country, Haiti. In 2022, the net migration rate for the DR, however, was -2.673 per 1,000 population (own estimations based on UNDESA 2022); that is, a larger number of people emigrated from the country, particularly to the United States, compared with those who immigrated to the DR. Nevertheless, the immigration flows are sizeable. Based on the 2017 National Immigrant Survey (ENI) (GoDR 2018), 5.6 percent of the DR's population was born outside the DR, with Haiti being most prevalent (87.2 percent of all immigrants or 4.9 percent of the population). Venezuela occupies second place (4.5 percent of all immigrants). The number of Venezuelan migrants has doubled in the last six years (ENI 2012; ENI 2017), while the Haitian population grew by 8.6 percent from 2012 to 2017(GoDR, 2018). Both immigrant populations are leaving their home countries following outbreaks of conflict, violence, poverty, and political instability.[7] Consequently, the DR receives people in increasingly vulnerable conditions.[8] An additional 2.7 percent of the population were born in the DR of at least one immigrant parent.

[7] Institutional deterioration, chronic poverty, unemployment, structural violence, and precarious health services are the main reasons for the exodus of Haitians from their country, while Venezuelans are escaping from a complex social, political, institutional, and economic crisis. Haitian migration is one of the most complex and challenging in the region (IOM DTM Feb 2021).

[8] New trajectories; simultaneous flows of emigration, transit, and immigration; increased vulnerabilities due to the COVID-19 pandemic; border closures; and the collapse of informal economies (in which migrants are overrepresented) have added additional layers of complexity to the challenges refugees and migrants face and have historically faced. (R4V 2022).

Migrants born in Haiti are commonly employed in the agriculture (representing 33 percent of Haitian workers), construction (26.3 percent), and retail and trade (16.3 percent) sectors (GoDR 2018). In the agriculture and construction sectors, Haitian-born workers represent approximately 30 percent of their labor force (own calculations based on data showed in GoDR, 2018). Haitian immigrant workers typically are employed in jobs that require little qualification, and are overrepresented in the informal job market, therefore leaving these populations in a situation of vulnerability. Dominican workers increasingly self-exclude themselves from such jobs, since (i) they are able to access various social benefits that raise their basic wage; and (ii) there are cultural factors that prevent them from participating in these kinds of jobs (ENI 2017, INM RD 2022). The ENI 2017 indicates that 47.6 percent of Haitians live in provinces with a high population concentration (e.g., Santo Domingo, Distrito Nacional, and Santiago). Haitians, however, represent the largest proportion of the population in provinces close to the Dominican Republic/Haiti border (8 percent) and in provinces that cultivate sugar cane (6.3 percent).

Although climate change or natural degradation are not directly reported by Haitians surveyed as a main reason for migrating, it may be a latent factor influencing such decisions. It is recognized that Haiti has a high degradation of its natural resources [9] which will impact economic activities that make use of them, such as agriculture, livestock and tourism. Haiti is also one of the most affected and vulnerable countries to climate risk and climate change.[10] In this sense, it is possible that natural degradation has led to loss in economic productivity which has driven migration. However, climate migration is not the most present reason to migrate for those surveyed, especially when climate degradation occurs over a long period of time, for example droughts or soil degradation. Likewise, extreme natural events, such as the tropical storm in August 2021 that further pushed millions of Haitians into food insecurity (Lutz and Yayboke, 2021), will likely continue to be important factors in the decision to leave Haiti towards the DR.

[9] Haiti ranks 165th out of 180 countries in the Yale University Ecosystem Vitality Index.

[10] Ranked as the second most vulnerable to climate risk between 1997 and 2016 in the Long-term Climate Risk Index for 1997-2016 (Germanwatch 2018) and third in the most recent (2000-2019). Ranked 168th out of 182 countries in the ND-GAIN 2020 Index (Notre Dame Global Adaptation Initiative 2022), which captures vulnerability to climate change and readiness to confront it.

Studies on Climate Migration

There is general agreement in the scientific community of the connection between climate change, natural degradation, and human mobility, but more research on the subject is called for. Globally, climate change is emerging as a potent driver of human mobility. As documented by the Intergovernmental Panel on Climate Change (IPCC) report of 2022, various studies have found links between climate change and human mobility, such as migration or forced displacement. This will include international migration, but most climate-induced migration is expected to occur within country borders. The report also states that "rapid-onset climatic events trigger involuntary migration and short-term, short-distance mobilities (…) slow-onset climatic events (such as droughts and sea level rise) lead to long-distance internal displacement, more so than local or international migration (Dodman et al., 2022, IPCC Chapter 6, p. 930)." The World Bank's Groundswell report estimates that internal climate migration may reach up to 216 million people by 2050 due to slow-onset climate impacts. The IPCC notes the need for further research on this complex topic.

Research has conceptualized migration as an adaptation strategy to climate change and socioeconomic challenges. Many studies summarized in the IPCC (2022) and other reports have found that migration is used as an adaptation strategy to escape degraded resources, consequences of extreme climate events, or to find better socioeconomic opportunities (sometimes viewed as a last resource). The relationship between migration and low resources, however, is not linear. Poverty and the impacts of climate change could create a situation whereby the poorest are trapped and do not have the opportunity to even use migration as an adaptive strategy, thus trapping them in places with degraded resources and plunging them further into poverty. Critics also observe the simplistic evaluation that sometimes is given to the migration process, portraying it as something that is either positive or negative. Migration can have both benefits and negative consequences for the migrants, for the origin community, and for the destination community. Hence, a more thoughtful discussion on how to increase the positive impacts of migration while managing the negative impacts is needed.

Empirical studies in the DR have applied quantitative and qualitative methods to document the links between migration, climate change, and natural degradation. A study by Cordero Ulate and Lathrop (2016) used a survey method to document the emigration process relating to environmental events from the border municipality of Jimaní (Independencia Province) toward a neighborhood located in Santo Domingo Norte. Extreme natural events, such as droughts and floods, were found to influence participant decisions to emigrate from Jimaní, highlighting vivid flooding events in that area that called for relocation of the entire population. These were not reported, however, as the main reasons to migrate; instead, migration was reported as an adaptation strategy to face economic and social disadvantages, with these environmental events only contributing to them but not being perceived as the main triggers. Additionally, Wooding and Morales (2014a and 2014b) have studied, qualitatively, the interactions between migration, natural degradation, and conservation policies in two communities around the natural park of Nalga de Maco, located in the Northwest and close to the border with Haiti. The study documents how waves of internal and Haitian migration to the area, coupled with unsustainable agricultural practices, have contributed to natural degradation in the area through agricultural expansion. The authors also discuss that natural degradation can be seen as a second-order reason for migrating, by influencing economic hardship and poverty, which is commonly referred as some of the main reasons for migrating, both by internal immigrants and those of Haitian origin. Other reports estimate the amount of migration that has occurred as a result of extreme natural events. For example, IFRC (2021) reports that in 2017, 69,000 people were classified as being internally displaced in the DR as a result of disasters caused by natural hazards.

Additionally, a recent report indicates the theoretical and contextual considerations to further study this topic in the DR. The report, "Diagnostic of Information for Public Policies: Migration, Environment, and Climate Change, Dominican Republic," includes a comprehensive review of national and international evidence on migration, climate change, and climate-induced migration, with the proposal for a study of climate-induced migration specifically in the DR (Wooding and Morales, 2016). The report highlights how migration within national borders is a strategy to escape the effects of extreme natural events (e.g., hurricanes, earthquakes), slow-onset impacts of climate change, and the consequences of overexploitation of natural resources (e.g., soil degradation). It also outlines climate change and municipal policies in the DR (e.g., adaptation strategies in agriculture), and how they are missing a thoughtful consideration of migration. Among the recommendations for further research, the report indicates the importance of gathering meteorological data for the study of climate migration, the need for adequate methods to capture localized movements, and a review of land exploitation systems and their impact on natural degradation and migration.

This report will define climate-migration in line with recent evidence. In this report, we use a similar definition as the one used on Groundswell WB Report, referring to migration that can be attributed largely (directly or indirectly) to slow-onset impacts of climate change on livelihoods through natural degradation such us shifts in water availability, crop productivity, ecosystem productivity, or to factors such as sea-level rise. Nevertheless, it's important to highlight a caveat with this definition. Climate change can have, at the same time, direct impacts in migration decision making (such as when a storm destroys someone's place of living) or indirect (such as reducing income of farmers because of a drought and pushing them to find other economic activities) (Cissé, 2022, IPCC Chapter 7). Additionally, various studies point out to the difficulty of determining the exact reason for migrating, given the complexity of the process and how push factors may be intertwined. Both methodologies try to control for it in different ways, but will ultimately still hold error and uncertainty because of this. In line with this, when studying climate migration using self-reports from people, it should not be expected that people could perfectly identify impacts from climate change from those caused by other factors. This will be further discussed when describing the results from each method.

PART 1:

QUANTITATIVE MODELING TO ESTIMATE CLIMATE MIGRATION IN THE DOMINICAN REPUBLIC

Methodology

This study uses a methodological approach to estimate climate migrants that was first used in World Bank's Groundswell report (2018). Analyses for the Groundswell report were the result of collaboration between World Bank Group staff and researchers from the Center for International Earth Science Information Network, Columbia University Earth Institute, City University of New York (CUNY) Institute for Demographic Research, and Potsdam Institute for Climate Impact Research. The novel methodological approach to estimating climate change impact on internal migration patterns was built from spatial methods to project future population distributions that can be calibrated to reflect the impact of various potential drivers of change. This study builds upon the Groundswell methodology, incorporating spatial refinements and integrating an international mobility component. The results and a summarized version of the methodology are described below. A more detailed explanation of the models, scenarios, data, and limitations is provided in Appendix 3.

Models

The model, a gravity-based spatial allocation-type framework (hereafter referred to as the INCLUDE model (Jones and O'Neil 2013; 2016)), produces scenario-based estimates of internal migration. The scenarios that were used are combinations of socioeconomic (development) and climate (emission) projections. On the one hand, the development projections provide estimates of national-level population change and urbanization rates, among other narratives and estimates. On the other hand, projections of greenhouse gas (GHG) emission concentration drive changes in environmental conditions which, in turn, may alter socioeconomic conditions through impacts on various socioeconomic livelihoods (further details on the scenarios are provided below). Future changes in the spatial distribution of the population, driven by migration, occur in the model as a function of the relative attractiveness of various subnational points in space. Relative attractiveness is influenced by socioeconomic and demographic characteristics of populations, economic conditions and livelihoods, historical and existing connections, political systems and stability, geographic characteristics and, most importantly for this work, climate impacts. With regard to climate and degradation impacts in particular, the model inputs changes in water availability/stress, crop yield/productivity, productivity of the ecosystem/natural biome, and seal-level rise. The INCLUDE model estimates the number of climate-induced migrants and their future locations by comparing population distributions that incorporate climate impacts with a scenario based on only a development trajectory (constant climate). Additionally, the calculations disaggregate between climate and "other" migrants[11] to further investigate the impacts of climate on spatial patterns of population change. To be considered an internal migrant in this model, a person must move across municipal boundaries.[12]

The international model is derived from a variation of the INCLUDE model, whereby it first estimates the bilateral country-level migrant flows between Haiti and the DR, and then identifies the portion of climate migrants and distribution of these migrants between locations. This work draws on a method to estimate origin-destination international movement that could intensify or decline as a result of environmental change. The method was used to produce migration projections across Central America and Mexico for the New York Times Magazine/ProPublica report on climate migration in the Americas (Jones, 2020). The international model operates based on two steps. First, total migrants (climate and other) for each time period are estimated at the country level from Haiti to DR. Haiti is considered as a single unit, so out-migrants are modeled for the country on aggregate. Second, migrants are distributed to municipalities within the DR based on the estimated relative attractiveness of each—using a gravity-type function that accounts for environmental conditions, economic conditions (through an agglomeration effect), and the existing Haitian population (considered a proxy for social networks). Similar to the INCLUDE model, climate migrants are distinguished from other migrants by comparing outcomes to a counterfactual scenario in which no climate change is assumed (e.g., climate is held constant at 2020 conditions), although there is much more uncertainty in these estimates than for the internal model. Advantage is taken of existing bilateral flow data (taken from the ENI 2017) to train and project future migration from Haiti to the DR as a function of aggregate climate impacts at the national level (i.e., crops, water, ecosystem productivity[13]), and the existing data on the distribution of Haitian migrants across the DR (from the 2010 Census), to estimate potential changes in origin-destination flows from Haiti to municipalities within the DR under the four alternative future scenarios detailed below.

The internal and international models are loosely coupled, in that the distribution of Haitian immigrants at each time period influences (slightly) internal migration in the subsequent time period, and internal migration within the country influences how migrants from Haiti chose a destination. When estimating migrants for each five-year period (in a sequential step-by-step manner), the internal model was applied first, followed by the international model that was used to distribute projected migrants from Haiti across the DR.

[11] Climate migrants are those driven by factors, either directly or indirectly related to climate change, while "other" migrants are those who are driven by factors other than climate change. The model is able to distinguish between the two by assessing the counterfactual scenario in which no climate change occurs against future scenarios that include climate change. Hence, "other" migrants are simply the number of migrants derived from the scenario without climate change, and climate migrants are the difference between this scenario and the one pertaining to climate change.

[12] While this definition is debatable, a decision was taken for the purpose of this study so that estimates would be more meaningful, actionable, and consistent with historical estimates of internal migration. It should be acknowledged that smaller or larger geographic definitions would influence the number of estimated migrants.

[13] Note that sea level rise is not included in this model.

Scenario Framework

This work adopts the extended scenario-based approach from the Groundswell Africa series (Rigaud et al. 2021), in which four plausible future internal climate migration scenario combinations are examined based on combinations of the Representative Concentration Pathways (RCP) (van Vuuren et al. 2014) and Shared Socioeconomic Pathways (SSP) (O'Neill et al. 2014). For each scenario, the projection represents an ensemble of model runs using combinations of crop, water, ecosystem, and Sea Level Rise (SLR) impact models from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP—more details on this data below). The scenario approach has several advantages. First, exploring migratory outcomes across alternative physical and demographic/socioeconomic futures allows researchers to begin to characterize the size and sources of uncertainty associated with projections of climate-induced migration. Second, varying both climate and demographic/socioeconomic pathways provides a means to evaluate different policy options in terms of the impacts on spatial population outcomes and the potentially avoided climate impacts of achieving more advantageous climate and societal outcomes (e.g., Oleson et al. 2015; Martinich et al. 2018).

On the one hand, RCPs are global scenarios representing trajectories of GHG concentrations (and other pollutants) resulting from human activity and corresponding to a specific level of radiative force in 2100. These were developed in advance of the IPCC 5th Assessment Report (IPCC, 2014). The scenarios simulate not only the volume of emissions, but also their corresponding climate change impacts.

Two RCPs (2.6 and 8.5) are included in this modeling work as drivers of climate impacts. RCP2.6 is a low emission scenario (Low Emission scenario), while RCP8.5 is characterized by increasing GHG emissions over time, leading to high atmospheric concentration (High Emission scenario). RCP8.5 implies little to no climate policy, and is characterized by significant increases in CO2 and CH4 emissions.

On the other hand, SSP scenarios span a wide range of potential future development pathways, and describe trends in demographics, human development, economy and lifestyle, policies and institutions, technology, and environmental and natural resources. Broadly, they are organized according to their respective challenge to adaptation and mitigation in each future world. Importantly, climate change impacts are not directly included in these scenarios. They can be thought, however, as consistent with broad assumptions regarding the primary factors driving challenges to adaptation and mitigation, namely population and emissions, respectively. National-level estimates of population, urbanization, and gross domestic product (GDP) are publicly available and are used for this project. Population estimates include assumptions regarding international migration; however, as mentioned, these assumptions are made in the absence of any information regarding climate change, exposure, and vulnerability. No assumptions are made in these scenarios regarding internal migration. In this work, two different SSPs are proposed for consideration: (i) SSP2 (Middle of the Road scenario) describes a world with development that occurs at rates consistent with historical patterns, and therefore has moderate levels of investment in human capital, technological change, and economic growth. (ii) SSP4 (Inequality scenario) describes a mixed world, with relatively rapid technological development of low-carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most in terms of global emissions. In other regions, however, development progresses slowly, inequality remains high, and economies are relatively isolated, leaving them highly vulnerable to climate change with limited adaptation capacity.

Following the Groundswell approach, four plausible socioeconomic and climate futures are proposed by combining these SSP and RCP scenarios (Figure 6). The scenarios allow for an examination of the relative importance of climate futures in driving potential migration outcomes. The scenarios can be characterized as follows:

1

A Pessimistic reference scenario (SSP4 Inequality and RCP8.5 High Emissions), in which global emissions remain high and development is disparate. Population growth in middle-income countries generally slows over the next few decades and the population declines after mid-century due to significant economic uncertainty. Urbanization rates are high due to rural economic decline, and GDP growth and education levels remain stagnant. 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.

The other three scenarios are defined in comparison to this reference scenario.

2

A more ***Climate-Friendly scenario (SSP4 Inequality and RCP2.6 Low Emissions)*** with lower emissions that reduce climate impacts, but holds the development scenario consistent with the pessimistic scenario.

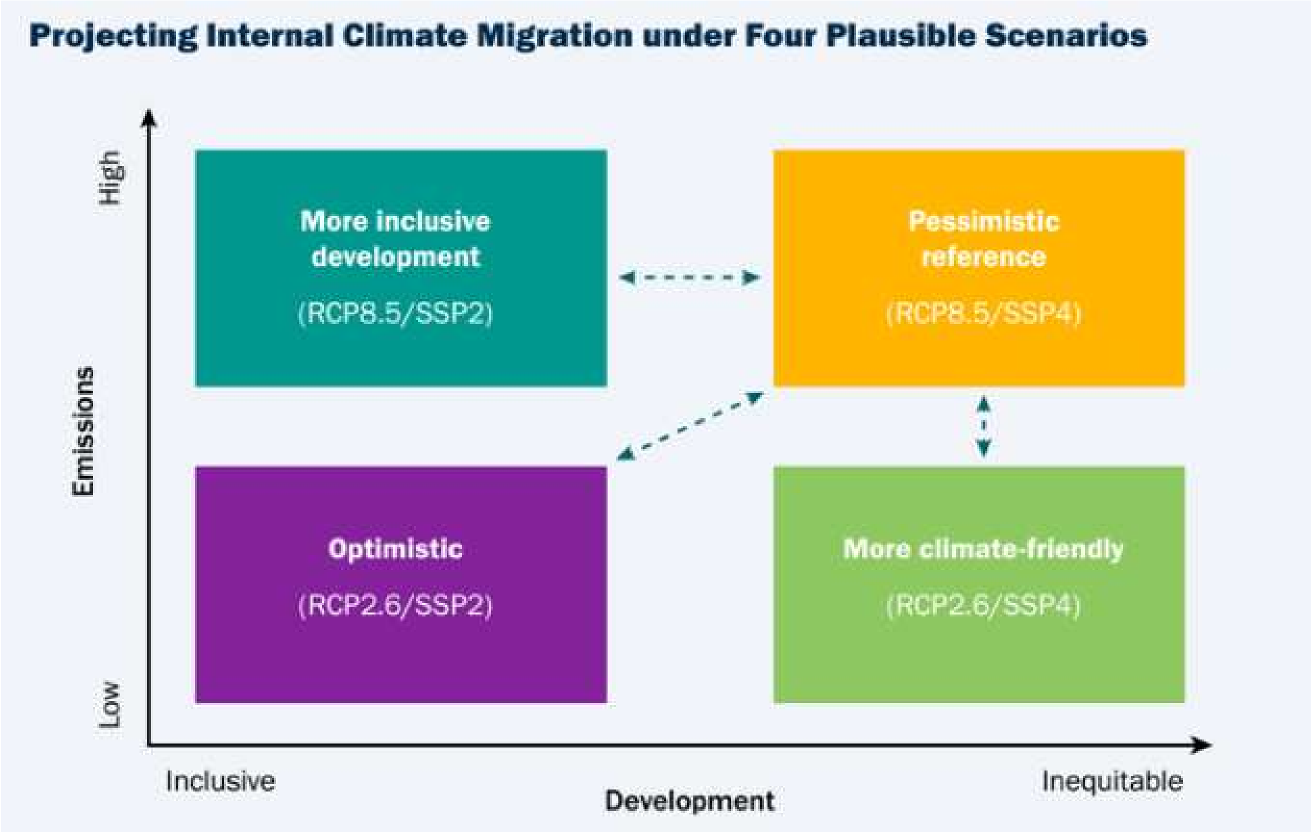
3

A more ***Inclusive Development scenario (SSP2 Middle of the Road and RCP8.5 High Emissions)***, which retains high emissions from the Pessimistic scenario, but provides a development scenario that is more optimistic and the potential for adaptation is higher than under SSP4. Population growth is higher, but urbanization rates are lower than in SSP4, while progress in education and GDP are higher than in SSP4.

4

An ***Optimistic scenario (SSP2 Middle of the Road and RCP2.6 Low Emissions),*** which combines the lower emission scenario that reduces climate impacts and provides a development scenario that is more optimistic.

Figure 6: Scenario Framework



Source: Framework drawn from Rigaud et al. 2021.

For each scenario, a small model ensemble consisting of four models was applied. Each ensemble member considers a different combination of General Circulation Model (GCM)—a global "climate model"—and sectoral impact models (which use the data produced by the GCMs to project changes in crop yield, water stress, and ecosystem productivity). The ensemble approach accounts for uncertainty in climate outcomes by considering a range of projected futures under each RCP.

Data

The data used in the modeling was drawn from the original Groundswell project, updated to reflect more recent updates where possible, and modified slightly for this project. Table 1 includes a list of the data employed in the modeling analysis. Detailed information about each data source and how they were included in the model can be found in Appendix 3.

Table 1: Datasets, Variables, and Sources

Variable	Source	Resolution	Time Series	Time Step	Indicator	Climate Driven
Water Availability	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Agriculture/Crop Yields	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Biomes/Ecosystem Productivity	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Sea Level Rise	NASA	30m	1990-2150	5-year	Changes in coastline (inundation)	Yes
Bilateral Internal Migration	ONE	Municipal	2005-2010	5-year	Count of migrants	N/A
Bilateral International Migration	ONE	Municipal	1990-2010	5-year	Count of migrants (Haiti to Dominican Republic municipalities)	N/A
Municipal Population	ONE	Municipal	2010	N/A	Count of people	N/A
Spatial Population (Totals, Age, and Sex)	WorldPop	100m	2000-2020	1-year	Population counts by age and sex	No
Elevation	SEDAC	30m	2015	N/A	Corrected elevation	No
Slope	SEDAC	30m	2015	N/A	Avarage slope	No
Water Bodies	ESRI	Vector	2019	N/A	Surface water	No
World Database on Protected Areas	IUCN	Vector	2019	N/A	Mandate for protection	No

Source: World Bank staff

Notes: ISIMIP = Inter-Sectoral Impact Model Intercomparison Project; ONE = National Office of Statistics (Oficina Nacional de Estadística) of the Dominican Republic; Worldpop = University of Southhampton's database; SEDAC = NASA's Socioeconomic Data and Applications Center; and IUCN = International Union for Conservation of Nature.

The impacts of climate change act through the first four variables on the list: water availability/stress, crop yields, ecosystem productivity, and SLR. For the purpose of this project, outputs are used from the ISIMIP modeling effort for crop production, water availability, and ecosystem impacts, which cover the historical period 1970–2010 and projections for 2010–2100. The future sectoral impact models are driven by a range of general circulation models.[14] The crop, water, and ecosystem simulations—at a relatively coarse spatial scale (0.5°)—represent indicators that capture the impact climate may have on specific types of livelihoods, a viability that will figure into the migration decision. Crop yields are modeled only for maize, wheat, rice, and soybeans, which are the main global staple crops selected for the Groundswell study.[15] The ecosystem models act in areas not covered by crop productivity data and simulate the natural growth of several different plant functional types, including grasses. Hence, Net Primary Productivity (NPP), simulated by these models, serves as an estimate of the productivity of a location's natural biome, including grassland biomes that may potentially support pastoral livelihoods.

Other variables that capture aspects not related to climate change or natural degradation also are included in the model. Bilateral internal and international migration data, the latter of which consists only of flows from Haiti to the DR, are from the National Statistics Office (Oficina Nacional de Estadística) of the DR, as are the municipal population data. These data were used to help train the model and are unique to this INCLUDE model application. The final four variables on the list are not drivers of migration but, instead, constitute the spatial mask used to restrict the land deemed suitable for human habitation. The population variable (WorldPop) serves as the base year population distribution (total population count by grid cell), as well as two variables in the migration model (age and sex structure). Each of these variables were tested and validated, and previous applications of the model found them to be statistically and/or practically significant in driving positive or negative impacts on the relative attractiveness of various locations. (For more methodological details, see Appendix 3.)

[14] Applied here are data that are driven by two general circulation models that provide a good spread for the temperature and precipitation parameters of interest: the HadGEM2-ES and IPSL-CM5A-LR climate models (more details in the methodological appendix.

[15] While other important crops are missing, the assumption made for modeling is that the deviation of these crops from historical productivity (which is what is actually used in the model) should correlate with that of other missing crops.

RESULTS

This section reviews results and key findings from the modeling work. For purposes of clarity, the results are organized into separate subsections pertaining to (i) internal migration and (ii) migration from Haiti to the DR.

Projected Internal Climate Migration 2020-2100

Depending on the scenario, the average estimated number of internal climate migrants range between 149,000 to 368,000 for the period 2020-2050 (1.2- 2.8 percent of the country's population and 30-74 percent of 2005-2010 internal migrants), and between 234,000 and 473,000 additional climate migrants for the period 2051-2100 (Table 2). Under each of the four scenarios, the model produces estimates of internal climate migrants, those driven to move due to some climate-related impact (water availability, crop yield, ecosystem productivity, and sea-level rise), and "other" internal migrants, which encompasses any migration not related to climate change but, rather, to development issues. The most Pessimistic scenario (RCP8.5/SSP4) yields roughly 346,500 internal climate migrants by mid-century, rising to 473,000 by the end of the century, comprising 2.9 percent and 5.3 percent of the population at that time, respectively.

The most Optimistic scenario (RCP2.6/SSP2) yields roughly 170,000 internal climate migrants by mid-century, rising to 234,000 by the end of the century and comprising 1.3 percent and 1.9 percent of the population at that time, respectively. While these represent a relatively small proportion of total population in the Optimistic scenario, climate migrants nevertheless comprise over 27 percent to 31 percent of all internal migrants under both scenarios. For reference, according to the 2010 Census (GoDR, 2010), 497,470 people (5.3 percent of the population in 2010) moved across municipalities between 2005 and 2010. It should be noted that, reflecting the difficulty to predict an uncertain future, the reported estimates for each scenario represent, in themselves, averages of a wider range (as reported in Table 2), estimated using the ensembled models (composed by four models each). Hence, estimates should not be considered a certain or exact number.

Table 2: Projected Internal Climate Migrants by Scenario, by 2050 and 2100: Dominican Republic (total, as percentage of all migrants, and as percentage of population).

Optimistic SSP2 - RCP2.6	2020 - 2050			2051 - 2100		
	Min	Avg	Max	Min	Avg	Max
Climate migrants	148,787	169,654	195,611	183,941	234,021	288,782
% of internal migrants	24.35%	26.85%	29.74%	25.68%	30.54%	35.17%
% of population	1.13%	1.29%	1.49%	1.48%	1.89%	2.33%
More Inclusive Development SSP2 - RCP8.5	**2020 - 2050**			**2051 - 2100**		
	Min	Avg	Max	Min	Avg	Max
Climate migrants	311,148	368,222	440,025	362,190	463,158	587,748
% of internal migrants	40.24%	44.35%	48.78%	40.49%	46.53%	52.47%
% of population	2.37%	2.80%	3.35%	2.92%	3.74%	4.74%
More Climate Friendly SSP4 - RCP2.6	**2020 - 2050**			**2051 - 2100**		
	Min	Avg	Max	Min	Avg	Max
Climate migrants	124,718	148,651	177,935	193,062	266,293	337,127
% of internal migrants	13.20%	15.34%	17.82%	15.58%	20.29%	24.37%
% of population	1.04%	1.89%	1.48%	2.18%	3.00%	3.80%
Pessimistic / Reference SSP4 - RCP8.5	**2020 - 2050**			**2051 - 2100**		
	Min	Avg	Max	Min	Avg	Max
Climate migrants	267,496	346,497	428,617	336,448	473,204	618,478
% of internal migrants	24.59%	29.69%	34.32%	24.34%	31.15%	37.16%
% of population	2.23%	2.89%	3.57%	3.79%	5.33%	6.97%

Source: World Bank staff analysis

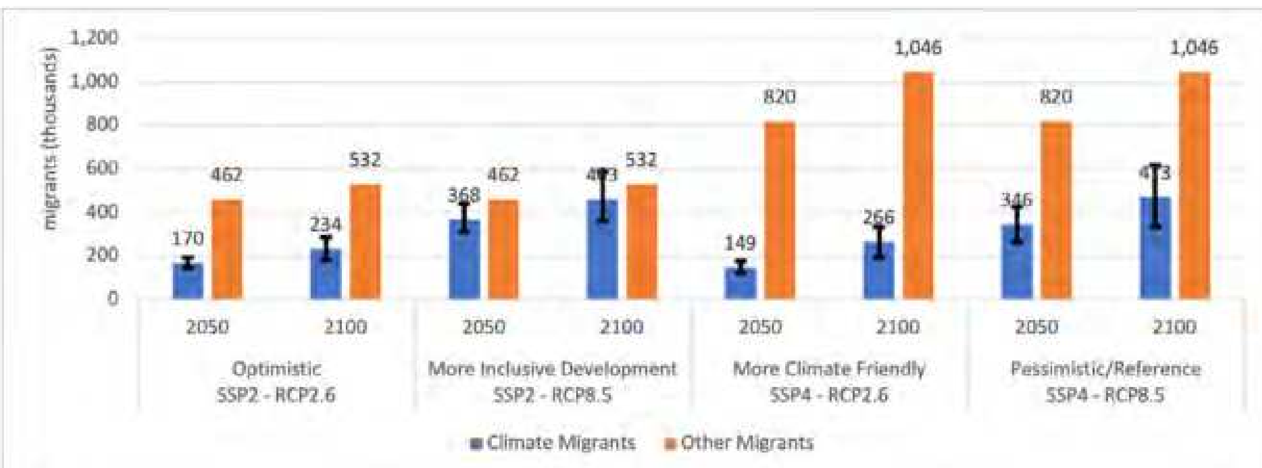
Note: Within each scenario, and ensembled model was composed using four models (GCM) each. These create a range of possible results, represented by the min and max, and the average of these. While the average is reported mostly in the text, the reader should keep in mind the wider range of possibilities and the uncertainty that it represents.

Unsurprisingly, the total number of projected climate migrants are higher in the two more pessimistic climate scenarios (those based on RCP8.5), with over 473,000 and 463,000 people in 2100 driven to move by climate-related factors under SSP4-8.5 (Pessimistic reference) and SSP2-8.5 (More Inclusive Development), respectively. Hence, these estimates suggest that, regardless of development projection, a future with high emissions would lead to more climate migrants than one with lower emissions.

Interestingly, the lowest number of climate migrants by 2050 did not come from the Optimistic scenario but, rather, from the scenario that projects low emissions with an unequal development (SSP4/RCP2.6 - "More climate-friendly"), revealing a trend in which the relative importance of development issues initially crowds out the climate impacts on migration, but later takes larger relevance. When RCPs are held constant, SSP4 (Inequality) future leads to slightly fewer climate migrants at mid-century, followed by a more rapid increase in climate migration after mid-century. Even in the reference Pessimistic scenario (SSP4/RCP8.5), the number of climate migrants is lower than in the scenario that holds high emissions but the SSP2 ("middle of the road") development projections. Likewise, the number of projected climate migrants by 2050 under SSP4/RCP2.6 (more Climate-Friendly)—the scenario with the optimistic climate scenario but coupled with the more pessimistic socio-economic future, are the lowest. What is discovered is that in the earlier decades of this projection, socioeconomic concerns dominated (reflected in the portion of total migrants defined as "others" and in Figure 7), while the impacts of climate change on migration increase in the latter half of this century will become continuously more important, particularly in the form of rural-to-urban migration.

The SSP2-8.5 future ("More inclusive development") is the scenario in which internal climate migrants are closer to the number of other internal migrants, particularly by end-century (Figure 7). As Table 2 and Figure 7 show, this scenario has the highest percentage of climate migrants relative to all internal migrants (44 percent in 2050 and 47 in 2100), and even by 2100, in the max estimate of the potential range, climate migrants slightly outnumber other migrants. The outcome is reasonable given that the SSP2 future ("Middle of the Road) represents a more positive socioeconomic future for a larger proportion of the population (e.g., continued slow convergence in educational attainment and income across all segments of the population) than the SSP4 future (Inequality), which would lead to less migrants driven by economic factors, particularly if the diffusion of wealth reinforces the viability of the agriculture sector. At the same time, because SSP2 is coupled with the RCP8.5 future (high emissions) in this scenario, climate impacts are severe, and thus the number of people forced to move due to climate-based disruption is higher. This scenario should be considered indicative of a likely outcome if climate change continues unabated but socioeconomic conditions improve. Conversely, the reference Pessimistic (SSP4-8.5) scenario, which also projects a similarly high number of climate migrants—although substantially more internal migrants driven by development factors (and hence, more migrants in total)—is a more likely outcome if a future of unabated climate change is coupled with increased inequality within the country.

Figure 7: Total Internal Climate and Other Migrants by Scenario, 2050 and 2100: Dominican Republic



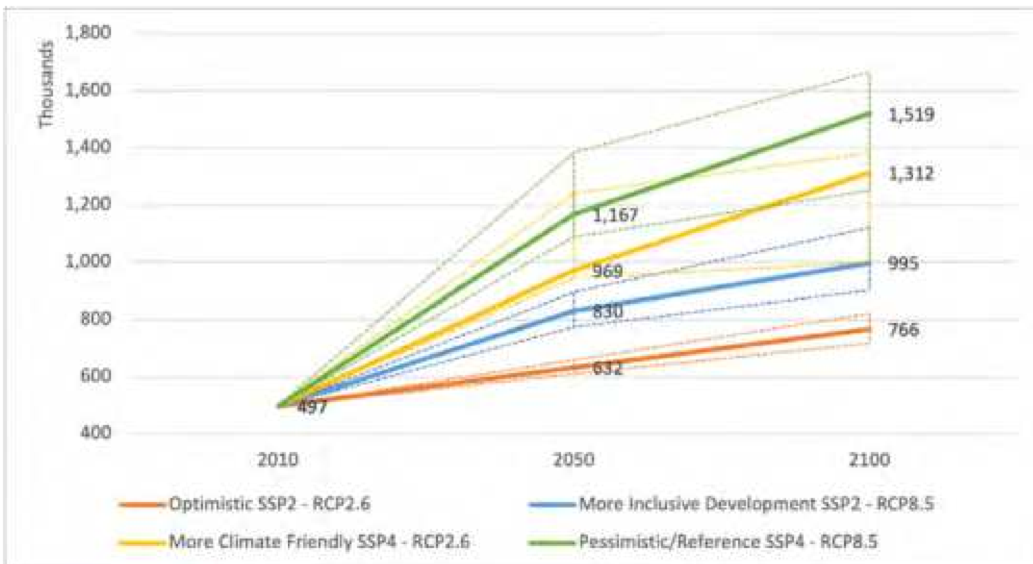
Source: World Bank staff analysis
Notes: RCP = Representative Concentration Pathways; SSP = Shared Socioeconomic Pathways. Whiskers represent min and max values from ensembled model (uncertainty in the estimate). Other migrants are calculated using the climate migrants estimates, and so the uncertainty is the same.

It is important to note that the population size of the DR changes between SSPs. As one might deduce by looking at the proportion of total population comprised of climate migrants, the SSP4 (Inequality) future is one where the DR population declines post mid-century, decreasing from 12 million in 2050 to 8.9 million in 2100.

Under SSP2, the population reaches 13 million in 2050, peaks around 2070, and then declines to just over 12 million in 2100. As such, and despite projecting a similar total number of climate migrants in the SSP4 scenarios (relative to SSP2 scenarios), climate migrants represent a substantial larger proportion of population in 2100 under both SSP4 scenarios.

Estimates of total internal migrants (climate plus others) show expected trends in which pessimistic development and climate scenarios lead to larger numbers of internal migrants (Figure 8). Three significant trends emerge. First, both of the SSP4-based (Inequality) scenarios project a higher number of total internal migrants than either SSP2-based scenario. The SSP4 scenario also projects a much smaller total population (over 3 million fewer people) for the DR by the end of the century, meaning much higher rates of internal mobility than the SSP2 future. Second, regardless of SSP, the RCP8.5 scenario (High Emission) leads to more internal climate migrants than the corresponding RCP2.6 scenario, an expected result given the more severe climate impacts projected under RCP8.5. Finally, under the Optimistic (SSP2-2.6) scenario, domestic migration is projected to decline slightly over the next few decades from observed 2010 numbers, before ticking back up after mid-century.

Figure 8: Total Internal Migrants (Climate plus Other) under each Scenario, 2010-2100: Dominican Republic



Source: Numbers for 2050 and 2100 come from World Bank staff analysis. The number for 2010 represents the total number of people moving between districts between 2005-2010, calculated by World Bank staff based on the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010).
Notes: RCP = Representative Concentration Pathways; SSP = Shared Socioeconomic Pathways. Dotted lines represent min and max values from ensembled model.

There is a fair degree of stability across scenarios in terms of the municipalities with the biggest gain and loss of populations as a result of climate change. The largest gains from climate migrants are consistently projected to occur in the urban municipalities of Santo Domingo Norte, Higüey, Santo Domingo Este, Los Alcarrizos, Villa Hermosa, and Santo Domingo Oeste, in that order. When net total internal migrants are considered, the largest gainers are mostly the same locations, with the addition of Distrito Nacional.

The largest net loss in population to climate-related factors over all scenarios occurs in the municipalities of Azúa, San Cristóbal, Baní, La Romana, Barahona, San Pedro de Macorís, Santiago, and San Juan. With the exception of Santiago and San Cristóbal, the projected climate out-migration of these locations is considerable compared to their population size. Most notably, the municipalities with the largest out-migration in relative terms to their population are the southern coastal municipalities of Sabana Grande de

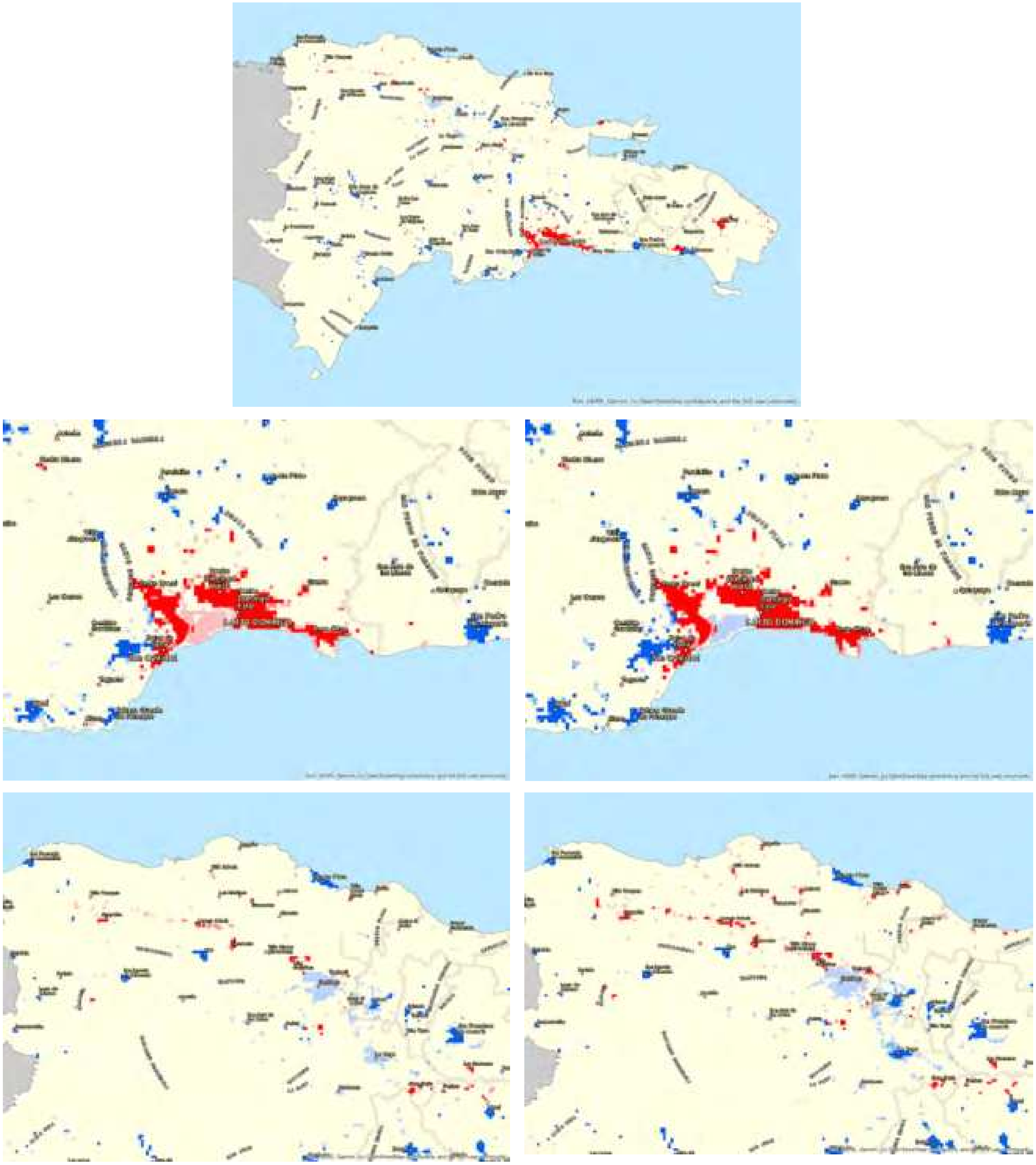
Palenque, Barahona, and Azúa, the border municipalities of Jimaní, Comendador, and Pedernales (which is also on the southern coast), and the municipalities of Tamayo, Neiba, and San Juan.

Maps with hotspots of climate in- and out-migration at the native 1-kilometer (1km) resolution show these trends in more detail (Figure 9). For practical purposes, hotspots are the locations that exhibit the largest (top or bottom 10 percent of all grid cells) differences in population totals across the four scenarios with climate change when compared to their corresponding "development-only" migration scenarios,[16] and for which there is agreement between three or four of the ensemble members in each scenario regarding the outcome. From the top panel, the primary hotspots of climate in-migration are the suburbs/urban fringe of Santo Domingo, Villa Hermosa, and the city of Higüey in the Southeast, and the area along the main highway to Santiago (region of El Cibao North and Northwest).

Climate out-migration hotspots include a few cities in El Cibao, including La Vega and Moca, as well as a few urban locations along the South Coast (e.g., San Pedro de Macorís, La Romana, and San Cristóbal). Santo Domingo itself yields an interesting pattern over time. The urban fringes of Santo Domingo (Norte, Oeste, and Este) consistently attracts climate in-migrants over the century. In contrast, central Santo Domingo attracts them from across the country during the first half of the century, but then becomes a net exporter of climate-induced migrants to its suburban fringe in the second half of century, as the densely settled urban core faces increased water stress because of reduced water availability and increased population density, and deteriorating conditions along the coastline. Finally, in El Cibao, a distinct pattern is clear over time, with climate impacts generally nudging people to the Northwest, away from the larger cities and toward the current smaller urban areas further north, where conditions are projected to be—in relative terms from climate change—better.

16 Simply the SSP2 and SSP4 futures projected under the assumption that climate remains constant.

Figure 9:
Projected Hotspots of Climate In-Migration and Out-Migration by 2050: Dominican Republic

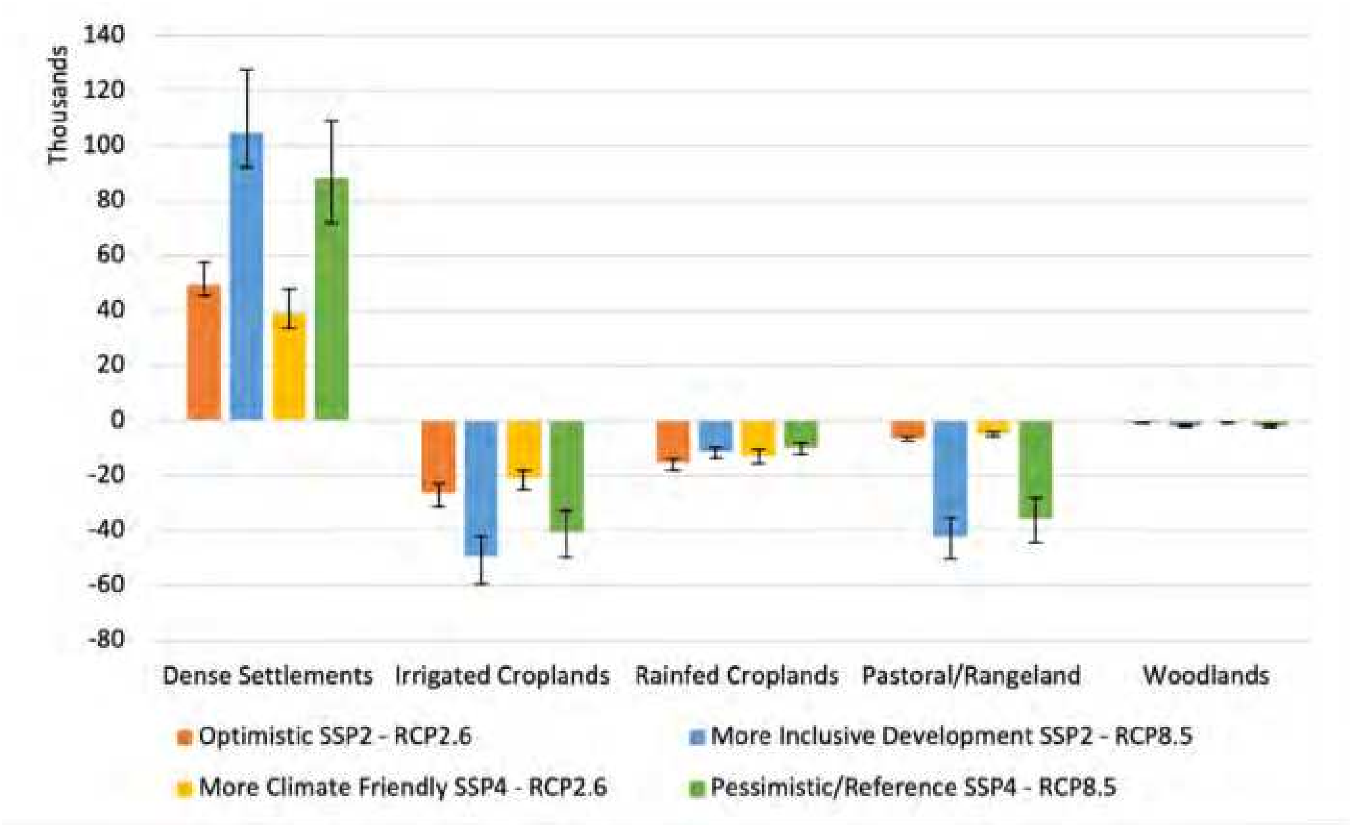


Source: World Bank staff analysis
Notes: Reds are hotspots of climate in-migration and blues of out-migration. Hotspots are the locations that exhibit the largest (top or bottom 10 percent of all grid cells) differences in population totals across the four scenarios with climate change when compared to their corresponding "development-only" migration scenarios. Darker shades of each color indicate areas where all four ensemble models project high levels of in/out migration across all scenarios, and lighter shades indicate that three of the four models agree. Places with larger populations are more likely to drive large numbers of migration and to appear as hotspots. A complete map for 2100 is provided in Appendix 4.

It is essential, when considering the hotspot maps, not to confuse areas of consistently projected high levels of climate-induced in-/out-migrants with a total population gain and loss. Hotpots of climate in-migration, for example, are regions where the number of total in-migrants is increased by the impacts of climate change when compared to a no-climate change scenario. This can occur even if total population is declining (as a result of natural decrease or out-migration for non-climate reasons). Similarly, the population can be increasing in a place characterized as a climate out-migration hotspot. Hotspots should be interpreted only as representative of the impact of climate change on total internal migration. For example, when "other" migrant movements —unrelated to climate change—are included in the projections, larger cities, such as Santiago or Distrito Nacional, continue to represent a net increase, even if they have out-climate migrant hotspots.

The largest numbers of internal climate migrants will arrive to dense settlements (i.e., cities), and come from irrigated croplands, pastoral lands, and rainfed croplands. This study assesses the impact of climate change on internal migration by livelihood zone, dividing the country into regions dominated by urban landscapes, irrigated croplands, rainfed croplands, pastoral/rangelands, and woodlands; and tally the projected number of net climate migrants over each. Under all scenarios (Figure 10), dense settlements are significant net receivers of climate-induced migrants, suggesting that the vast majority of people who move as a result of climate impacts seek out urban areas (this includes migrants already located in urban areas—so-called urban-to-urban migrants—as well as rural-to-urban migrants). The more dire climate scenario (RCP8.5) produces more than twice the number of migrants into urban areas than the RCP2.6 (Low Emission) scenario under both SSPs. Irrigated croplands and pastoral/rangelands (largely in El Cibao and adjacent regions of the Cordillera Central), are generally the largest net senders of climate migrants. Rainfed croplands generally fair better (although are still net senders under all but the SSP4-8.5 Pessimistic scenario in 2100 (See Appendix 4). The low population in woodland areas renders these regions somewhat neutral.

Figure 10:
Net Internal Climate Migrants by Livelihood Zone and Scenario, 2050:[1] Dominican Republic.



Source: World Bank staff analysis
[1] Data for 2100 is provided in Appendix 4.
Note: SSP = Shared Socioeconomic Pathways.

These numbers include a small and conservative estimate of SLR's effects on human mobility. SLR as a driver on its own accounted for a small portion of projected climate migrants (less than half a percentage point by 2050 and less than 2.5 percent by 2100 in the SSP2 scenarios), but this could be due to limitations on modeling the diverse factors of this phenomenon beyond inundation and storm surge and because movements due to SLR may be within the same municipality (see limitations section in Appendix 4 for more information).

Projected International Climate Migration 2020-2100

For this project, the INCLUDE model was combined with an econometric model for projecting international migration from Haiti to the DR, which reports slightly different outputs. Like the internal model, the impacts of climate change are inferred by comparing the scenarios in which emission pathways and climate change impacts are included (e.g., RCP2.6 and RCP8.5), as well as scenarios which hold climate constant (SSP-only). However, whereas the internal INCLUDE model operates at a 1 kilometer resolution and results are aggregated up to the municipal level, the international model projects a single estimate of total migrants from Haiti to the DR at each time step, and those migrants are then distributed across the 155[17] municipalities of the DR. Climate migrants originating in Haiti are derived by municipality within the DR and at the national level. Also similar to the internal model, other and total migrants are projected and reported for each time-step/scenario. Nevertheless, the uncertainty in this model is more pronounced than in the internal model, given the less-granular origin data and the high correlation of climate and economic drivers in Haiti.

The range of outcomes across and within scenarios is fairly wide, reflecting wide uncertainty in the exact number of migrants. For example, under the Pessimistic scenario, if each ensemble member is considered individually, the maximum number of the scenario is more than three times the minimum and with differences of many hundreds of thousands. On the one hand, the wide range of climate migrants reflects uncertainty in the climate inputs from the ISIMIP models (data source of the climate inputs). On the other hand, uncertainty in the total number of migrants is driven by not only climate uncertainty but also by the interaction between climatic and socioeconomic conditions.

Likewise, the wide range of outcomes across scenarios reflects a significant level of uncertainty in the relationship between nationwide climate drivers in Haiti and of movement into the DR. Additionally, it should be noted that these figures reflect no change in border policy (on either side) over the course of the century—an unlikely outcome if the number of migrants changes substantially, if conditions deteriorate substantially, or both. It also reflects a future in which Haiti's fragility, conflict, and vulnerability conditions continue the trends of the last few decades (which are reflected in the historical data used for this model). Given the increased uncertainty in this international model, the estimate table (Table 3) and the description of results focus on relative changes and trends instead of estimated numbers. The range of outcomes for each scenario in Table 3 reflects the minimum and maximum share of climate migrants projected by each individual model ensemble member, and the average reflects the ensemble mean. [18] The reported trends should be taken cautiously and used in conjunction with other data sources and knowledge to inform policymaking.

[17] This was the number of municipalities in the 2010 Census, which was the basis for this analysis. This number has changed since then.

[18] As mentioned in the methodological section, for each scenario, a small model ensemble consisting of four models was applied. Each ensemble member considers a different combination of GCM (a global "climate model") and sectoral impact models (which use the data produced by the GCMs to project changes in crop yield, water stress, and ecosystem productivity). The ensemble approach accounts for uncertainty in climate outcomes by considering a range of projected futures under each RCP.

Climate migrants coming from Haiti into the DR are expected to represent six to 20.1 percent of all migrants by 2050, with the highest number and share of climate migrants in the Pessimistic scenario. Under the Optimistic SSP2/RCP2.6 scenario, the average projected share of climate migrants from Haiti to the DR is around 6 percent by mid-century. This proportion rises to 11.2 percent by the end of the century. The scenario SSP2/RCP8.5 (more Inclusive Development) that holds development pathways inclusive but uses the Pessimistic climate scenario, has an average projection of 19 percent by mid-century, owing to the worsening environmental conditions in this scenario. This percentage is expected to rise to 26 percent by the end of the century. Unlike the middle-income DR, the population under SSP4 (Inequality) in Haiti, a low-income country, is projected to be substantially higher than under SSP2 (Middle of the Road), a result of a much slower decline in fertility rates projected under SSP4 (relating to stagnant education attainment levels under the more Inequality scenario). As such, the average total number of projected arrivals from Haiti is expected to be much greater under the two SSP4 scenarios. Climate migrants correspond to over 20 and 28 percent of total migrants from Haiti under the Pessimistic scenario for mid and end of century, respectively (the highest share among scenarios). Two trends dominate these projections: (i) the SSP4 scenarios produce more total migrants as a function of worsening socioeconomic conditions in Haiti relative to the DR, and (ii) the RCP8.5 scenarios project a much larger number of climate migrants than the corresponding RCP2.6, in absolute terms, as well as a proportion of total migrants.

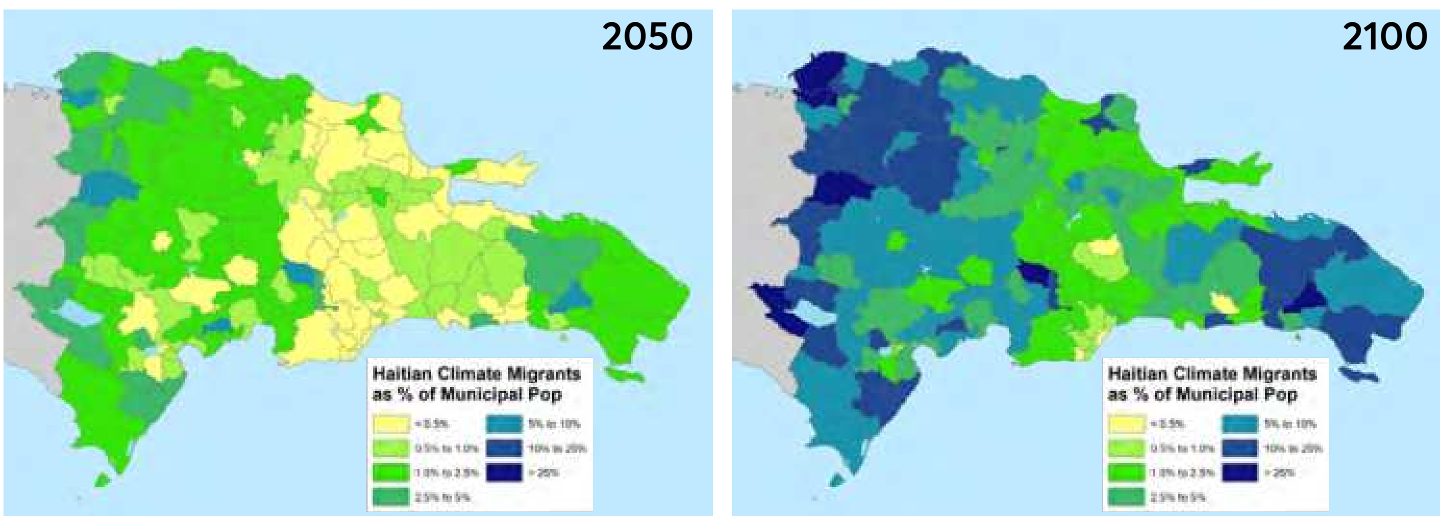
Table 3: Percentage Climate Migrants from Haiti to the Dominican Republic

% of climate migrants relative to total migrants	2020 - 2050			2051 - 2100		
	Min	Avg	Max	Min	Avg	Max
Optimistic RCP2.6 / SSP2	4.9%	6.0%	7.0%	9.6%	11.2%	12.8%
More Inclusive Develompent RCP8.5 / SSP2	14.5%	118.8%	20.3%	18.0%	26.0%	27.6%
More Climate Friendly RCP2.6 / SSP4	6.9%	7.8%	8.5%	10.5%	13.3%	14.4%
Pessimistic / Reference RCP8.5 / SSP4	16.3%	20.1%	22.5%	22.2%	28.1%	31.1%

Source: World Bank staff analysis
Notes: RCP = Representative Concentration Pathways; SSP = Shared Socioeconomic Pathways

The estimated distribution of these future climate migrants into municipalities seems largely similar to current trends, but with some changes in the local intensity of in-migrants. In terms of absolute number of climate in-migrants, the capital region, urban areas of El Cibao (especially Santiago, Guayubín, and Mao), the livestock and agricultural region of San Juan, and the eastern municipality of Higüey, are the largest receivers of Haitian immigrants. Many of these municipalities, however, are dominated by urban areas and are thus heavily populated. Expressed as a proportion of municipal population (Figure 11), municipalities along the Haitian border (e.g., Monte Cristi, Pepillo Salcedo, Pedro Santana, Jimaní, and La Descubierta), and important agricultural locations in the Southwest such as Sabana Yegua, Polo, and Rancho Arriba a bit further to the Northeast, disproportionately receive Haitian migrants. If this trend develops at the intensity projected by the model, these municipalities may find certain public services stressed by the influx of migrants. With adequate preparation and planning, however, the influx of potential agricultural workers could also provide a boom to the local economies. It therefore is important to consider any potential large-scale migration for the opportunities it offers, as opposed to assuming mobility is an inherent threat.

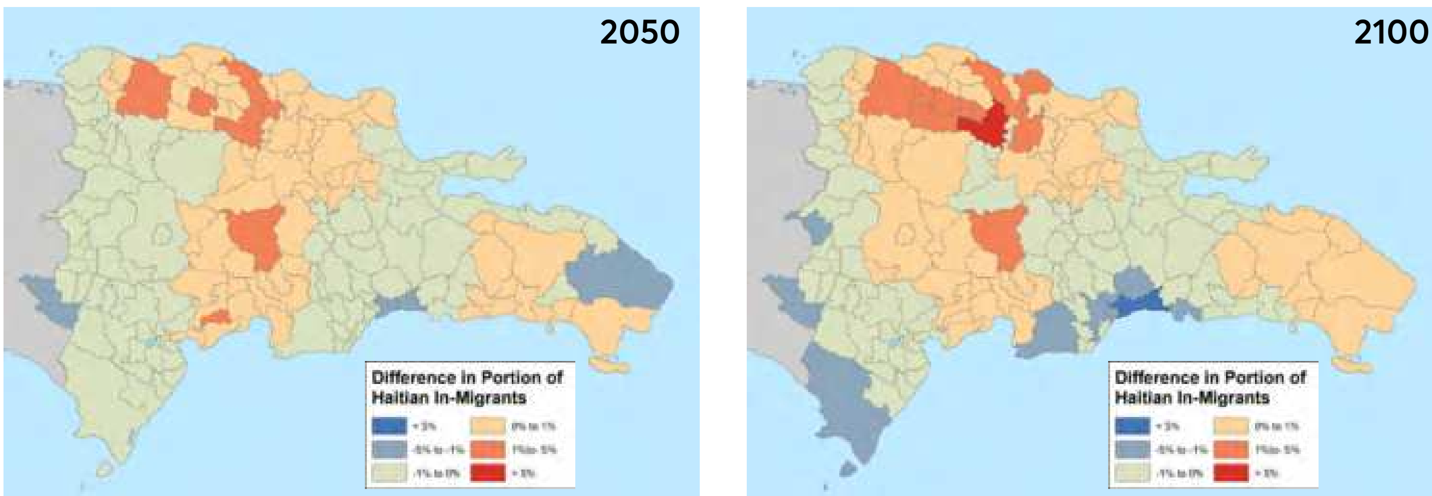
Figure 11: Projected Climate In-Migrants from Haiti (top maps), Expressed as a Proportion of Population (bottom maps) by Municipality, 2050 and 2100: Dominican Republic



Source: World Bank staff analysis

Migrants coming from Haiti, who are driven by the impacts of climate change, could change the distribution of Haitian migrants across municipalities. When projected Haitian migrants are disaggregated into climate/other by municipality, Figure 12 illustrate how these climate migrants may shift the country's proportional distribution (relative to all Haitian migrants).[19] The model projects an increasing proportion of Haitian migrants arriving across most of El Cibao, including Santiago, the latter a city projected to be a net sender of domestic climate migrants. Elsewhere, a corridor running through most of the Cordillera Central and south through Azúa Province is projected to experience a relative increase in the proportion of Haitian in-migrants, while Santo Domingo and areas along the border with Haiti are expected to experience slight declines in the relative proportion of Haitian arrivals.

Figure 12: Difference in Proportion of Haitian In-Migrants: Dominican Republic

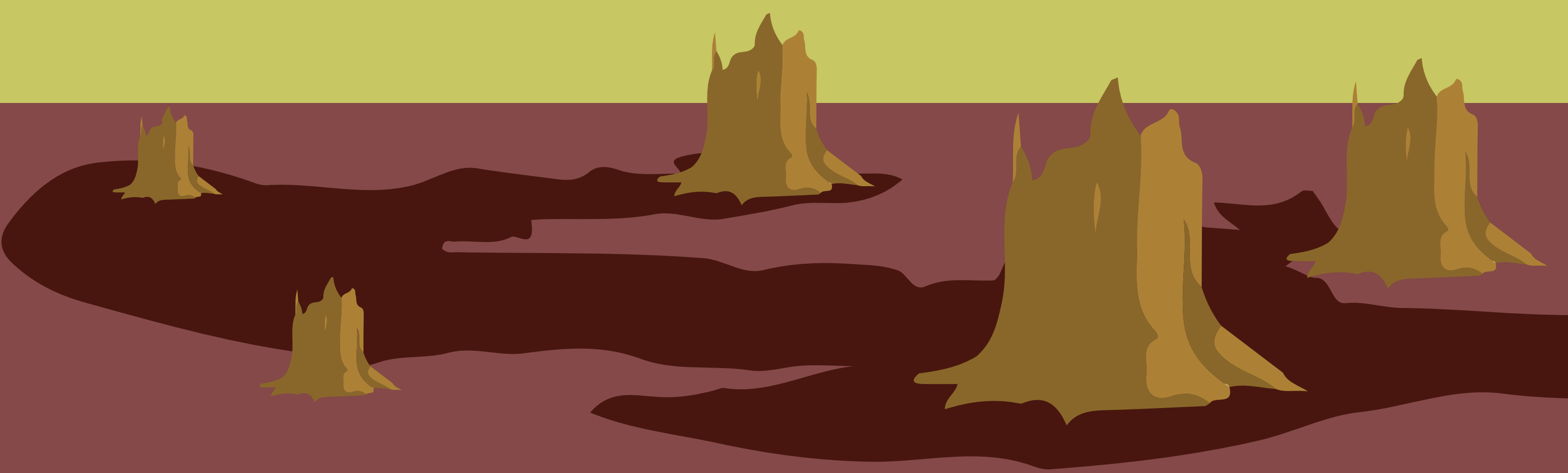


Source: World Bank staff analysis.
Notes: To calculate this, the analysis takes the 2050 and 2100 distribution of all migrants and compares it against a hypothetical scenario in which Haitian climate migrants follow the same pattern of municipal residence as non-climate migrants - the difference can be attributed to the municipal pattern driven by climate impacts.

[19] To calculate this, the analysis takes the 2050 and 2100 distribution of all migrants and compares it against a hypothetical scenario in which Haitian climate migrants follow the same pattern of municipal residence as non-climate migrants - the difference can be attributed to the municipal pattern driven by climate impacts.

PART 2:

QUALITATIVE CASE STUDY OF RESTAURACION MUNICIPALITY IN TERMS OF INTERNAL EMIGRATION CAUSED BY CLIMATE CHANGE AND NATURAL DEGRADATION



Methodology

This study used a qualitative in-depth semi structured interview method to explore the decision-making of internal migrants and its relationship to climate and environmental variables. Because of the method, the study was performed in a delimited area—Municipality of Restauración—so that responses and experiences were able to be better contextualized.

Restauración was selected based on consultation with local experts, since it interlinks a target area for reducing carbon emissions and because of its relevance on migration, agriculture and forestry. It is not only part of the influence area of ERP (Appendix 5), but also is a municipality that has historical relevance to the process of migration, internally and internationally, due to its location on the border with Haiti and registering previous significant internal migration waves. Furthermore, forestry and agriculture are important economic activities and, theoretically, they constitute a mechanism through which climate change and natural degradation may impact internal migration. The characteristics of Restauración are described in the following section.

Interviewees were Dominicans who had emigrated from localities within Restauración to other localities in the DR and who had been involved with agriculture in their community of origin. While the main target subjects were internal migrants who emigrated because of climate change, this characteristic was not possible to identify, ex-ante, due to various challenges. Instead, it was decided to prioritize those who had (i) emigrated, (ii) who they themselves or their families had worked in agriculture within their community of origin, and (iii) who were originally from communities which, according to key informants, suffered significantly from degradation in terms of natural resources compared to other vicinities within the municipality. The expectation was that by focusing on these characteristics, the sample would include emigrants who had been impacted by climate change and natural degradation. Nevertheless, while the driver may have been climate change, it was difficult to accurately establish a distinction between those environmental impacts caused specifically by climate change or other causes. The methodology therefore centers on a discussion of mechanisms that may have been caused by climate change (e.g., reduced water availability or land productivity). It is important to note, however, that the influence of direct human actions, such as deforestation or the overexploitation of resources, as well as other climatic variables, may also have influenced these mechanisms.

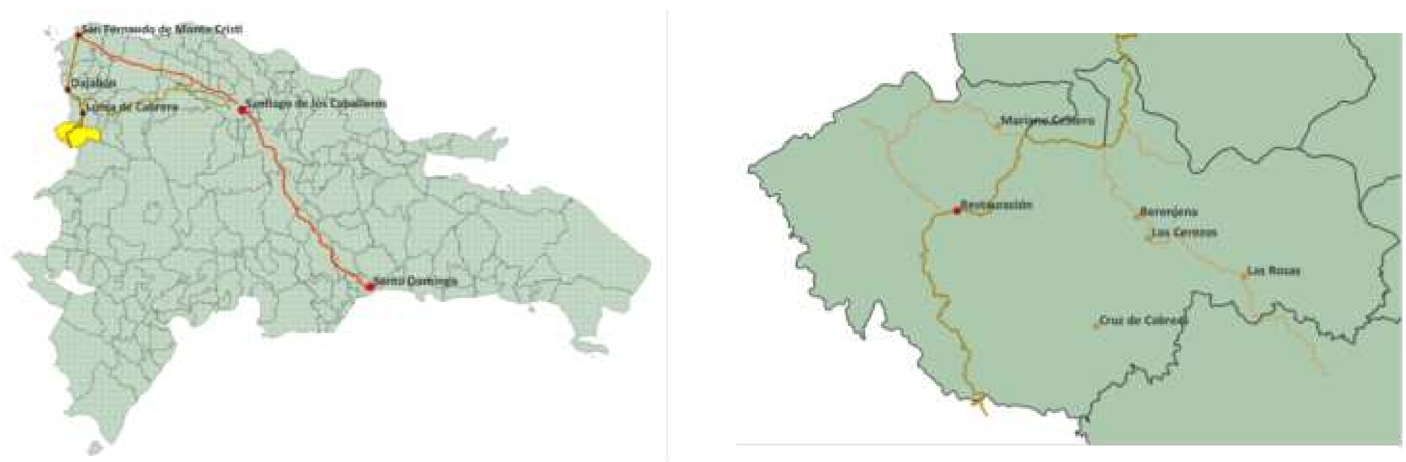
Because of the challenges identifying migrants, which by definition do not live anymore in the specific area of interest, the study used a non-probabilistic sampling method called "snowball". The research team started with interviews to key informants (e.g., local public workers, local leaders, etc.) and asked if they could connect the team with people that emigrated from the two localities and had been involved with agriculture; as the team interviewed new participants, more contacts were requested from new interviewees. The team continued this process until additional interviews were not providing new information, which is a recommended criteria to determine sample size in qualitative methods, called "reaching saturation" (Skovdal and Cornish, 2015). The limitation of this method is that the subjects may be connected, potentially reducing the variability of experiences. However, it was assessed that this was the best available method for this research topic. Because of the logistical challenges of commuting to diverse locations in the country where participants emigrated, most interviews had to be performed remotely via cellphone.

Ultimately, 17 emigrants and 10 key informants were interviewed, reaching an acceptable sample size and representation of subgroups to be able to carry out a rigorous qualitative study. While both men and women tend to emigrate from Restauración, despite multiple efforts to find times and venues suitable for women, most of those the team was able to interview were male (13 out of 17). It was also shared by key informants that most of those who emigrate are the young —a characteristic reflected in the sample with a median age of 22 when migrated (minimum: 17; maximum: 49). In the sample, some had migrated as recently as one year ago, while others had migrated as far as 40 years ago (median: 12; mean: 17). By design, every interviewee either had been involved in agriculture prior to emigrating or had helped her/his family in this activity. In particular, most of the women did not consider themselves as farmers, preferring to focus on education or household tasks, despite alluding to assisting their spouses or parents in agricultural tasks, such as harvesting. The final sample size involved those who had emigrated from Las Rosas (11 out of 17) and Cruz de Cabrera (3), with the remaining coming one each from Berenjena, Cruce de Mariano, and the urban area of Restauración.

Climatic and Socioeconomic Context of Restauración

Restauración is located in the northwest of the country and in the southern part of Dajabón Province. [20] It is demarcated to the north by the Municipality of Loma de Cabrera, to the south by Elías Piña Province, to the east by Santiago Rodríguez Province, and to the west with the border of Haiti (Figure 13). Restauración was created as a municipality in 1892 and is 283.6 km2 in area; it has 42 vicinities, including an urban area of the same name.

Figure 13:
Location of Restauración[1] and Vicinities within Restauración,[1] Dajabón Province, Dominican Republic



Source: World Bank staff using Open Street Maps locations and roads and Census 2010 borders.
[1] The yellow area in the map on the left represents Restauración, red dots represent main cities, and red and brown lines represent key highways; the map on the right shows vicinities of interest in Restauración, with the main highways and roads drawn in dark brown and light brown, respectively.

[20] The province is formed of four municipalities: Loma de Cabrera, Restauración, Partido, and El Pino

According to data from the 2010 Census (GoDR 2010), Restauración had a population of 7,274 people. Fifty-four percent were men and 39 percent lived in the urban area. Within Dajabón Province, Restauración is the municipality representing the lowest average age (26.4 years), and has the highest average number of children per family (2.5) (GoDR 2017). It has poverty and extreme poverty levels of 79 and 38 percent, respectively. Only 9.9 percent of the population is supplied with drinking water from a tap in their homes and 23 percent of the water is sourced from springs. In terms of fuel, the most prevalent are firewood (52 percent) and coal (5.4 percent) (FUNGLODE n.d.). Restauración's illiteracy rate is at 25.2 percent, higher than the national rate of 12.8 (GoDR 2017).

Restauración has one main highway that connects its vicinities with Haiti and other provinces of the DR. The main road to Restauración, Highway 45, connects the municipality and its urban area to Lomas de Cabrera to the Northeast, and provides access to not only the provincial capital of Dajabón but also to other roads that reach Santiago city via Duarte Highway, one of the main highways in the DR. Trade, as well as most other transportation, head in this direction to Dajabón.[21] In the other direction, highway 45 also connects the Southwest to the international highway that traverses the DR to Haití and back to Elias Piña. Transport in this direction is more difficult due to the border crossings. Other local roads of lower quality emerge on Highway 45, such as one heading southeast in the direction of Elias Piña, connecting many communities (e.g., Las Rosas and Los Cerezos) (Figure 13).

[21] Annual operational development plan of the municipality of Restauración for 2020-2024 (Restauración Municipal Government 2020)

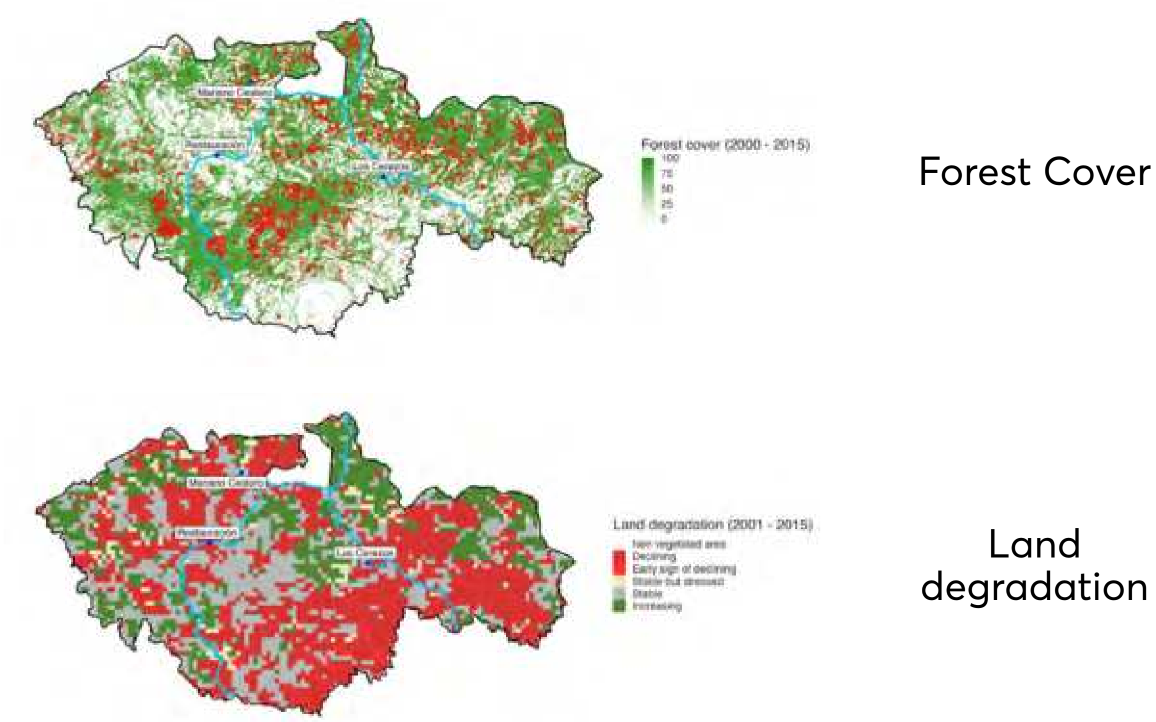
Agriculture and Forestry in Restauración

Agricultural and forestry production constitutes the main source of income in the communities of Restauración. The municipal annual development plan reflects agro-industrial wood processing as the main economic activity, followed by agriculture and livestock. Agriculture is the sector with the highest employment (37 percent). The most common type of agriculture in the area is rainfed, which depends on the rainy and dry seasons and is concentrated on short-cycle products such as beans, peas, corn, and cassava, among others. Forest plantations are mainly of the pine varieties: Pinus occidentalis and Pinus caribaea, as well as Honduran mahogany, caoba (Swietenia macrophylla). For some key informants, the management and exploitation of forests have expanded significantly in the area during the last decade. Some interviewees complement their exploitation of wood with agroforestry products (e.g., coffee or cacao). In some cases, farmers compartmentalize their land to enable multiple cash-crops, trees, and perennial crops. While livestock is also an important economic activity in Restauración, it is not as predominant as in the neighboring municipalities of Dajabón Province, and the neighboring province of Santiago Rodriguez Province where it is the main activity. Nevertheless, the intensity of these activities in the region has had environmental, trade, and economic implications for the municipality, particularly in the form of deforestation and land degradation.

These communities have experienced various changes in agricultural practices and agrarian systems. Changes in agricultural practices are the result of awareness raising by experts from the Ministry of Agriculture (Ministerio de Agricultura), nongovernmental organizations, and international cooperation agencies. These institutions encourage farmers to cease the practice of burning and the use of agrochemicals and, instead, advocate replacing them with sustainable practices that include the use of live barriers, crop rotation, and organic fertilizers. Nevertheless, many continue to use such unsustainable practices, and the slash-and-burn agriculture continues predominantly in the area. In terms of agricultural systems, these have changed due to natural and human factors that have influenced crop substitution. These include a decrease in peanut production because of reduced demand and orientation of buyers, the substitution of coffee plantations for varieties resistant to diseases common in the area (roya del café; (Hemileia vastatrix)); and its consequent impact on the recovery of the forests.

Deforestation is a core issue in the municipality and province. According to the Hansen Global Forest Change v1.9 (2000-2021) dataset (based on Hansen et al. 2013), Dajabón is the third province with the highest forest lost rate between 2001 and 2020 with 7.6 percent; the second if we exclude the Capital that only has 8.7 percent of forest cover in 2000. Restauración was the 32nd (out of 155) district with more forest cover in 2000 due to 60.2 percent of its territory being covered by forest. Similarly, between 2001 and 2020, it had a deforestation rate of 22.8 percent, ranking 56th in the country, albeit 31st if considered as hectares lost (Figure 14 (upper image) shows the spatial distribution of deforestation in the municipality). Deforestation in the municipality is attributed to three main factors: (i) the presence of sawmills to take advantage of forest resources; (ii) slash-and-burn agriculture; and (iii) deforestation to create grassland for livestock. The presence of sawmills has led to the cutting of timber trees, mainly in mountainous areas, and the consequent loss of forest. Slash-and-burn agriculture also has contributed to deforestation, with the cutting of trees to make way for short-cycle agricultural crops or livestock production. The predominant importance of livestock as an economic activity in neighboring areas of Dajabón Province and Santiago Rodriguez Province also affects Restauración's forests.

Figure 14:
Deforestation and Land Productivity Category in Restauración, Dominican Republic, 2001 2015.



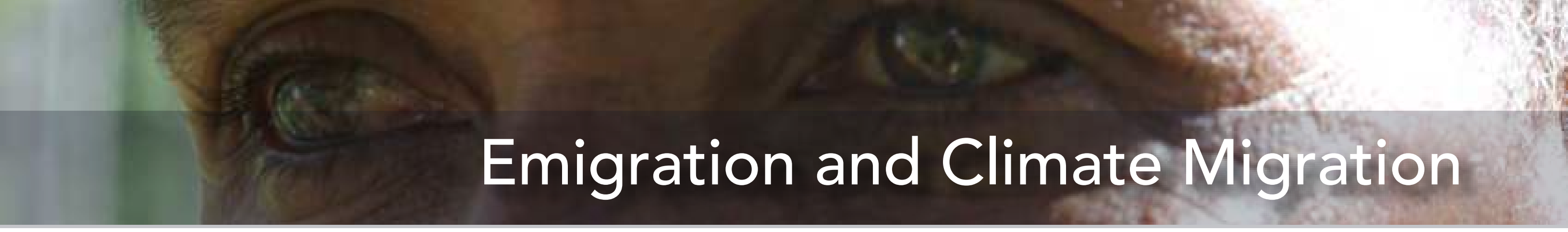
Sources: (i) Hansen Global Forest Change v1.9, based on Hansen et al 2013; (ii) Land Productivity Dynamics LPD-MODIS (derived from NDVI product of MODIS/Terra Vegetation indices 16-Day L3 Global 250m SIN Grid V006).

According to key informants, deforestation has had various impacts on water availability and soil productivity. Participants pointed to deforestation as the main reason that water streams, rivers, and rainfall are decreasing. Declining rainfall directly affects agriculture production, since crops depend on it. Further, rivers have raised in political importance as an issue of national security. Soil erosion, and its consequent reduced productivity, also is linked to deforestation; with the loss of forest cover, soil becomes devoid of protection from rain and wind. Torrential rains tend to wash away the soil and increase the erosive process—somewhat more pronounced in the mountainside areas. According to the Land Productivity global datasets, about half of the land in Restauración declined in productivity between 2011 and 2015. Figure 14's lower image illustrates how this has generalized across the municipality in the period 2001-2015, including in the areas of Lomas de Cabrera and Las Rosas.

"Well, the [trees] that have disappeared, the ones that we farmers have cut down. The upper part had a lot of mahogany, cedar, almond, cabirma, cigua. And that has disappeared, most of the rivers have been ceded to the farmers due to the lack of resources, if you are the father of a family and you do not have resources, you are going to depredate a forest to produce food (...) number of farmers manage the ground with fire (…), knocking down trees and the land has been degraded."

(Key interviewee, male, and a member of the Local Forest Association).

When discussing Restauración's environmental issues, key informants often perceive that a contributing factor is the intensive unsustainable agricultural practices carried out by immigrant workers. Many key informants commented on the large number of Haitian workers employed and living in the area, who occupy or use land that has been abandoned or which is shared by Dominican farmers working under sharecrop schemes. Under these schemes, Dominican landowners allow Haitian immigrant workers to practice agriculture in their lands, with landowners receiving an (often large) share of the production. A problem expressed by the interviewees is that these schemes often use unsustainable practices, such as slash and burn and indiscriminate deforesting. It was also recognized that Dominicans landowners sometimes have a shared responsibility in this issue by allowing (or even incentivizing) these practices. In some cases, key informants reported that Haitian immigrants use lands that Dominicans left after emigrating.



Emigration from Restauración

According to interviews, the main reasons for people to emigrate from Restauración's communities (emigration drivers) are lack of employment, low agricultural productivity, and the need and wish to pursue better educational opportunities. The first two are related as they represent barriers to meeting people´s needs and motivating them to find other options. In this sense, migration becomes an adaptation strategy to low agriculture productivity and lack of alternative jobs. This strategy is most attractive to young people, who see the challenges that their parents confront with agriculture and aspire to different education and opportunities.

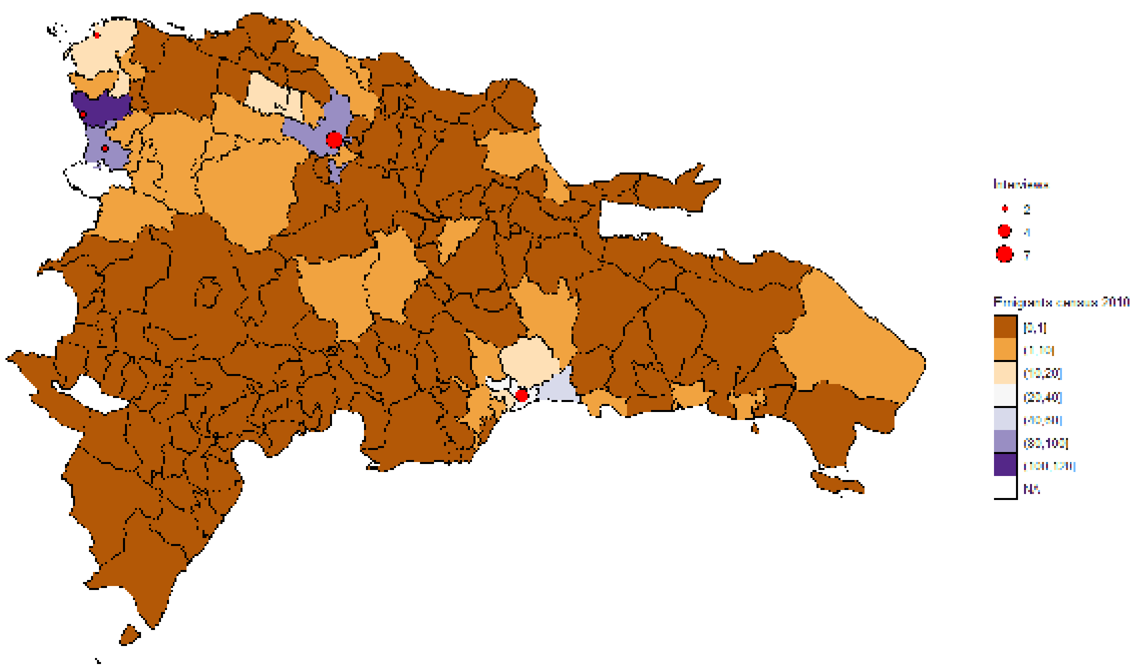
"(I used to work) in agriculture, I used to work with people, and they gave me something (to do)… picking peas, planting pine trees in forests… It's not easy for young people to be involved in agriculture… I don't like agriculture."

(Interviewee No. 16, age 25, when migrated, female, who migrated to Santiago)

Social networks, family, and/or friends are key resources to facilitate the migration process in any given destination. The migratory process usually initiates as a result of contact with family or friends who serve as the link to migration; they are considered a key to facilitating the process. In the observed cases of families, usually the first to leave the community is the father; once established at the destination, the other family members will follow. The main help that friends or family provide is the provision of a place to live while the now emigrant gets a job and can live independently. Absent of these links could be seen as a barrier to use this adaptation strategy.

The main destinations for emigrants from these communities are the urban centers of Dajabón, Loma de Cabrera, Montecristi, Santiago, and Santo Domingo. The economic dynamism of urban centers makes these the preferred places of destination, since employability is easier. In these locations, instead of agriculture, participants are engaged in activities of the tertiary or secondary sector, such as mechanics, operating machinery, or having small businesses. Santiago and Santo Domingo present advantages over Dajabón, Montecristi, and Loma de Cabrera in terms of offering more diverse labor opportunities. The advantage of Dajabón and Loma de Cabrera is their proximity to the communities of origin, which allows emigrants to maintain ties with the communities from where they emigrated and in some cases continue carrying out productive work. These main destinations are also evident when looking at data from the 2010 Census (Figure 15).

Figure 15:
Number of Interviews Held for the Study, and the Emigration from Restauración, Dominican Republic



Sources: World Bank staff based on data from the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010) and from the number of interviews carried out for this study.

Notes: The graph was created based on a question included in the 2010 Census regarding the municipality in which the person (5 years and older) was living in 2005. Emigrants on this map are those participating in the Census outside Restauración in 2010 and who reported as having been residing in Restauración five years previously, in 2005. The data did not report emigrants from Restauración Municipality to their own district, and so are represented as NA.

Migration Caused by Climate and Natural Degradation

Even though the participants' most present reasons for emigrating are related to education or work, when inquired, they recognize how natural degradation and changes in climate played a role through loss of agricultural productivity. Participants were aware of the link between environmental degradation and migration, given the fragility of agriculture livelihoods due to hydrometeorological factors (i.e., too much or too little rain), deforestation, and the loss of soil production, all of which translates into a loss of agricultural production. The following comments exemplify these links:

"… At the time there, people mistreated the trees, and nothing was achieved, and that is why many people decided to move from there. At the time, several of us emigrated because the situation was terrible."

(Interviewee No. 11, 57, female, migrated to Santo Domingo).

"… What I cultivated was lost; when it was not because of one thing it was because of another. When I saw that what I grew resulted in many (economic) commitments, I got out of it, but I had to pay for those commitments [loans] because everything was lost."

(Interviewee No. 8, 41, male, migrated to Montecristi).

Participants referred to the hydrological changes, particularly regarding precipitation and the effects on the sowing and harvesting seasons, which led to unpredictability and production loss in what had been a rainfed farming system. Since the area relies on rainfed agriculture, the reduction or loss of agriculture production is identified by emigrants as the result of extremes (i.e., from dry to too much rain during the rainy season), thus influencing their decision to leave and seek employment elsewhere. Interviewees added that because of these extremes, it was difficult to maintain their traditional knowledge and practices. Furthermore, one person perceives that the reduced formation of rain clouds is directly the result of deforestation.

"There in the countryside, there is no irrigation system… and (if) I sowed and it did not rain, it was spoiled… and if it rained, the rain was spoiling it. The agricultural system is based on the rain that makes it wet …. When the weather was favorable, the land produced peanuts, beans, corn… Many farmers from the countryside have emigrated."

(Interviewee No. 1, 60, male, migrated to Santiago).

"All of that is needed. When there are no forests or anything like that, where do the clouds go to provide the fall of water?"

(Interviewee No. 5, 41, male, migrated to Montecristi).

"… I joined forces with a boy … We planted about two loads of beans, and they were lost [because] no water fell, and the harvest was a burden... I was left with a lot of trouble. I went to Dajabón and he went to Santiago. Agriculture is an adventure, of course, because if you plant and it rains, it could happen that you get production, but if it doesn't rain, what can happen?"

(Interviewee No. 6, 30, male, migrated to Santo Domingo).

Likewise, issues relating to low soil productivity are perceived as the cause of lower yields. For many interviewees, the land "is tired" or "it is denied to man." The low productivity of soil relates to erosive processes, whereby when it is washed away by excessive water or wind, it no longer has the capacity to sustain agricultural crops. This fact is validated by the following comments, one of which is as follows:

"As long as one helped the land, it was productive, but if he did not help it, it was not. If you repeat it three times it is productive, but the fourth time the products are not given, they give 'aplejíos' [crops that are not developed]. "

(Interviewee No. 5, 41, male, migrated to Montecristi).

Farmers have attempted applying different strategies in order to adapt to the reduction in productivity. Among the strategies used by the interviewees to deal with reduced production are the use of fertilizers, herbicides, and pesticides to improve crop productivity. Farmers also have moved to plots that are less degraded or that have been unused for some time; in other words, a migration of the land instead of migration to another place of residence. These strategies did not always achieved expectations and are often compounded by the challenges and sometimes it was difficult of finding more productive lands (for example, one that could be irrigated):

"But, if one sows with fertilizer there, he has a little strength, but if he doesn't find how to put fertilizer or how to help her (the land), it doesn't matter. In the times that I worked, there were years that came good and others that came bad, but when there was water everything was fine; but not when it was dry."

(Interviewee No. 5, 41, male, migrated to Montecristi).

"People sow in different places ... They say (one should) sow in the first and last months. The land is denied … If one had control of the water it would be better. If it were irrigated land it would be better, but if you sowed and it doesn't rain you lose it."

(Interviewee No. 6, 30, male, migrated to Santo Domingo).

"(…) One lived changing (land). This year he sowed here and the other year elsewhere. (…) (because) one thought that the land was bad and changed, seeking improvement."

(Interviewee No. 9, 27, male, migated to Santiago).

Faced with such livelihood challenges, migration and the search for employment have become the main strategy to improve living conditions. As explained by one interviewee:

"Las Rosas is difficult, because it is difficult to live without a job. Over there, people live off agriculture and things are lost when it rains or it is dry, and the land has been denied to man there. If it is not one thing, it is the other. To live there, you must have a job. "

(Interviewee No. 17, 41, female, migrated to Dajabón).

Staying, Despite Climate Change and Natural Degradation

While many end up migrating influenced by the climatic and environmental conditions and low agricultural productivity, others stay and continue to work in agriculture and forestry. While our study design was meant to capture perceptions of people who migrated, key informants in the area also gave us the view of people who remain in the area and are able to make a living with agriculture and agroforestry. These cases contrast with those who have emigrated and serve to observe a resilience to these changes and strategies used.

One of the most commented adaptation strategies was the diversification of activities, mainly in the agroforestry and forestry sectors. Agroforestry was referred to as one of the main farming diversifications, particularly in relation to the cultivation of coffee and cocoa, products that are encouraged by local branches of the Ministry of Agriculture (Ministerio de Agricultura). Agroforestry not only promotes the conservation of forestry and resulting land recovery, it also allows farmers a source of annual income throughout the year when the forests are cultivated with perennial crops (e.g., oranges, avocados). The cultivation of coffee and cocoa are reminiscent of traditional agricultural activities, practiced within areas that were originally affected by pests, where new varieties now have been introduced that are resistant to the roya del café disease.

One key informant even mentioned that the development of forestry and agroforestry in Restauración has significantly improved the economic prospects of the municipality and has motivated people to return, including he, himself. Likewise, other interviewees indicated that communities such as Baúl, Los Cerezos, and La Berenjena also have seen a return of migrants. While this excitement is likely warranted, there also may be difficulties to enter these economic activities for low-income farmers with few resources or land to invest, as they require more time and investment than "cash-crops". Some policies are canalized through local associations, such as the provision of plants and support to set up plant nurseries, and have help farmers overcome these barriers (Figure 16). Nevertheless, this did not seem widespread even across households of the same community where it was implemented.

Figure 16: A Plant Nursery and Cocoa Crop in La Berenjena, Dominican Republic

Source: World Bank staff fieldwork

Other adaptations strategies and policies, such as the use of production technologies or technical support, were also mentioned, although with less success. Production technologies, such as the use of herbicides and chemical fertilizers, are reported as allowing farmers to increase their productivity. Likewise, interviews mentioned adaptation policies provided by the government. For example, they mentioned technical support ("extensionismo agrícola") and the use of machinery. Even though there are problems with technical support, the workshops and training sessions with farmers allow them to implement strategies that improve crop productivity. This support is provided not only through government institutions such as the Ministry of Agriculture, but also through non-governmental organizations that provide occasional aid to farmers. Additionally, the Ministry occasionally supports farmers with their tractor to help prepare the land. While these strategies and policies were mentioned occasionally, it was clear that they needed improvement to effectively support farmers.

"The use of chemical products burning are very harmful. But that is what is used in practice. It's always about raising awareness so they don't use it. There are agricultural plants, which, for example, they use to try to take care of the soil, for example, live barriers... That is one way. (...) For example, organic fertilizer. There are many practices that producers are always taught to take care of the soil and try to eliminate those (unsustainable) practices that they use."

(Key informant, male, employed by the local branch of the Ministry of Agriculture).

Interestingly, factor that was mentioned by a few emigrants and key informants is the desire of some to return to their communities of origin if labor conditions improved. Mentioned previously, the improvement and economic potential of the forestry and agroforestry sectors prompted some people to return to Restauración. Other key informants also mentioned some people that returned once they realized the difficulties of the urban life, including security issues, difficulties finding jobs, and the longing for a calmer lifestyle. Others also returned after finishing studies if they had a profession suitable for the area. Return migration was also seen as a viable possibility by some interviewed emigrants due to changes in their communities, such as electric power service, construction of aqueducts, improvement of neighborhood roads, and new jobs such as reforestation brigades. Nevertheless, some key informants mentioned cases of people returning after a negative experience in the cities and having difficulties being reintegrated as they had sold their lands and had no place to practice agriculture again. Hence, keeping their lands after migrating (or having their family still living in the area) and having a viable economic alternative seems to be a pre-condition for such return.

"… If one has something to survive on, one lives calmly in the field. I even have a little house in the country. Country life is much calmer than in town, because in town one goes to work afraid of being mugged or someone doing something to you on the way to work. In the country, one can leave the house open without fear that thieves will steal the little things one has there."

(Interviewee No. 16, 25, female, migrant to Santiago).

CONCLUSIONS AND RECOMENDATIONS FOR A CLIMATE AND MIGRATION POLICY

Results of this study show how climate change and natural degradation may cause increased cross-border and internal migration in the Dominican Republic, even if indirectly. Without significant adaptation policies, significant flows will continue into the near future. Agriculture emigrants from Restauración perceived that changes in precipitation patterns and land degradation contributed to their low agricultural productivity, making it difficult to sustain a life in these rural communities, and ultimately influencing their decision to migrate to urban areas. Estimates of the quantitative model in fact show that the slow onset of events, such as sea-level rise, reduction of water availability, and crop and ecosystem productivity, will cause approximately between 170,000 to 368,000 additional internal climate migrants in the period 2020-2050 and between 234,000 and 473,000 during the latter half of the century (2050-2100). Similarly, by 2050, between six and 20.1 percent of migrants from Haiti may arrive to the DR driven by climate change, with the percentage and total number increasing in the second half of the century. This study therefore indicates that natural degradation and climate change will continue to cause migration within and to the DR.

Internal climate migration will come from several locations, but will primarily arrive to a few spots, contributing to the existing rural-to-urban flow, changes in the labor structure, and demographic pressures. Results show that internal out-migration/emigration will come from many locations, such as coastal cities, irrigated and rainfed cropland, and pastureland. In-migration will continue to arrive to many cities, especially the urban strip of Santo Domingo Province. This will likely contribute to people—especially the young—leaving rural communities and agriculture sector jobs to seek better opportunities in the cities. Cross-border climate migration from Haiti also will follow similar patterns, arriving in larger numbers; this also will continue to supply labor in the agriculture sector, especially in the border regions from where young Dominicans are leaving. Understanding these trends will help inform policymaking to maximize the positive development impacts of migration while, at the same time, to minimize the costs.

Climate migration should not be conceptualized as an exclusive category distinct from other types of migration. Even if people report that the main reason to migrate is "to find a better job," understanding their rationale for not being able to make a dignified living in their place of origin is nevertheless important. This study documents how climate change and natural degradation influence this pattern; for example, through lower productivity in agriculture—one of the main economic activities in the Dominican rural countryside. Even though the modeling approach has been able to distinguish climate migrants from other types of migrants, climate migrants may nevertheless report the economic reasons as the most pressing, given that the impacts of climate change indirectly affect their livelihoods and provide them with a reason to migrate. The qualitative and quantitative modeling approach in this study has provided an avenue to explore the subjacent motives and a comprehensive view on the issues.

The findings of this study call for more integration between migration and climate policy within an adaptation framework, with a view to improving the effectiveness of both types of policies. As it currently stands, neither the NDCs nor the National Adaptation Plan of the DR treats migration as an essential policy area. A similar case is true for climate change and natural degradation as a subpolicy area within the migration policy, other than forced displacement caused by natural hazards, such as hurricanes, floods, or earthquakes. As discussed in this report, the inclusion of the drivers and impacts of migration caused by climate change and natural degradation within an adaptation framework would be an important step toward effective climate and migration policy.

Moreover, addressing climate migration should be further integrated in far-sighted green, resilient, and inclusive development planning, following a territorial approach. Following the framework of the World Bank's Country Climate and Development Reports (CCDRs), the best climate policy is one that is, at the same time, good development policy. Climate migration should not be addressed independently; instead, it should be further integrated with other areas of development policy. Some sectors that seem especially important are social inclusion, urban planning and resilience, water management, and agriculture and forestry, although these should not be considered an exhaustive list. Likewise, given the different climate migration paths and drivers in each region, a territorial approach is needed to design policy solutions suited for each region, in addition to national policies.

Policy recommendations can be framed along three main pillars. These will fall in line with the key findings of the 2023 World Development Report (World Bank 2023) and the policy response framework outlined in the 2022 KNOMAD/World Bank migration and development brief (KNOMAD 2022). These frameworks and the results of this study highlight three pillars of policy recommendations (summarized in Table 4): (i) Coherent legal and institutional framework; (ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process; and (iii) Climate adaptation and mitigation that focus on preparedness and anticipatory action.

(i) Policy coherence on the legal and institutional framework

Policies must be supported by a coherent legal and institutional framework. National policies and strategies relating to climate-driven migration must be integrated into climate policy and processes, particularly in the context of adaptation. Support is necessary ensuring lower turnaround rates and the professionalization of migratory civil servants, with a dedicated module or seminar on climate-induced migration as part of the curriculum of the Master's degree on Migration and Development in the Caribbean at the DR's National Migration Institute (Instituto Nacional de Migración). At the same time, issues relating to climate change must be integrated into migration policies and processes in a noticeably clear manner, including the promotion of continuous policymaking dialogue among the two disciplines—through the National Climate Change Council, the National Migration Council , Ministry of Agriculture, Ministry of Labor, Ministry of Environment, Ministry of Interior, and the Ministry of Economy, Planning, and Development, —and strengthening the necessary capacities and awareness among civil servants. Likewise, the institutional framework must consider the production of more research, analytical work, and geographically sensitive data generation and collection, to further understand these issues and ways to address it.

(ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process

Migration policy in the Dominican Republic can transform into effective climate policy when accepted as a valid adaptation strategy. Migration is often conceptualized as an adaptation strategy to deal with degraded resources, climate change, or other harmful situations in communities of origin. Recognizing migration as a valid adaptation option in climate policy could support people in dealing with the effects of climate change (especially those trapped because of insufficient resources to even migrate), as well as support a planned, safe, and dignified movement that will increase positive impacts while reducing the negative. Planned relocation includes measures to minimize the human costs arising from climate change (Ferris and Weerasinghe 2020; Bergmann 2021). In this sense, greater attention is needed to ensure that affected persons are involved fully in decisions regarding their potential and planned relocation.

There are different alternatives to support this climate migration process. These may include the identification of areas for voluntary relocation based in early warning systems of unviable situations, developing action plans codesigned with local communities, and mobilizing technical and financial support. This could be the case, for example, of coastal cities and towns affected by sea level rise, applying lessons learned from the DR's Sierra de Bahoruco, Sierra de Neiba, and Lake Enriquillo experience.[22] Other ways that appeared relevant in the context of the study are, for example, reskilling programs for people seeking jobs in the cities and incentives for educational opportunities to be tailored for those wishing to return with occupations that match the needs of their communities.

[22] The Government of the DR has relocated many affected by a rise in water levels in Lake Enriquillo to the new town of Boca de Cachón, a US$24 million community built by the government to house people on the verge of losing their homes to the lake.

Migration policy can also support designing solutions to safe and orderly cross-border climate-induced migration, in a manner that heightens the positive social and environmental impacts. Migration policies that recognize the current importance of Haitians workers for the labor market of DR, particularly in agriculture, and their vulnerability to social and climate drivers, could help create programs that incentivize them to utilize sustainable practices that take care of the environment, while helping supply the labor in agriculture that Dominicans appear to be exiting.

(iii) Climate adaptation and mitigation focused on preparedness and anticipatory

Recognizing that climate change and natural degradation may cause large flows of human mobility, and that climate and environmental policies may influence the size of these flows, becomes relevant in considering a more holistic adaptation framework. Climate adaptation and mitigation policies, such as those implemented through the agriculture, water, and forestry sectors, could have significant influence on the need for migration. For example, helping farmers adapt to the effects of climate change, supporting improvement in productivity, and reducing the drivers of natural degradation and water stress may have significant effects on the number of people that will need to migrate, as well as the potential for return migration, for those who were previously displaced and their origin community becomes viable again. Supporting people to overcome barriers to enter agroforestry, promoting green jobs in the forestry sector; [23] providing technical and technological support to increase agriculture and land productivity, as well as irrigation and water management, were all discussed in the qualitative study as policies that will improve people's livelihoods (albeit with mixed success) in their communities of origin—all of which influence migration. These could leverage existing programs at the country level, such as the ERP in the DR.

Improving waste management planning and practices is crucial, particularly in the water and sanitation sectors and in precarious settlements. Inadequate waste disposal and management not only exacerbate environmental pollution but also pose severe health risks, contaminating water sources, and hindering access to clean water and sanitation facilities. It also directly affects maritime, freshwater, estuaries, and groundwater ecosystems, which are vital to the DR´s economy and environmental conservation. Improved waste management is especially critical in underprivileged communities, where the lack of infrastructure and resources can lead to dire consequences on living standards and public health outcomes. By focusing on enhancing waste management strategies, including the development of sustainable disposal methods and systems, the DR can mitigate these risks, protect livelihoods and ecosystems. This is not just an environmental imperative but a fundamental aspect of advancing public health, economic growth, and social sustainability.

[23] While not mentioned in the interviews, other sectors also are able to produce green jobs. The ERP includes projects to generate green jobs even in the livestock and agriculture sectors.

Adaptation policies in the form of preparedness and anticipatory actions are not only needed in origin rural communities, but also in the adaptation of cities that are projected to be both in and out-migration hotspots. Results from this study highlight the large influx of climate migrants that will arrive to cities, as well as the underlying motivations to migrate to these locations, mainly the search for good jobs, services and education. Urban planning will need to take into account estimates like those produced by this study to prepare resilient services and labor markets. Moreover, the results also highlight large numbers of urban-to-urban migration driven by water stress caused by growing populations and sea level rise. In this sense, resilient infrastructure and water management systems will be required to support the growing population pressure and climate stressors. Further quantitative and qualitative research is needed to validate these projections and recommendations with local communities, leaders, and experts and more localized data sources.

An integrated territorial development lens can help integrate adaptation policies across rural, border, and urban areas. The highly regionalized climatic and economic situations of origin and destination communities, and therefore of the drivers and journeys of climate migrants, evidence the need to consider local and territorial approaches. Results from this study show that drivers and journeys of migrants are deeply related to their place of origin, which influence their social networks across the country and the viable intermediate and final destinations they have as options. This evidence the importance of geographically and regionally contextualizing climate migration and the policies to address it. In this sense, it is important that national policies facilitate regional plans for climate migration and adaptation, based in localized results and knowledge, and avoid imposing a common solution and plan nationally.

The Law No. 368-22 on Territorial Development, Land Use, and Human Settlements, establishes guidelines for zoning, land use, environmental protection, and urban development, aiming to balance development needs with environmental conservation and the welfare of the population. It emphasizes the importance of participatory planning, involving communities and stakeholders in decision-making processes to ensure that development projects meet the needs and aspirations of the local population. As such, national planning instruments at the Ministry of Economy, Planning, and Development (MEPYD), such as the regional development strategy for border areas “Mi Frontera RD” already integrate climate and migration policy and can serve as reference for other planning instruments in the country.

Table 4.
Summary of Policy Recommendations to Address Climate Migration in the Dominican Republic

PILLAR	POLICY RECOMMENDATIONS
(i) Coherent legal and institutional framework	Support technical roundtables among the National Climate Change Council, the National Migration Council, Ministry of Agriculture, Ministry of Labor, Ministry of Environment, Ministry of Interior, and Ministry of Economy, Planning, and Development, to better integrate environmental, agricultural, and migratory policies in the country. Provide technical advice and facilitate knowledge exchanges with small-island states in Latin America and in other regions, including through regional platforms. For instance, through the Greater Caribbean Climate Mobility Initiative (GCCMI) and similar regional platforms. Create clear and established legal frameworks to support climate-induced migration pathways at the national level. Mobilize international technical, institutional, and financial support to provide regional responses to facilitate safe and planned cross-border climate migration. Support the professionalization and reduce the turnover of migratory civil servants with a dedicated module or seminar on climate-induced migration as part of the curriculum of the National Migration Institute´s Master's degree in Migration and Development in the Caribbean. Promote further research, analytical work, and data generation and collection on these issues.
(ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process	Develop early warning systems to enable prior planning for slow and rapid human mobility flows in response to climate change impacts and natural degradation. Boost national and international resource mobilization to finance subsidies and enable safe and planned migratory pathways for internal and cross-border climate migrants.

PILLAR	POLICY RECOMMENDATIONS
(ii) Supporting migration as a valid adaptation strategy to ensure a planned, safe, and dignified process	Planned relocation may imply the voluntary movement of people to other cities or areas within a country. Greater attention is needed to ensure that affected persons are involved fully in decisions regarding their relocation. Codesign and implement climate-induced relocation plans with local communities. Lessons learned from the DR's Sierra de Bahoruco, Sierra de Neiba, and Lake Enriquillo experience can be a starting point[1]. Support climate-informed territorial development, planning instruments and socio-environmentally sustainable investments that address rural-urban corridors and the unique challenges or border areas. Prepare and update local development and climate action plans to allow the mobility of people, identify their destination, and ensure appropriate preparations and key services for arrival at destination (e.g., health, education, and housing). For instance, support the continuity and adequacy of educational process for internal migrants.
(iii) Climate adaptation and mitigation focused on preparedness and anticipatory action	Periodically update territorial planning instruments at the Ministry of Economy, Planning, and Development (Ministerio de Economía, Planificación y Desarrollo, MEPYD) to take into account predicted climate migration flows. Invest in the adaptation of rural and border communities and other out-migration hotspots, to enable potential migrants to stay in place, where viable, are also important. National planning instruments at MEPYD, such as the regional development strategy for border areas "Mi Frontera RD" already integrate climate and migration policy and can serve as reference for other planning instruments in the country. Prioritize strategies aimed at supporting livelihoods and addressing the risk of displacement caused by climate change in areas adjacent to protected zones.

PILLAR	POLICY RECOMMENDATIONS
(iii) Climate adaptation and mitigation focused on preparedness and anticipatory action	The Emissions Reduction Program (ERP) in the DR may constitute an avenue for future preparedness in green and sustainable sectors. The program may provide technical and financial support in favor of national efforts. This program could be leveraged to reverse unsustainable practices in the forestry and agriculture sectors that are factors that influence the decision to migrate. Address the barriers to enter the agroforestry field through incentivization and subsidy programs, and promote green jobs in the forestry sector. Provide technical and technological support to increase agriculture and land productivity, irrigation, as well as water management to address factors that influence the decision to migrate. Enhance waste management to reduce environmental pollution and health risks, especially in water and sanitation sectors, ensuring equitable access to clean resources, and supporting public health and environmental preservation. Minimize the use of harmful chemicals by large agricultural producers to reduce the speed of soil and water degradation and its subsequent impacts on climate-induced migration from rural areas. Improve urban-rural corridors and increase awareness of the importance of sustainable agricultural practices among rural and urban youth. Strengthen technical assistance for preparedness as a critical measure in cities expected to receive an influx of migrants over the next few decades. Invest in infrastructure and employment in cities (e.g., Santo Domingo, Santiago, Higüey), as well as in sustainable areas. Likewise, given water stress and sea-level rise pressures on cities, climate resilient urban planning is needed to ensure cities are able to accommodate growing numbers of people under conditions of climate stress, including resilient infrastructure, housing, and services, with social inclusion and cohesion considerations.

[1] The Government of the DR has relocated many affected by a rise in water levels in Lake Enriquillo to the new town of Boca de Cachón, a US$24 million community built by the government to house people on the verge of losing their homes to the lake.

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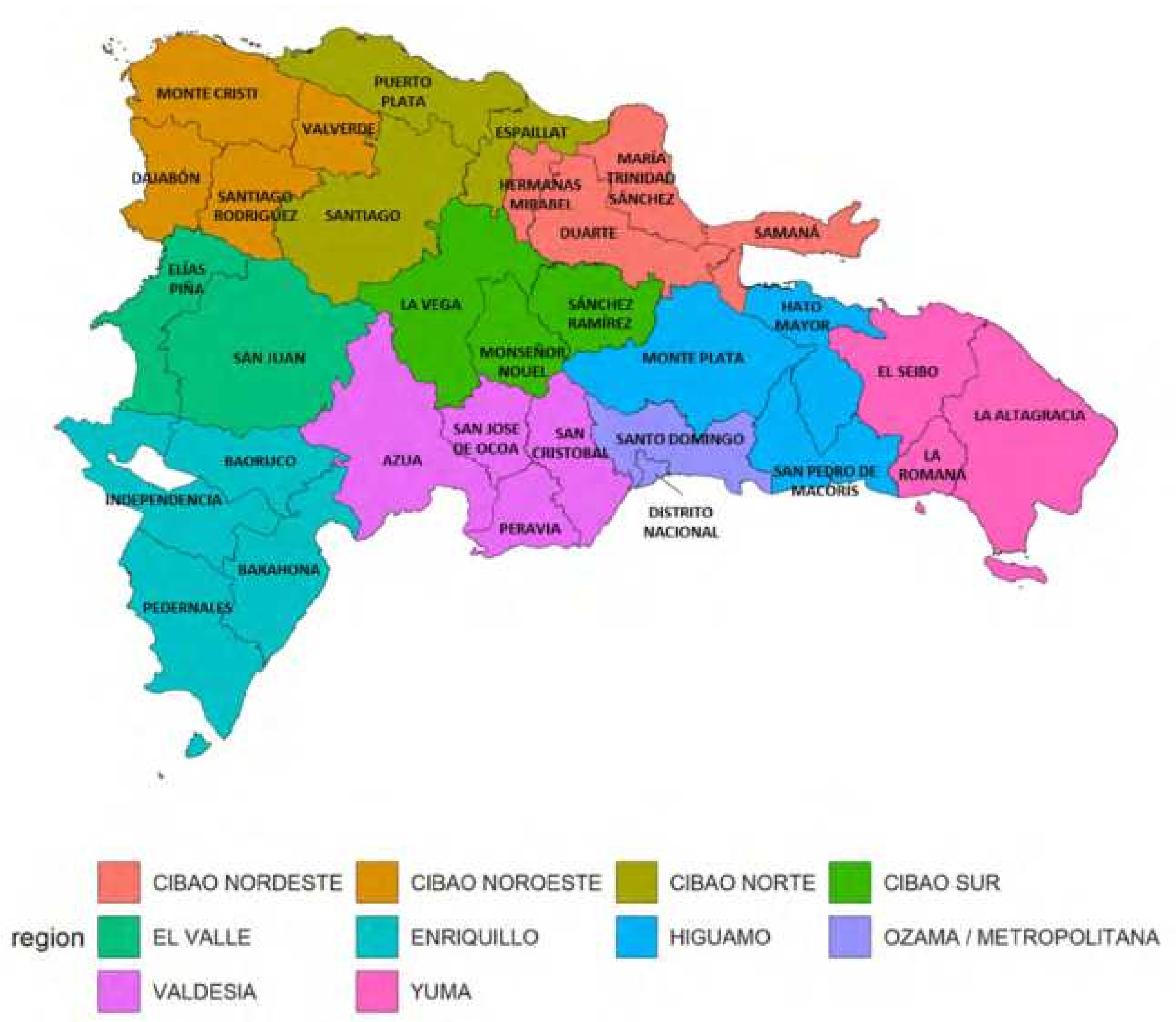
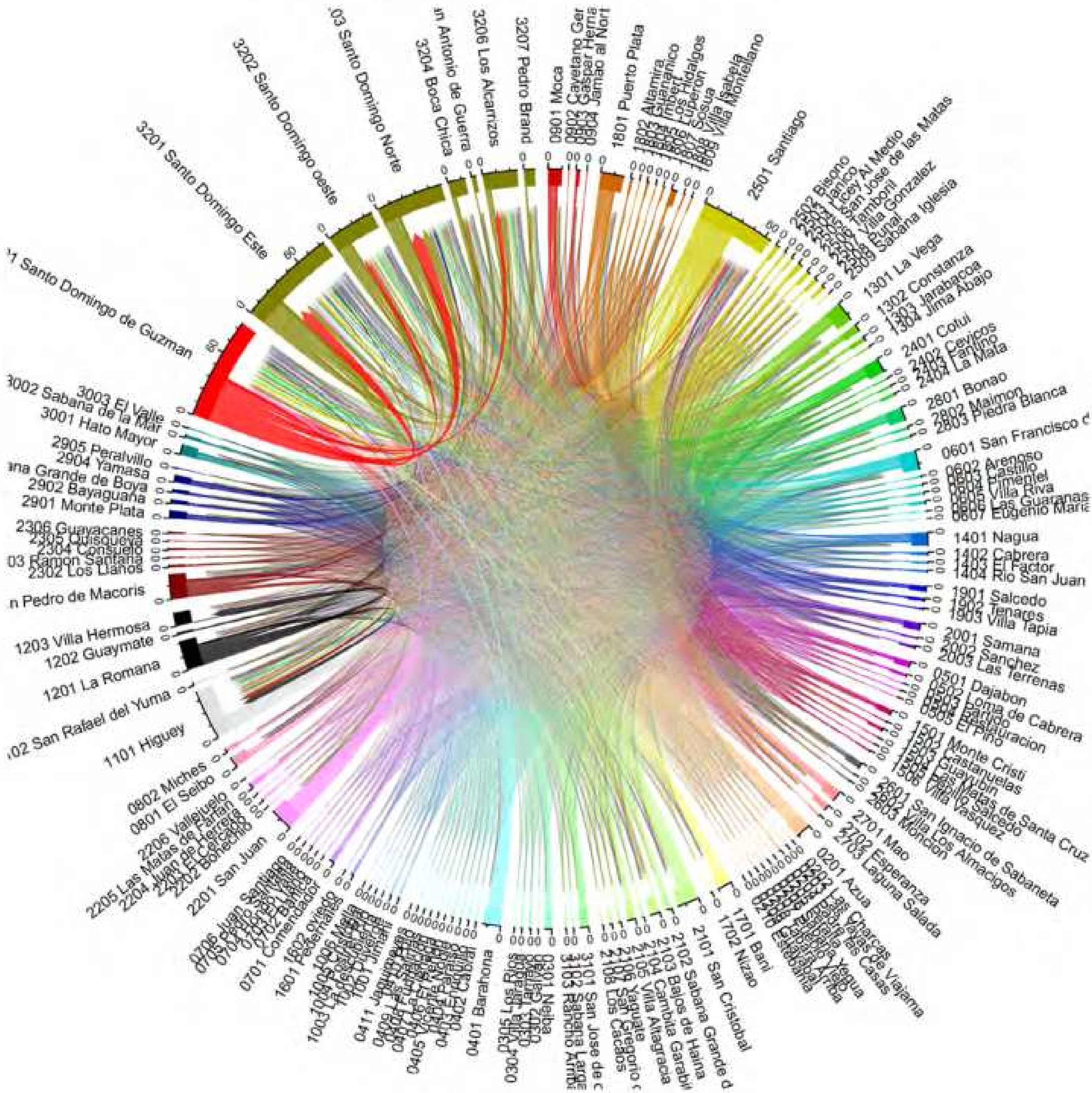
APPENDIX

Appendix 1.
Map of Regions and Provinces of the Dominican Republic



Source: World Bank staff based on data from the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010).

Appendix 2:
Internal Migration between Municipalities of the Dominican Republic



Source: World Bank staff based on data from the 2010 National Population and Housing Census of the Dominican Republic (GoDR 2010).
Notes: Tick marks represent 12,000 people. The graph was created based on a question in the 2010 Census regarding the municipality in which a person (5 years and older) was living in 2005. The number represents those who, in 2005, were living in another municipality of the Dominican Republic.

Appendix 3:
Methodological Details of Modeling Exercise

Data

The data used in the modeling was drawn from the original Groundswell (Rigaud et al. 2018) project, updated to reflect more recent revisions, where possible, and modified slightly for this project. Table A3.1 includes a list of the data employed in the modeling analysis.

Table A3.1. Datasets, Variables, and Sources

Variable	*Source*	*Resolution*	*Time Series*	*Time Step*	*Indicator*	*Climate Driven*
Water Availability	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Agriculture/Crop Yields	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Biomes/Ecosystem Productivity	ISIMIP	0.5°	1970-2100	5-year	Deviation from baseline	Yes
Sea Level Rise	NASA	30m	1990-2150	5-year	Changes in coastline (inundation)	Yes
Bilateral Internal Migration	ONE	Municipal	2005-2010	5-year	Count of migrants	N/A
Bilateral International Migration	ONE	Municipal	1990-2010	5-year	Count of migrants (Haiti to Dominican Republic municipalities)	N/A
Municipal Population	ONE	Municipal	2010	N/A	Count of people	N/A
Spatial Population (Totals, Age, and Sex)	WorldPop	100m	2000-2020	1-year	Population counts by age and sex	No
Elevation	SEDAC	30m	2015	N/A	Corrected elevation	No
Slope	SEDAC	30m	2015	N/A	Avarage slope	No
Water Bodies	ESRI	Vector	2019	N/A	Surface water	No
World Database on Protected Areas	IUCN	Vector	2019	N/A	Mandate for protection	No

Source: World Bank staff

The impacts of climate change takes place through the first four variables on the list: water availability/stress, crop yields, ecosystem productivity, and sea level rise (SLR). Bilateral internal and international migration data, the latter of which consist only of flows from Haiti to the Dominican Republic (DR), are from the DR's National Statistics Office (Oficina Nacional de Estadística) (as are the municipal population data). These data were used to help train the model, and are unique to this application of the INCLUDE model. The final four variables are not drivers of migration; instead, they constitute the spatial mask used to restrict the land deemed suitable for human habitation. The population variable (WorldPop) serves as the base year population distribution (total population count by grid cell), as well as the two variables in the migration model (age and sex structure). Each of these variables was tested and validated, and previous applications of the model found them to be statistically and/or practically significant in driving positive or negative impacts on the relative attractiveness of various locations.

Inter-Sectoral Model Intercomparison Project

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is an ongoing community-driven modeling effort organized by the Potsdam Institute for Climate Impact Research, and is designed to provide a framework to compare multiscale, cross-sectoral climate impact projections (Warszawski et al. 2014). Based on the Representative Concentration Pathways (RCP) and Shared Socioeconomic Pathways (SSP), ISIMIP facilitates a quantitative assessment of impacts across multiple sectors and models, based on common climate and socioeconomic background scenarios and climate model inputs. A major goal of the project is the development of policy-relevant metrics. Over the course of this century, policymakers will be tasked with assessing the costs associated with mitigation efforts against those for adapting to a warmer world. In that spirit, the project is motivated by and organized around a central question: how do impacts vary between 2°C, 3°C, and 4°C of global warming? Research is designed to isolate "tipping points," the level of environmental change associated with rapid increase in negative sectoral impacts.

This project uses outputs from the ISIMIP modeling effort for crop production, water availability, and ecosystem impacts, which cover the historical period 1970–2010, and projections for 2010–2100. The future sectoral impact models are driven by a range of general circulation models. Here, the data is driven by 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 Met Office Hadley Centre for Climate Science and Services (United Kingdom) and the IPSL-CM5A-LR climate model developed by the Institut Pierre Simon Laplace (France) climate modeling center. The crop, water, and ecosystem simulations—at a relatively coarse spatial scale (0.5°)—represent indicators that capture the impact climate may have on specific types of livelihoods, the viability of which will figure into the migration decision (e.g., climate acting through other mechanisms). These climate impacts were selected because the literature shows that water scarcity, declining crop yield, and the decline in pasturage are among the major potential climate impacts facing lower- and middle-income countries, and these impacts also will be significantly important drivers of migration.

Water and Crop Models

The primary ISIMIP drivers used in this analysis are water availability and crop yields. Output from the water sector model is representative of river discharge, measured in cubic meters per second in daily/monthly time increments, and is influenced by rainfall and changing temperature. Crop sector model outputs estimate the annual crop yield of four staple crops (maize, wheat, rice, and soybeans) in tons per hectare at a 0.5° x 0.5° grid cell resolution, and they are a function of rainfall, temperature, CO_2 concentrations, irrigation, and other management practices. Because the impact of climate change on local conditions (i.e., the deviation from historic local norms) is more indicative of potentially disruptive change than absolute yields, the approach adopted here is from the Groundswell report (Rigaud et al. 2018) in which the data are transformed to reflect periodic deviation from the 40-year historical baseline.

The data are converted to five-year average water availability and crop production (in tons) per grid cell, and an index is then calculated that compares those values with the 40-year average for water availability and crop production for 1970–2010:

$$Index = (D_{avg} - B_{avg}) / B_{avg} \qquad \text{Eq. 1}$$

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.

To account for uncertainty in future climate outcomes, also adopted is the Groundswell approach to select ISIMIP crop and water model outputs based on different combinations of climate, crop, and water models. Applying the combinations—two global climate models driven by two different emission scenarios which, in turn, drive two sets of sectoral impact models (described below)—provides a range of plausible population projections while also indicating regions where the models tend toward agreement (Rigaud et al. 2018). The modeling for this assessment employed two General Circulation Model (GCMs) – 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 (Table A3.2). The crop and water models were selected by experts at the Potsdam Institute for Climate Impact Research, based on several criteria, including model performance over the historical period, diversity of model structure, diversity of signals of future change, and availability of not only observationally driven historical but also global climate model-driven historical and future simulations. Table A3.2 presents the combinations of models used.

Table A3.2. Matrix of Global Climate Models and Crop/Net Primary Productivity and Water Model Combinations

	Crop/NPP Simulation			
Water simulation	HadGEM2-ES, LPJmL (crop) LPJml (NPP)	HadGEM2-ES, GEPIC (crop) Visit (NPP)	IPSL-CM5A-LR, LPJmL (crop) LPJml (NPP)	IPSL-CM5A-LR, GEPIC (crop) Visit (NPP)
HadGEM2-ES,LPJmL (water)	Model 1			
HadGEM2-ES, WaterGAP2		Model 2		
IPSL-CM5A-LR, LPJmL (water)			Model 3	
IPSL-CM5A-LR, WaterGAP2				Model 4

Source: Adopted from Rigaud et al. 2018.
Notes: NPP = Net primary productivity.

Ecosystem Productivity

In the same way that crop production is an important metric of farm-based livelihoods, ecosystem productivity is an important measure for pastoral livelihoods. In this project, ecosystem productivity is used as a potential driver in nonurban areas where the crop data indicate that agriculture is not taking place (e.g., those places likely suitable for pastoralism). Using ecosystem productivity only in areas lacking crop productivity, data is deemed preferable to including an overlay of net primary productivity (NPP) on top of the crop production, since there is high spatial collinearity between the crop and ecosystem metrics.

Ecosystem productivity is estimated in terms of NPP. The ecosystem models simulate the natural growth of several different plant functional types, including grasses; thus, NPP simulated by these models serves as an estimate of the productivity of a location's natural biome, including grassland biomes that may potentially support pastoral livelihoods. Like the water and crop metric, NPP is transformed to represent local periodic deviation from the historical baseline. The NPP sectoral models proposed in this work are the LPJmL and Visit models—the former to be used with the LPJml crop production and water availability models, while the latter is to be used with the GEPIC crop and WaterGap water models—and the models are also driven by the same GCMs as the water and crop models.

Sea Level Rise

The analysis also will consider SLR projections from the IPCC Sixth Assessment Report (AR6) (IPCC 2022), available through the Physical Oceanography Distributed Active Archive Center at the NASA Jet Propulsion Laboratory (Fox-Kemper et al. 2021). Data cover the period 2020-2150 and are provided for all future scenarios covered in the AR6. Projections for individual processes that cause sea level to change also are included in the dataset. Globally averaged projections, regional projections on a regular global grid, and local projections at individual tide gauge locations are all provided. Following the Groundswell methodology, sea-level rise data are used to represent the loss of habitable land due to the SLR of each coastal grid cell.

Internal/International Migration and Municipal Population

Bilateral international migration flows between Haiti and the DR are derived from two sources; the DR's 2010 National Population Census (referred to as 2010 Census going forward) and the 2nd National Immigration Survey (ENI 2017). These data can be accessed through the DR's National Statistics Office (www.one.gob.do). Five-year immigration flows are reported at the municipal level over the period 2005-2010, and are disaggregated by age and sex.

Internal migration flows (at the municipal level) are from the 2010 Census. Five-year bilateral flow data are compiled based on each household's current place of residence and place of residence five years prior. The data were provided by the World Bank team, but also can be accessed through the DR's National Statistics Office.

Subnational population totals at the municipal level are from the 2010 Census, and were used to cross-validate the gridded spatial population data. They also provide a historical point of reference for projected future municipal level population.

Spatial Population Age and Sex Structure

The WorldPop organization (University of Southampton; Stevens et al. 2015) produces population estimates with age/sex breakdowns for each 100 meter x 100 meter grid square on the planet. The intended function of WorldPop data is to serve as default, open access datasets for United Nations agencies planning humanitarian and development interventions, and to help governments fill census gaps. As such, the mission of the WorldPop group overlaps with the goals of the predictive analytics project.

Estimates of the spatially explicit distribution of the population are derived from census data and produced using a semi-automated dasymetric modeling approach that incorporates census and a wide range of open access ancillary datasets with a flexible, "random forest" estimation technique. A combination of widely available, remotely-sensed, and geospatial datasets (e.g., settlement locations, settlement extents, land cover, roads, building maps, health facility locations, satellite nightlights, vegetation, topography, refugee camps) contribute to the modeled dasymetric weights, and then the random forest model is used to generate a gridded prediction of population density at ~100m spatial resolution. This prediction layer is then used as the weighting surface to perform dasymetric redistribution of census counts at a country level. Assessment of the product indicates improvements in mapping accuracies and other population mapping approaches (Stevens et al. 2015), particularly the (i) Gridded Population of the World (GPW), a data center of NASA's Earth Observing System Data and Information System; and (ii) Global Human Settlement Layer Population Estimates (GHS-POP), supported by the European Commission, Joint Research Centre, and Directorate-General for Regional and Urban Policy, with the first (i.e., (i)) tending to over-allocate population across rural areas, and the second (i.e., (ii)) over-concentrating population in urban areas and, crucially, often missing settlements in West Africa that are difficult to detect via satellite imagery.

For this work, WorldPop serves two purposes. First, the 2020 WorldPop data serve as the base year distribution upon which the model is applied at its native 1 kilometer (km) resolution. Second, the data are used to cross-reference the census data, specifically the municipal level population, to ensure that the spatial model represents the underlying census data correctly.

Elevation, Slope, Surface Water, and Mandate for Protection

The spatial population model includes a geospatial mask that acts as a weight, proportionally scaling the population potential (attractiveness) for each grid cell as a function of the area within each cell deemed suitable for human habitation. A mask is constructed from four geospatial data layers: surface water, elevation, slope, and protected land. These data are overlaid to produce a single mask from which is extracted the portion of each cell suitable for habitation. The ESRI World Water Bodies 2013 (DeLorme 2014) dataset is applied to mask global surface water. Elevation and slope data are from the Global Multi-Resolution Terrain Elevation Data 2010 (GMTED2010; Danielson and Gesch 2011). The elevation of the highest permanently populated settlement in each continent is applied as a ceiling to exclude land from future habitation as a function of high elevation. In general, development costs increase substantially on land exhibiting a slope greater than 15 percent, which is also the point at which many municipalities impose development regulations (e.g., Theilacker and Anderson 2010). Here, account is made for the likelihood that improved technology will reduce the costs associated with excess slope and, instead, impose a threshold of 25 percent, an oft-cited "no-development" threshold in municipal regulations across the United States (Houck 2005).

Finally, the International Union for the Conservation of Nature (IUCN) World Database on Protected Areas is used to mask land as a function of mandate for protection (IUCN 2015). Specifically, any area classified under IUCN categories (Ia) (strict nature reserve), (Ib) (wilderness area), (II) (national park), (III) (national monument or feature), or (IV) (habitat/species management area) is masked as not suitable for development/habitation.

In some cases, existing base year population was found in cells otherwise completely masked as a function of mandate for protection. There are two possible explanations. First, the algorithm used to distribute the existing population across grid cells in the GPW data base year does not specifically account for protected land and, as such, population and protected land may overlap in the base year. Second, in many cases, new mandates for protection grandfather existing populations (e.g., people living in newly designated national forest land in the United States). For modeling purposes, both cases are treated identically. For example, cells that are 100 percent masked as a function of mandate for protection are not eligible to receive any projected future population growth. These cells, however, are allowed to lose people during periods of population decline. This decision reflects perception of this study of real-world population change in areas with not only existing population but also prohibitions on new development.

Scenario Framework

This work adopts the extended scenario-based approach from the Groundswell Africa report (Rigaud et al. 2021), in which four plausible future internal climate migration scenario combinations are examined (Figure A3.1) based on combinations of the RCPs (van Vuuren et al. 2014) and SSPs (O'Neill et al. 2014). For each scenario, the projection represents an ensemble of model runs using combinations of crop, water, ecosystem, and flood impact models from the ISIMIP. The scenario approach has several advantages. First, exploring migratory outcomes across alternative physical and demographic/socio-economic futures allows researchers to begin to characterize the size and sources of uncertainty associated with projections of climate-induced migration. Second, by varying climate and demographic/socio-economic pathways provides a means for considering and evaluating different policy options in terms of the impacts on spatial population outcomes as well as the potential avoided climate impacts of achieving more advantageous climate and societal outcomes (e.g., Oleson et al. 2015; Martinich et al. 2018).

Representative Concentration Pathways (RCPs)

Developed in advance of the IPCC 5th Assessment Report, RCPs represent the latest generation of global scenarios for climate change research (IPCC 2014). The RCPs are trajectories of greenhouse gas (GHG) (and other pollutants) concentrations resulting from human activity corresponding to a specific level of radiative forcing in 2100. For example, RCP4.5 implies a future where radiative forcing of 4.5 W/m is realized by the end of the century. An important characteristic of the RCPs is that they do not rely on a fixed set of scenario-specific assumptions regarding economic development, technological change, or population growth. Instead, there are many different socioeconomic futures or pathways that may lead to the same level of radiative forcing. This framework allows researchers to consider alternative policy decisions with combinations of societal, economic, and technological change. As such, a future with high population but rapid development of clean technology may achieve the same level of radiative forcing as a world characterized by low population growth but continued reliance on fossil fuels. This framework is exceptionally useful from a policy analysis perspective, as it allows researchers to specify specific levels of global temperature change (e.g., 1.5°C) and then explore alternative policy options to achieve emission levels consistent with the goal. Previous scenarios, by contrast, specified the socioeconomic conditions from which climate change/impacts were then calculated.

Climate output, consistent with two RCPs (2.6 and 8.5), are included in this work as drivers of the climate impacts considered in the modeling. The two RCP scenarios considered in this work are now discussed in more detail.

RCP2.6 is a Low Emission scenario. GHG emissions begin to decline by 2020, and radiative forcing peaks by mid-century before declining to near current levels by 2100. This scenario is consistent with the extremely rapid adoption of new, cleaner technologies, slower population growth, and strong environmental policy. To achieve an RCP2.6 future, new technologies would need to be widely employed in the next 5 to 10 years. The extended RCP2.6 scenario assumes “negative emissions” by 2070, meaning humans are removing more CO2 and CH4 from the atmosphere than they are releasing.

RCP8.5 is characterized by increasing GHG emissions over time, leading to high atmospheric concentration. It is a future consistent with scenarios of energy intense development, continued reliance on fossil fuels, and a slow rate of technological development. Alternatively, pathways characterized by rapid population growth and land use intensification (croplands and grasslands) are also consistent. RCP8.5 implies little to no climate policy, and it is characterized by significant increases in CO2 and CH4 emissions.

Shared Socioeconomic Pathways (SSPs)

The five SSPs, described in more detail in O'Neill et al. (2015), span a wide range of potential future development pathways, and describe trends in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. Broadly, they are organized according to the respective challenges to adaptation and mitigation in each future world. Importantly, climate change impacts are not directly included in these scenarios; however, they can be thought of as consistent with broad assumptions regarding the primary factors driving challenges to adaptation and mitigation, namely population and emissions, respectively. National-level estimates of population, urbanization, and GDP have been released for each SSP and are available through the SSP database (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about).

Population estimates include assumptions regarding international migration; however, once again, these assumptions are made in the absence of any information regarding climate change, exposure, and vulnerability. This work will attempt to model the potential impacts of climate change on international migration. No assumptions are made regarding internal migration. In this work, it is proposed to consider two different SSPs, described here in more detail.

SSP2 (Middle of the Road) describes a world with development that occurs at rates consistent with historical patterns, and therefore has moderate levels of investment in human capital, technological change, and economic growth. Demographic outcomes are consistent with Middle of the Road expectations about population growth, urbanization, and spatial patterns of development. Trends vary across regions and over time but, on average, they fall near the center of expectations about future outcomes rather than toward the upper or lower bounds of possibilities.

SSP4 (Inequality) describes 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. In other regions, however, development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving them highly vulnerable to climate change with limited adaptive capacity.

Scenario Combinations Proposed for the Modeling

Following the Groundswell approach, four plausible socioeconomic and climate futures are proposed by combining these SSP and RCP scenarios (Figure 6). The scenarios allow for an examination of the relative importance of climate futures in driving potential migration outcomes. The scenarios can be characterized as follows:

1

A Pessimistic reference scenario (SSP4 Inequality and RCP8.5 High Emissions), in which global emissions remain high and development is disparate. Population growth in middle-income countries generally slows over the next few decades and the population declines after mid-century due to significant economic uncertainty. Urbanization rates are high due to rural economic decline, and GDP growth and education levels remain stagnant. 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.

The other three scenarios are defined in comparison to this reference scenario.

2

A more ***Climate-Friendly scenario (SSP4 Inequality and RCP2.6 Low Emissions)*** with lower emissions that reduce climate impacts, but holds the development scenario consistent with the pessimistic scenario.

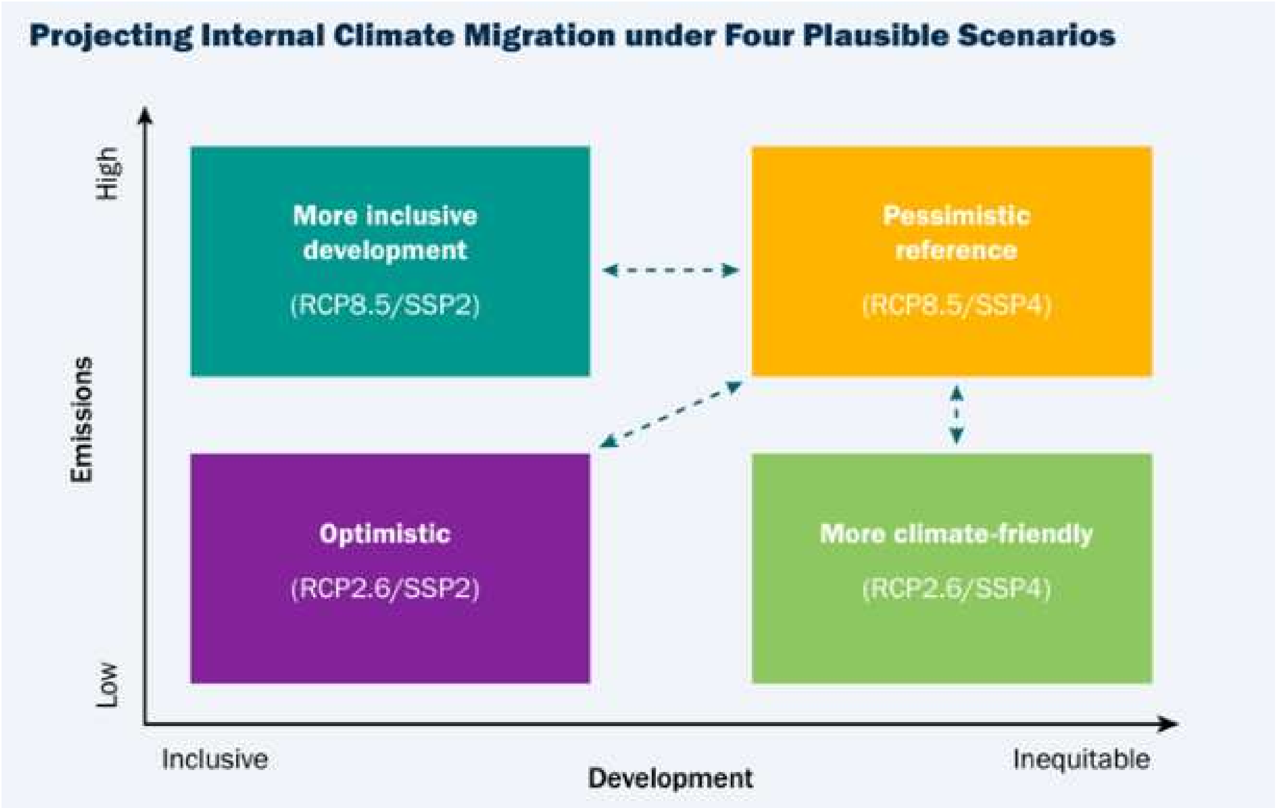
3

A more ***Inclusive Development scenario (SSP2 Middle of the Road and RCP8.5 High Emissions)***, which retains high emissions from the Pessimistic scenario, but provides a development scenario that is more optimistic and the potential for adaptation is higher than under SSP4. Population growth is higher, but urbanization rates are lower than in SSP4, while progress in education and GDP are higher than in SSP4.

4

An ***Optimistic scenario (SSP2 Middle of the Road and RCP2.6 Low Emissions),*** which combines the lower emission scenario that reduces climate impacts and provides a development scenario that is more optimistic.

Figure A3.1: Scenario Framework adopted from Groundswell Africa; Rigaud et al. 2021)



Source: Rigaud et al. 2021.

Modeling Methods

The modeling approach is divided into two sections. The first details the model used to project international migrants from Haiti to the DR, while the second describes the INCLUDE model for projecting internal climate migration. For each decadal projection, the internal model was applied first, and then the international model was used to distribute projected migrants from Haiti across the DR. The models are loosely coupled in that the distribution of Haitian immigrants at each time step influences (slightly) internal migration in the subsequent time step, and internal migration within the country influences how migrants from Haiti chose their destination.

The International Model

This work draws on a method for estimating origin-destination international movement that could potentially intensify or decline as a result of environmental change used to produce projections of migration across Central America and Mexico for the New Times Magazine/ProPublica report on climate migration in the Americas (Lustgarden 2020). Advantage is taken of existing bilateral flow data (from the ENI 2017) to train and project future migration from

Haiti to the DR as a function of aggregate climate impacts at the national level (crops, water, ecosystem productivity[24]), and the existing data on the distribution of Haitian migrants across the DR (from the 2010 Census), to estimate potential changes in origin-destination flows from Haiti to municipalities within the DR[25] under the four alternative future scenarios detailed below. The international model operates in two steps; (i) at the country level, total migrants for each time period are estimated; and (ii) migrants are distributed to municipalities within the DR.

From the historical migration data, out-migration rates from Haiti to the DR are calculated over each of the historical periods. National-level outflows to the DR are then modeled as a function of the theorized drivers of movement, using a Poisson log-linear regression model:

$$\log(\mathrm{m}_{ij,t}) = \propto + \beta_1 A_{i,t} + \beta_2 W_{i,t} + \beta_3 D_{ij,t} + \log(P_{i,t}) \qquad \text{Eq. 1}$$

where ($m_{ij,t}$) is the count of migrants from country HTI (Haiti) to DR at time *t*; A is the five-year deviation of crop yield/NPP from historical baseline; *W* is the five-year deviation in water availability from the historical baseline; *D* is the size of the population born in HTI currently residing in the DR; and ($P_{i,t}$) is the population of country *i* at time *t*.

To distribute the projected migrants from HTI to municipalities within the DR, a probability distribution is calculated, where the likelihood that a migrant chooses to reside within a municipality is computed as:

$$\mathrm{v}_{i,t} = D_{ij,t}(A_{i,t} * W_{i,t}) \qquad \text{Eq. 2}$$

where $v_{i,t}$ is the potential attractiveness of each municipality *i* to an migrant from HTI, and migrants are distributed according to:

$$\mathrm{I}_{i,t} = \mathrm{v}_{i,t}/\sum v_i \qquad \text{Eq.3}$$

where $I_{i,t}$ is the number of immigrants arriving in municipality i at time j, and the denominator is the sum of $v_{i,t}$. As such, migrants are distributed to municipalities proportional to the relative attractiveness of each location.

[24] Note that sea level rise is not included in this model.

[25] In the model, Haiti is considered as a single unit; that is, out-migrants are modeled for the country on aggregate. Migrants are then distributed across municipalities within the DR using a gravity-type function that accounts for environmental conditions, economic conditions (through an agglomeration effect), and the existing Haitian population (considered a proxy for social networks).

Internal Model (INCLUDE)

The INCLUDE model downscales national population projections to subnational raster grids as a function of geographic, socioeconomic, and demographic characteristics of the landscape and existing population distribution. Gravity-type approaches, commonly used in geographic models of spatial allocation and accessibility, take advantage of spatial regularities in the relationship between population agglomeration and patterns of population change. These relationships can then be characterized as a function of the variables known to correlate with spatial patterns of population change.

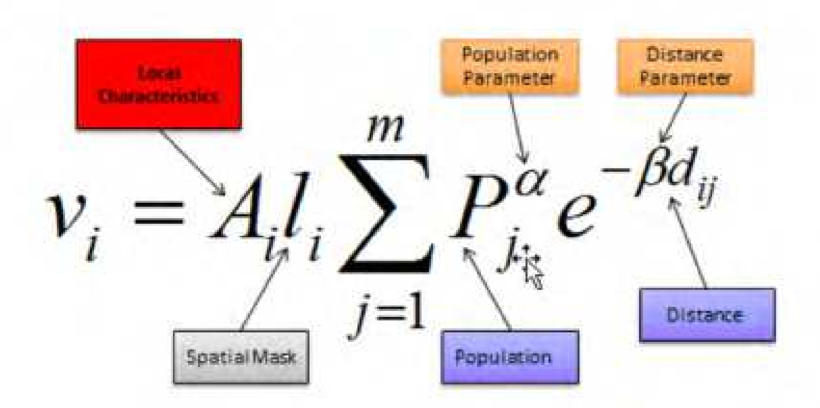
The INCLUDE model uses a modified form of population potential, a distance-weighted measure of the population taken at any point in space that represents the relative accessibility of that point (e.g., higher values indicate a point more easily accessible by a larger number of people). Population potential can be interpreted as 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 (Rich 1980), and it can be considered an indicator of the potential for interaction between the population at a given point in space and all other populations. Population potential will typically be higher at points that contain, or are close to large populations; thus, it is also an indicator of the relative proximity of the existing population to each point within an area (Warntz and Wolff 1971).

Historically, population potential is often considered as a proxy for attractiveness, under the assumption that agglomeration is indicative of the various socioeconomic, geographic, political, and physical characteristics that make a place attractive.

For this assessment, the calculation of potential is modified by adding variables that describe local/regional conditions, including climate impacts on economic livelihoods and weighting the attractiveness of each location (grid cell) as a function of the historical relationship between these variables and observed population change. Population potential is, conceptually, a relative measure of agglomeration, indicating the degree to which amenities and services are available. In the INCLUDE model, this value shifts over time as a function of the population distribution, assumptions regarding spatial development patterns (e.g., sprawl versus concentration), and of certain geographic characteristics of the landscape. The Groundswell approach expanded the model by considering the local impact of climate on certain key sectors. In this further expanded version of the model, the agglomeration effect is enhanced or muted as a function of the influence of Haitian in-migrants. Furthermore, the version of the model applied here operates at higher spatial and temporal resolution (1 km and five-year time intervals, respectively).

Beginning with the 2020 gridded population distribution for each country, the model estimates changes in the spatial population distribution (including the impact of climate change) in five-year time steps by (i) calculating a population potential surface (a distribution of values reflecting the relative attractiveness of each grid cell); and (ii) allocating population change to grid cells proportionally, based on potential. To generate estimates of internal migration under climate change, scenarios are then run for each of the relevant SSPs that exclude the impacts of climate change. That is, the values for all variables that are influenced by climate change are held constant at current day values (crop, water, NPP, drought likelihood, and sea level). The differences in the spatial population distribution between the two scenarios that include climate drivers and this “no-climate” scenario are attributed to migration induced by changing conditions, since the only variables that have changed are those impacted by a shifting climate.

In this version of the INCLUDE model, population potential (*Vi*) is calculated as a parametrized negative exponential function:



$$v_i = A_i l_i \sum_{j=1}^{m} P_j^{\alpha} e^{-\beta d_{ij}} \qquad \text{Eq. 4}$$

where spatial mask (l) prevents population from being allocated to areas that are protected from development or unsuitable for human habitation, including areas that will likely be affected by sea level rise between 2020 and 2050. Pj is the population of grid cell j, and d is the straight-line distance between two grid cells. The population and distance parameters (α and β) are estimated from observed patterns of historical population change. The β parameter is indicative of the friction of distance or the cost of travel that generally determines the shape of the distance–density gradient in and around urban areas (e.g., sprawl versus concentration). The α parameter captures returns on agglomeration externality, interpreted as an indicator of the characteristics that make a place more or less attractive.

Importantly, the SSPs include no climate impacts on aggregate total population, urbanization, or the subnational spatial distribution of the population. The INCLUDE approach was modified by incorporating additional spatial data, including the ISIMIP sectoral impacts, and projections of the mean sea-level rise. The index *Ai* is a weight on population potential that is calibrated to represent the influence of these factors on the agglomeration effect that drives changes in the spatial distribution of the population. All of the data are incorporated into the model as 1 km gridded spatial layers. The value *Ai* 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 stress, crop yields, ecosystem services, and the likelihood of drought relative to “normal” conditions.

Calibrating the Model

The spatial model is calibrated over two decadal periods (2000-2010 and 2010–2020) of observed population change relative to observed conditions. As noted above, the value A_i is calculated as a function of these different climatic/socioeconomic indicators and acts as an adjustment to relative attractiveness.

In order to carry out the procedure, model estimates of the α and β parameters are necessary, and A_i must be calibrated. Two separate procedures are employed.

The α and β parameters are designed to capture broad-scale patterns of change found in the distance-density gradient, which is represented by the shape/slope of the distance decay function from Equation 2. The negative exponential function described by Equation 4 is significantly 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 α and β, the model in Equation 2 is fitted to the 2000-2010 and 2010-2020 population change from WorldPop, and the values of α and β that minimize the sum of absolute deviations are calculated as:

$$S(\alpha,\beta) = \sum_{i=1}^{n} \left| P_{i,t}^{mod} - P_{i,t}^{obs} \right| \qquad \text{Eq. 5}$$

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. The model is fitted for two time steps (2000-2010 and 2010-2020) and the average of the α and β estimates is taken.

In this modified version of the population potential model, index A_i is a cell-specific metric that weights the relative attractiveness of a location (population potential) as a function of environmental and/or socioeconomic conditions. The modeling approach requires that the relationship between A_i and the different local indicators is estimated, which are hypothesized to impact population change. When α and β are estimated from historical data (e.g., observed change between 2000 and 2010), a predicted population surface is produced that reflects optimized values of α and β, such that absolute error is minimized. Figure A3.2 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 five-year time step.

It is hypothesized that this error can be explained, at least partially, by a set of omitted variables, including environmental/sectoral impacts. To incorporate these effects, the value of A_i is first calculated, such as to eliminate εi (Figure A3.2) for each individual cell (which is labeled "observed A_i"):

$$\Delta P_{i,t}^{obs} = A_i * \Delta P_{i,t}^{mod} \quad \text{Eq. 6}$$

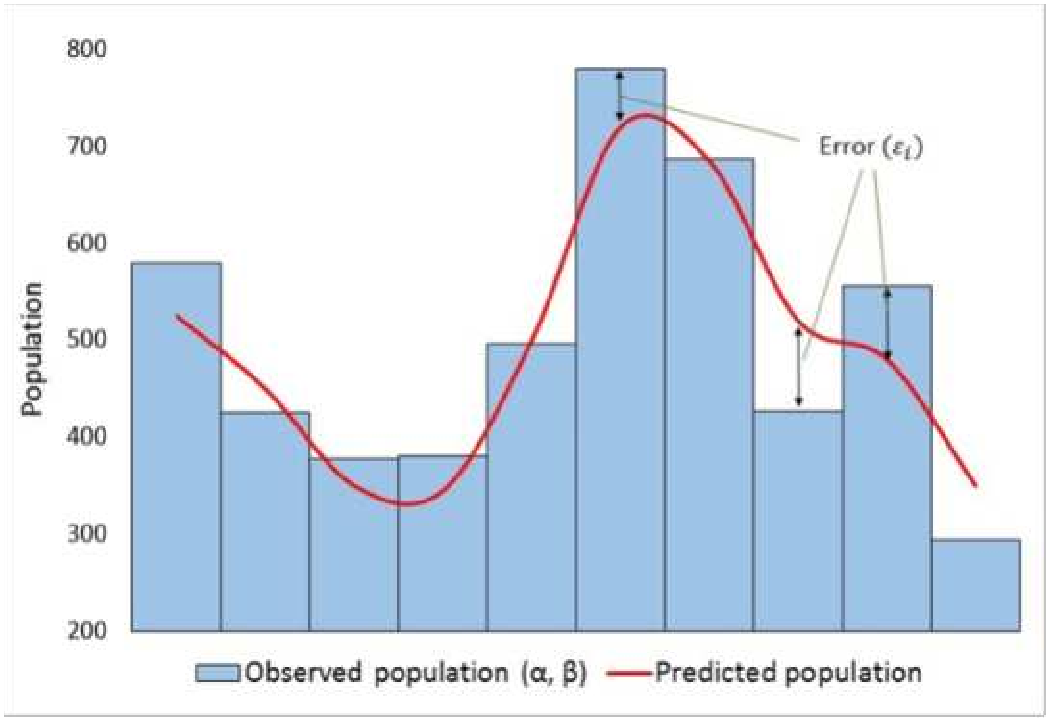
where $\Delta P_{i,t}^{obs}$ and $\Delta P_{i,t}^{mod}$ are the observed and modeled population change for each cell i and A_i is the factor necessary to equate the two.

The second step is to estimate the relationship between observed index A_i and the different potential drivers of spatial population metrics by fitting a spatial lag model:

$$A_{i,t} = \rho W A_{i,t} + \beta_1 C_{i,t} + \beta_2 H_{i,t} + \beta_3 N_{i,t} + \varepsilon_{i,t} \quad \text{Eq. 7}$$

where *C*,*H* and *N* are the five-year deviations from the historical baseline on crop yield, water availability, and net primary production, respectively. Together these variables and their respective coefficients constitute the set of explanatory variables that go into producing index A_i. Note that for any grid cell in which *C* (crop yield) is a nonzero value, the value of *N* (net primary production) is automatically set to zero, so that only one of the two variables is contributing to index A_i. Finally, ρ is the spatial autocorrelation coefficient and W is a spatial weight matrix. From this procedure, a set of cell-specific *A* values is estimated.

Figure A3.2.
Cross Section of Grid Cells Illustrating Observed and Projected Population Distributions



Source: World Bank staff analysis
Note: The error term is used to calibrate index A(i).

For future projections, projected values of each independent variable are used along with their respective coefficient estimates from Equation 7 to estimate spatially and temporally explicit values of A_i. To produce a spatially explicit population projection for each time step, estimates of α and β from the historical data (which reflect the business-as-usual nature of SSP2) are applied to produce estimates of the agglomeration effect, to which the spatio-temporally variant estimates of A_i for the SSP4 (described above) are applied and, finally, exogenous projections of national urban and rural population change are incorporated and the model is applied as specified above.

Past testing of the model indicates that cells meeting certain criteria should be excluded from the calibration procedure. First, cells that are 100 percent restricted from future population growth by the spatial mask (l, Equation 2) are excluded, as the value of v_i in these cells (0) renders the observed value of A_i inconsequential. Second, the rural and urban distributions of observed A_i were found to include significant outliers that skewed coefficient estimates in Equation 7. In most cases, these values were found to correspond with very lightly populated cells, where a small over/under prediction of the population in absolute terms (e.g., 100 persons) is actually quite large relative to total population within the cell (e.g., large percent error). The value of A_i (the weight on potential), necessary to eliminate these errors, is often proportional to the size of the error in percentage terms, and thus can be quite large, even though a significantly small portion of the total population is affected. Including these large values in Equation 7 would have a substantial impact on coefficient estimates. To combat this problem, the most extreme 2.5 percent of observations are eliminated on either end of the distribution.

Estimating Internal Climate Migrants

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 and the development-only (the "no climate" models) that include the nonclimate related drivers. Migration is a "fast" demographic variable compared with fertility and mortality; it is responsible for much of the decadal-scale redistributions of population (Rigaud et al. 2018). Without significant variation in fertility/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. In this work, to be considered an internal migrant, a person must move across municipal boundaries. Thus, for each municipality, the impact of climate change is considered to be the difference between the Climate and No-Climate scenario (e.g., SSP2/RCP8.5 versus SSP2/No-Climate). To estimate total internal migration under any scenario, the positive differences at the municipal level between any scenario are summed with its corresponding No-Climate scenario to derive total climate migrants.

Sources of uncertainty and Limitations

There are several sources of uncertainty in the climate migration modeling results presented here. Additionally, it is important to acknowledge how choices regarding data inputs and scenarios impact the outcomes. Uncertainty will impact the range of estimated number of climate migrants within and across each scenario, including the projected difference between the four socioeconomic/climate change scenarios and the corresponding respective development-only (No Climate-Change) scenarios. These are described here. The following is a description of some of the sources of uncertainty in the model:

1. ***Variation in ISIMIP impacts across ensemble members (uncertainty in sectoral change).*** In many areas of the world, the combination of the LPJmL water and crop models project different impacts than the WaterGap-GEPIC combination of water and crop models. This results in different projected regional effects in the INCLUDE model—with some model ensemble members projecting improving conditions and net climate in-migration, while others may project net climate out-migration in the same region.

2. ***Variations between the two General Circulation Models (GCM) can amplify the ISIMIP differences (climate uncertainty).*** The GCMs were selected in part because their future precipitation trends differ substantially in magnitude and, partly, even in sign across different parts of the world. This variance in precipitation across the GCMs, in turn, impacts the water and climate models, which then drives different patterns of projected future migration.

3 ***Time-space arc in the exogenous population projections and the drivers of spatial population change (temporal uncertainty).*** There is a temporal component to the modeling which can influence population distribution trajectories. For example, stronger sectoral impacts early in the 80-year time period of the projections will have greater influence than the same impacts later in the period. This is because those early impacts affect the gravitational pull of locations in the future. This creates a "temporal" momentum over which later Climate (and No-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 locations in the study, projected population growth is greatest over the next decade; if conditions also are predicted to deteriorate somewhat severely during that period, the impact on migration will be greater than if the deterioration had taken place during a more demographic stable period.

4 ***Spatial trends in climate drivers that run concurrent to socioeconomic drivers will have a larger impact than those that run counter to socioeconomic drivers (spatial uncertainty).*** For example, if sectoral impacts occur in ways that reinforce trends in places where the No-Climate scenarios suggest there will be a population gain or loss, that impact will be magnified (multiplicative effect) relative to impacts that counteract the agglomeration effect embedded in the SSP-only (No-Climate) model. In other words, if the No-Climate model finds a place is relatively attractive, and the sectoral climate impacts are positive or neutral (relative to other areas that see negative impacts), then this will tend to reinforce the attractiveness of that area. Conversely, in remote areas experiencing population decline and negative climate impacts, the "push" factors will be reinforced. This creates a "spatial" momentum that gains traction over time (and which interacts temporal momentum (see Item 3 above). The combined impact of these two factors can increase the range of outcomes within scenarios (across ensemble members), thereby increasing uncertainty.

5 ***Model parameterization (uncertainty in the historical data).*** The model was calibrated using observed population changes in association with observed climate impacts (e.g., as represented by ISIMIP model outputs) for two time periods: 2000-2010 and 2010-2020. This was done using the two separate sets of model combinations: LPjML water and crop models, and WaterGAP water and GEPIC crop models. There are different parameters that correspond to the different models. If the parameter estimates are close together across the different crop/water model, then there will be less variation in the population distribution projected by each of the models. As such, the uncertainty around the ensemble mean (measured using the coefficient of variation) will be lower and parameter estimates will be higher. Conversely, if parameter estimates are not similar, the parameter estimates will tend to be lower because the signal of the climate impact on population distribution is diluted; thus there will be greater uncertainty around the ensemble mean.

6 ***Limited historic time series for model calibration (uncertainty in the relationship between the drivers of migration and changes in the population distribution).*** Limited historic data of the type necessary to fit the model (e.g., spatially explicit data pertaining to the dependent and independent variables in the model) leads to a relatively short period over which to train the model. As noted above, the model was calibrated using two historic decadal periods; 2000-2010 and 2010-2020. Thus, the empirical relationship between changes in local conditions and spatial population dynamics (the population response to changing conditions), is based on a limited set of data, which leads to uncertainty in projected outcomes arises as result of several factors. First, the model parameters may describe a historic period that is not representative of the true, longer term relationship between drivers and population outcomes. While not necessarily the case, it is important to consider whether the period 2000-2020 deviates in any way from the longer historic baseline and, importantly, whether there is any reason to believe the period is not representative of the likely relationship between drivers and outcomes moving forward. Second, because the calibration period is short, it may not be representative of the full range of outcomes that have been observed over time, and thus the model parameters, which themselves are averages of the empirical relationship over the two decadal periods, may not truly be measures of central tendency. Finally, the projections in this work cover a long time-horizon (80 years). Basing long-term projections on a short historic time-series is potential problematic, as it is highly likely that there will be some deviation from the observed historic relationship.

7 ***Challenges associated with the cross-border component of the modeling (uncertainty in the projections of Haitian in-migration to the DR).*** The international component of the spatial population model is a form of econometric model commonly used to project bilateral flows of people (as well as goods and services, etc.) between nations/regions. While this approach is rooted in the current "state-of-the-art", it is important to consider the limitations associated with the approach, particularly within the context of the two countries in this study. Most notably, the model is trained based on migration data originating from a single census period, a result of the lack of existing historic data. Whether the data are truly representative of historic trends is difficult to ascertain, particularly in a country where migration patterns have been, at least anecdotally, known to shift substantially over time as a function of conditions and extreme events. In this model, the migratory response to conditions is based on a single snapshot, and thus may not be representative of the true relationship(s), or more likely, the true range of potential outcomes. Related, the model is also based on a relatively small set of drivers, and instead relies heavily on the size and location of the historic diaspora in driving projections (in this model mitigated or enhanced as a function of changing environmental conditions). Once again this is not an unusual approach, given the relative dearth of historic data on migration and the drivers of migration in most countries. However, here we have a small set of drivers drawn from a single historic period, it must be noted that significant uncertainty in projected future migration may arise as a result.

Additionally, it is notoriously difficult to project "shocks" that may drive significant changes in migration. While the modeling work here includes projections related to slow-onset environmental change, it does not include projections of rapid-onset extreme events like hurricanes (and the associated flooding/mudslides) that have been known to affect the region. Furthermore, uncertainty in the total number of migrants is driven by not only climate uncertainty but also by the interaction between climatic and socioeconomic conditions. Likewise, the wide range of outcomes across scenarios reflects a significant level of uncertainty in the relationship between nationwide climate drivers in Haiti and of movement into the DR (in comparison to the 1-km resolution that was available for the internal INCLUDE model). Additionally, it should be noted that these figures reflect no change in border policy (on either side) over the course of the century—an unlikely outcome if the number of migrants changes substantially, if conditions deteriorate substantially, or both. It also reflects a future in which Haiti's fragility, conflict, and vulnerability conditions continue the trends of the last few decades (which are reflected in the historical data used for this model). Future socio economic and political shocks are not considered in the model, although it can be argued that the data on Haitian migration used to train the model may already reflect, at least partially, socio economic and political conditions of the country. However, because the timing of such events is important in projecting the temporal component of any impact on migration, there remains substantial uncertainty in the timing of mobility that may be related.

8 ***The base-year distribution (uncertainty in the current population distribution).*** Through past research, it was found that the choice of spatial population product (e.g., GPW, WorldPop, GHS-Pop) for the base year (2020) had a significant impact on both aggregate and spatially explicit projections of future climate-induced displacement and migration. In some cases, the variation between projections produced for the same country/scenario, using different data products in the base year (e.g., GPW versus WorldPop), was larger than the variation observed across different scenarios using the same base year product (e.g., SSP2/RCP2.6 versus SSP4/RCP8.5, using WorldPop as the initial population distribution). This suggests that many of the modeling outcomes might reflect the base year distribution more so than the actual drivers of change. It is important to consider the implications of the choice of base year product, and to consider how the base year distribution is likely to impact outcomes (e.g., using GPW will lead to larger numbers of migrants into cities than World-Pop, owing to the known bias toward rural areas in the former).

9 ***The crop models exclude several locally important crops.*** The ISIMIP models project change in crop yields for four major staple crops: maize, wheat, rice, and soybeans. This choice reflects the global importance of these crops. In the DR, however, sugar, bananas and, to a lesser extent, coffee and cocoa, are of significant importance. At this time, there are no data pertaining to these crops over the time period necessary for application in this model. As such, the analysis relies on the staple crop data to indicate the degree to which conditions can be expected to vary at the local level, relative to historical conditions. A reduced capacity to produce maize or wheat could correspond to declines in the capacity to produce sugar or bananas (depending on what is driving the decline). Theoretically, however, the opposite also could be true. The results presented here should be consumed with the knowledge that local variations may differ from projections in the ISIMIP data.

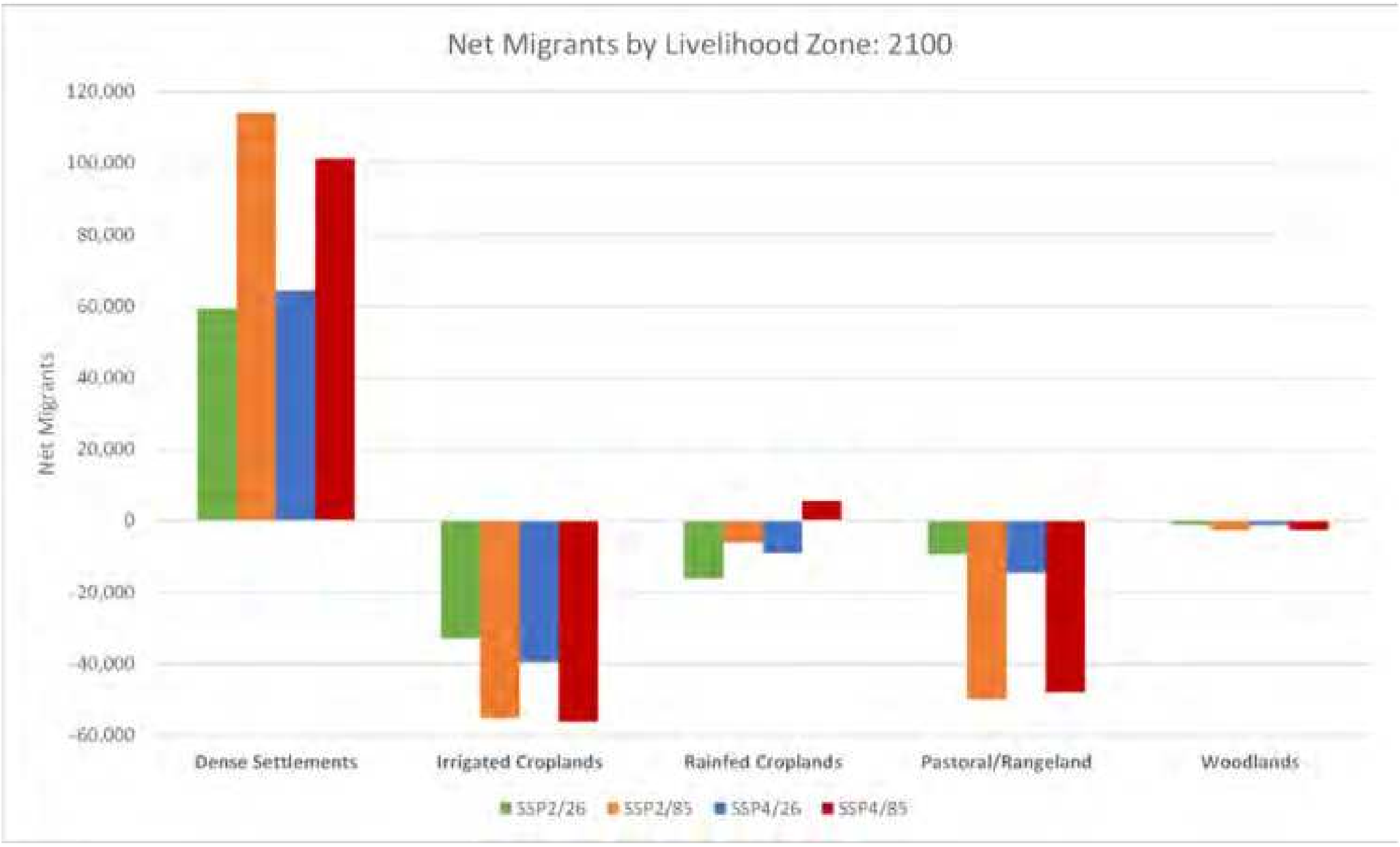
10 ***The modelling approach might miss human mobility impacts from SLR.*** The complexity of SLR impacts pose a number of challenges from a modeling perspective. First, while inundation and storm surge are factors that can be projected and are modelled in this study, other impacts such as salt-water intrusion, loss of drinking water supply, or the perceptions regarding SLR and its impact on residential choice are very difficult to model at present. This is due to both a lack of data and the uncertainty surrounding the impact of SLR on household-level perceptions regarding coastal threats. Also, in this study, a migrant is defined as someone that moves between municipalities. However, many of those likely to be impacted by SLR may not choose to leave their current municipality, but only to relocate within that community. In our modeling approach, these families would not be considered migrants. Even assessing the movement patterns using the 1km -resolution data (highest resolution available) might miss some people relocating because of SLR.

Appendix 4:
Additional Tables and Figures from Quantitative Modeling, Dominican Republic

Figure A4.1.
Hotspots in the Dominican Republic, 2051-2100

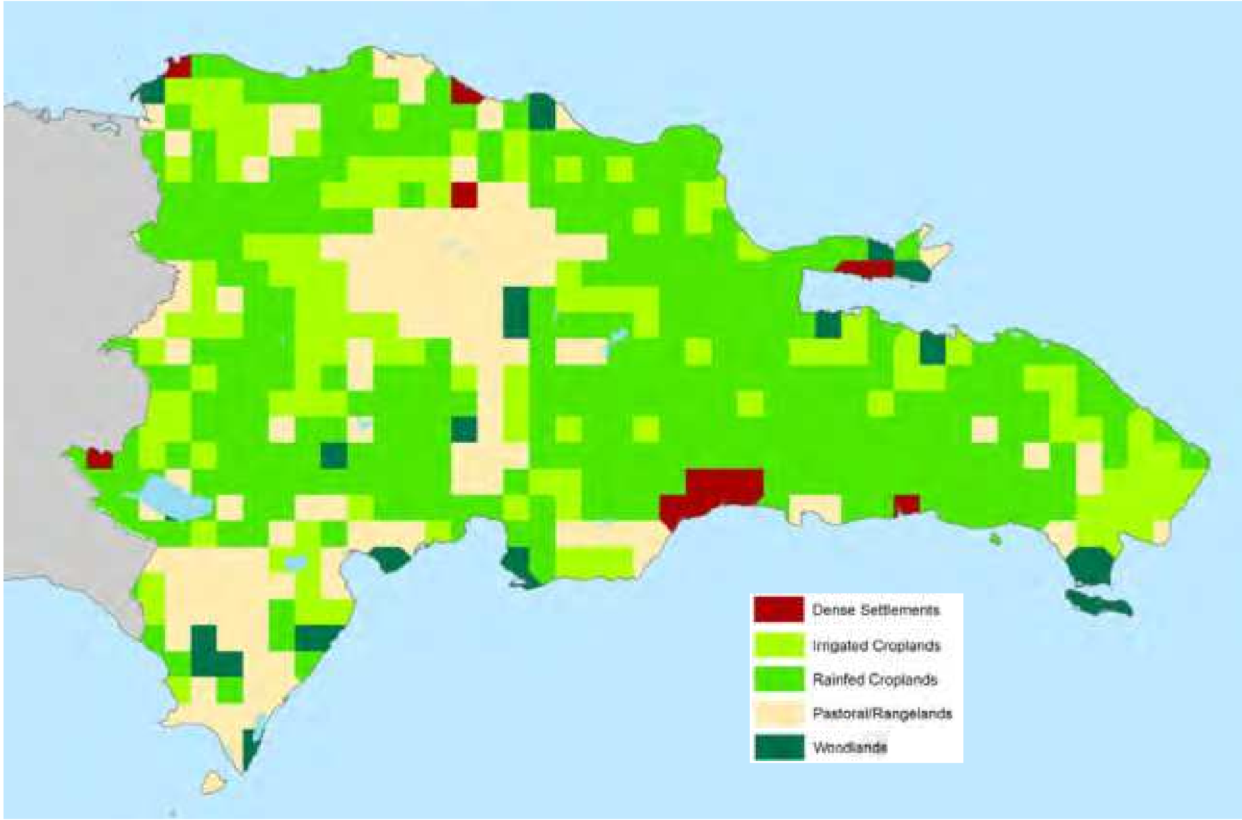
Source: World Bank staff analysis

Figure A4.2.
Net Climate Migrants by Livelihood, 2051-2100: Dominican Republic



Source: World Bank staff analysis

Figure A4.3.
Livelihood Zones: Dominican Republic



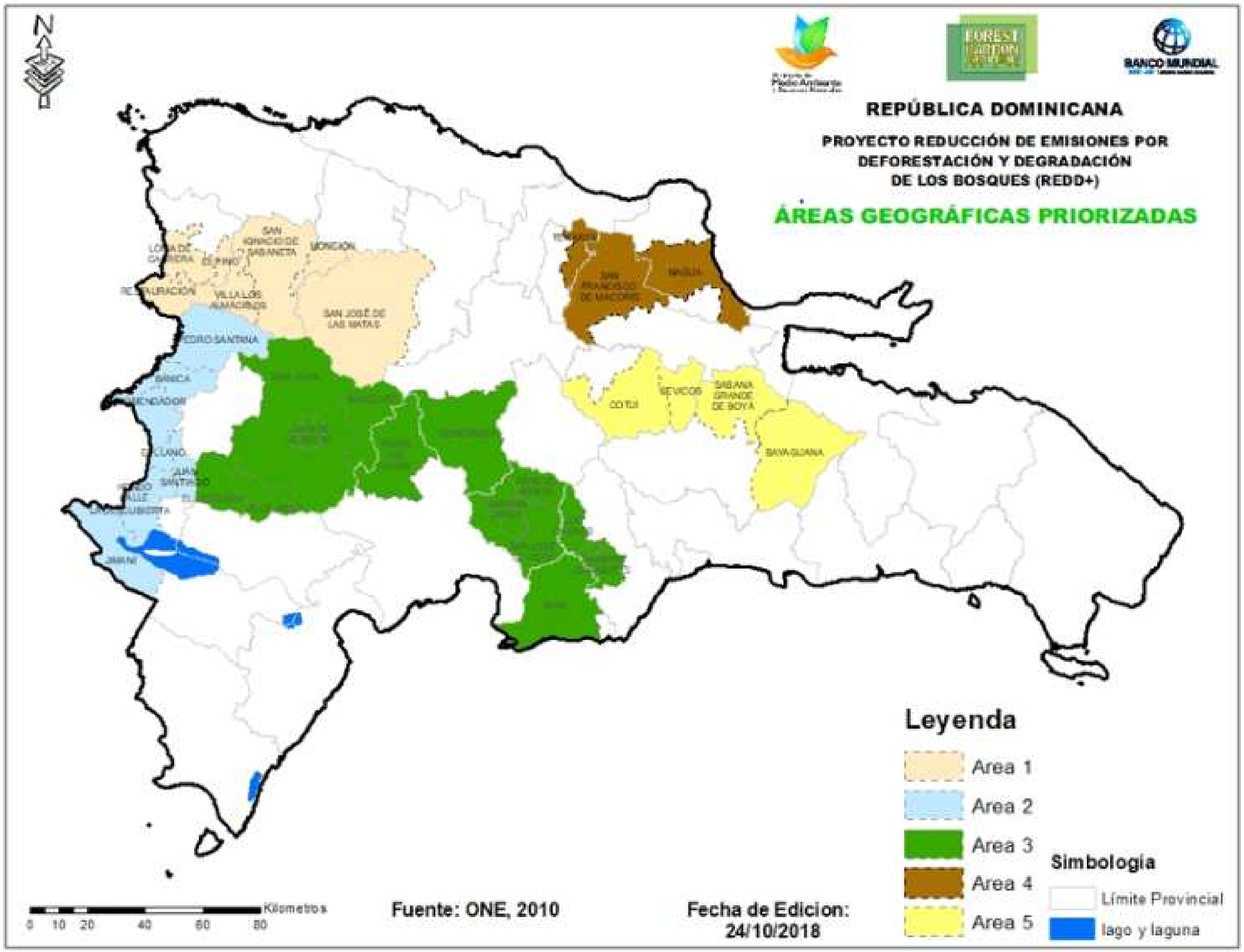
1 Data is used only to differentiate results by livelihood zone. It was not used to produce estimates during modeling.

Figure A4.4.
Projected Population by Livelihood Zone, 2050 and 2100: Dominican Republic

	SSP2/26		SSP2/85		SSP4/26		SSP4/85	
	2050	2100	2050	2100	2050	2100	2050	2100
Dense Settlements	5,243,505	5,097,497	5,298,990	5,152,214	5,073,498	3,986,614	5,122,561	4,023,572
Irrigated Croplands	1,433,524	1,317,233	1,410,617	1,294,775	1,253,557	859,953	1,233,863	843,202
Rainfed Croplands	3,979,398	3,626,599	3,983,421	3,636,554	3,384,618	2,314,373	3,387,288	2,328,876
Pastoral/Rangelands	2,387,240	2,274,427	2,351,475	2,233,644	2,219,463	1,661,028	2,188,575	1,627,745
Woodlands	88,506	79,019	87,681	77,522	74,312	48,626	73,128	47,194

Source: World Bank staff analysis

Appendix 5:
Prioritized Areas for the Emissions Reduction Program, Dominican Republic



Source: World Bank (2021) Project Appraisal Document - Dominican Republic Emission Reductions Program