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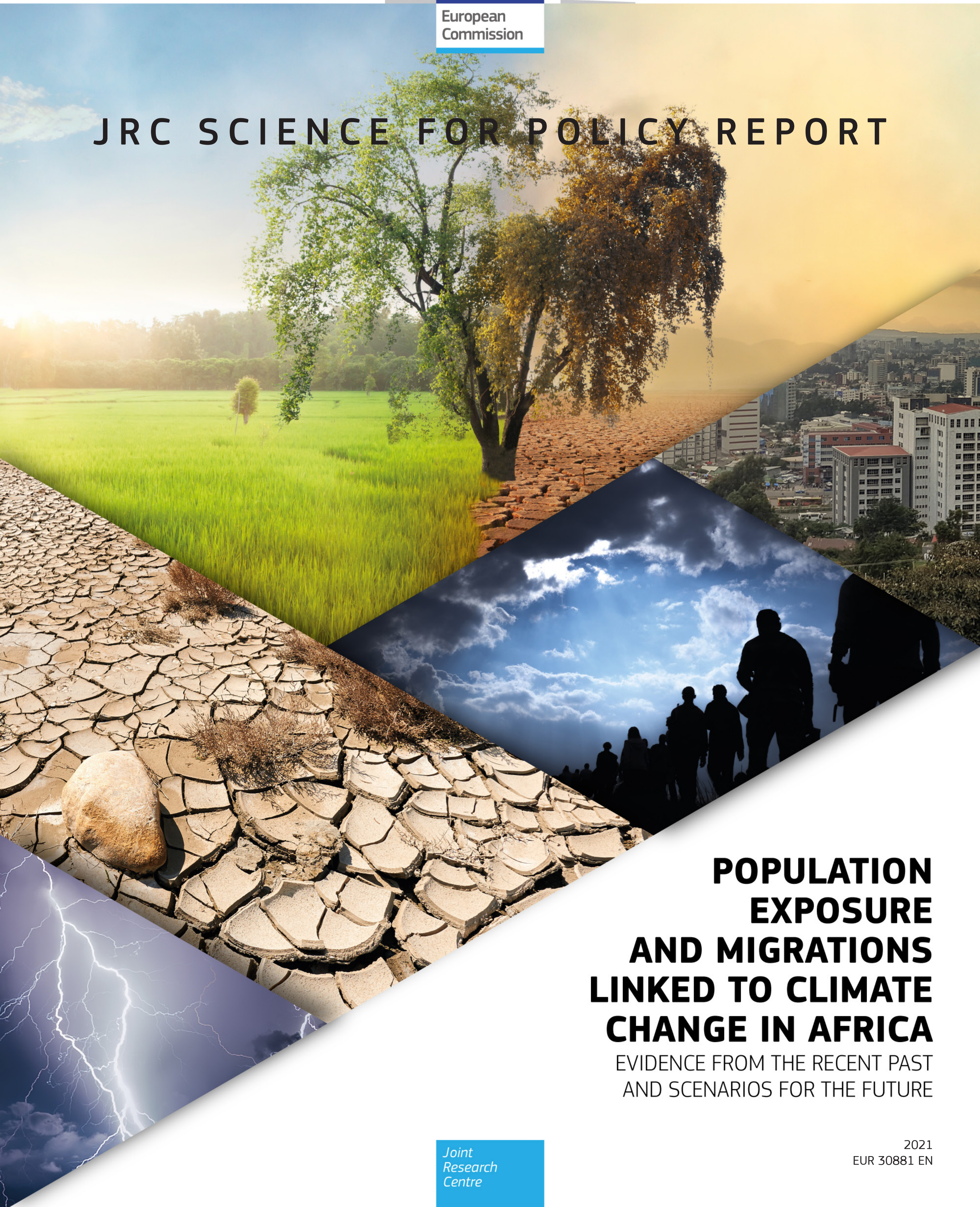

POPULATION EXPOSURE AND MIGRATIONS LINKED TO CLIMATE CHANGE IN AFRICA

EVIDENCE FROM THE RECENT PAST AND SCENARIOS FOR THE FUTURE

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Population exposure and migrations linked to climate change in Africa

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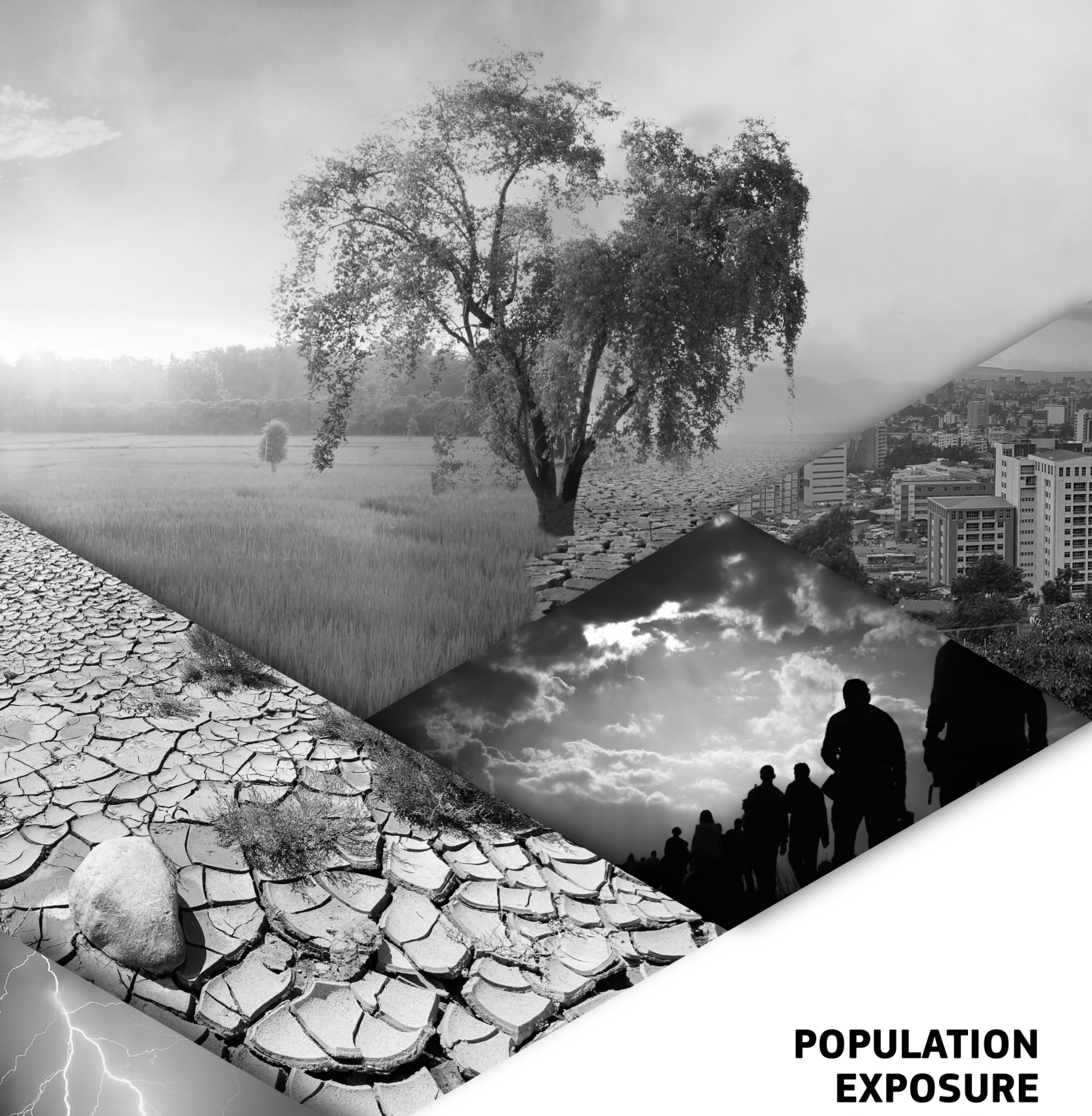

POPULATION EXPOSURE AND MIGRATIONS LINKED TO CLIMATE CHANGE IN AFRICA

EVIDENCE FROM THE RECENT PAST AND SCENARIOS FOR THE FUTURE

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EXECUTIVE SUMMARY

Many public debates and political discourses in the recent years have highlighted the impact of climate change on migration. These debates are still influenced by early estimates, which predicted that millions of people would be fleeing climate change effects. Part of this alarmist narrative is linked to a lack of definition of *climate migrants* which also hinders the design of policies to tackle the issue.

Over the years, EU policy has evolved from ad hoc initiatives and definitions of migration and climate change as *threat multipliers* towards a more holistic, balanced and integrated approach. This reflects the fact that climate change impacts stretch across policy areas, institutional boundaries and geographic borders and therefore cannot be addressed in isolation.

The main purpose of this report is to contribute to the ongoing integration of EU policies on climate change, adaptation and migration. The specific objectives are:

- to identify associations between climate change and displacement in Africa, in recent decades;

- to provide spatially explicit estimates of populations exposed and vulnerable to climate change impacts up to 2070 for several scenarios of climate change[1] and socio-economic development,[2] and to discuss the implications for climate-driven migration in Africa.

For the part dealing with the future, the report quantifies the size of population that could be exposed and vulnerable to climate change impacts on agricultural productivity. For the purpose of this study, vulnerable populations are defined as those living in rural areas, with low education and in poverty. For the past, the report tries to identify associations between displacement (intended as the difference between immigration and emigration from a certain area independently of the origin and destination of the flows) and a series of climate change variables. These macro analyses are complemented by case studies on the relation with urbanisation in Egypt, with drought in the Sahel regions and with conflicts in Sudan and South Sudan. Finally, the report considers individual perspectives of African citizens using survey data on their perceptions about climate change and the desire to migrate.

The main findings of the report are summarised below.

PROJECTIONS OF POPULATIONS EXPOSED AND VULNERABLE TO CLIMATE CHANGE

Regions in Africa are among the most exposed to climate change impacts. This high level of exposure is driven by population growth and by the impacts of climate change on

1 The representative concentration pathways, RCP2.6 and RCP6.0, as explained in Chapter 2
2 The shared socio-economic pathways, SSP1-SSP5

agricultural productivity, which are expected to be more severe in tropical and subtropical regions than in temperate regions.

Our results indicate that within Africa the most affected region in terms of overall size of exposed population would be Western Africa. According to the most impactful scenarios, by 2070, up to 15% of the population in Western Africa would be exposed to the negative impacts of climate change, here defined as living in areas where agricultural productivity drops by 20% or more. In the same region, 9% of the total population would be exposed and living in rural areas, 10% would be exposed and have a low level of education and 1.5% would live below the poverty threshold of $1.9 per capita per day.

While the level of exposure in the projections mainly depends on the level of greenhouse gas emissions, the vulnerability of exposed population depends mainly on socio-economic development. This underlines the need to address the adverse consequences of climate change through both climate and development policies. A reduction of emissions can reduce population exposure, but improvements in education, poverty and urbanisation will be critical when considering conditions of vulnerability.

The socio-economic scenario with the most adverse consequences in terms of exposure and vulnerability also corresponds to a pathway of resurgent nationalism, and weak global institutions. Under these conditions, it seems unlikely that the large numbers of vulnerable populations in large parts of Africa will have the means to adapt to climate change by migrating to other countries. Figures on exposure and vulnerability should be interpreted as upper-bound estimates of those populations that will need to adapt to climate change impacts. The quantification of the number of migrants within exposed and vulnerable populations is a complex task that faces several challenges and uncertainties, such as the difficulty to disentangle climate change from other migration drivers. Despite the challenges, evidence from the recent past can shed light on the climate change-migration nexus.

FROM EXPOSURE AND VULNERABILITY TO MIGRATION: THE NEXUS BETWEEN CLIMATE CHANGE AND NET MIGRATION IN THE RECENT PAST

We explored a large range of climate change indicators, but we were not able to find a statistically significant and unequivocal relationship between climate change and displacement across the entire African continent. What emerges from our analyses is rather a patchwork of signals of associations between climate change and displacement, that vary from one African region to another.

In the Northern African region, the duration and the frequency of heat waves are positively associated with displacement. However, this link is less clear in areas where the population is expanding, either due to natural increase or urbanisation. These results show that population growth and/or the level of urbanisation are the prevailing factors which influence migration in the Northern African territories, while climate change impacts appear less important in such demographic processes.

In Western Africa, a positive association between extreme temperatures, drought severity and displacement emerges only when focusing on the specific context of the Sahel region, with its already established seasonal migrations, often linked to recurrent droughts and food shortages.

In Eastern Africa, the lack of a clear association between displacement and climate change could be due to the influence of climate effects on the occurrence of conflicts. In the case study of Sudan and South Sudan, the results indicate a higher incidence of violence in urban than in rural areas and an association between climate anomalies and an increase in organised violence. The fact that areas affected by conflicts are often also experiencing higher immigration than emigration supports the notion that climate-induced migration may increase the competition for resources (e.g., food and employment) in the host areas and exacerbate ethnic tensions with the host communities.

Results for Southern Africa are useful to show how the impact of climate change on displacement is mediated by effects of climate change on agricultural productivity. In Southern Africa, we find a positive association between extreme temperatures and displacement, which could be connected in particular to the declining yields of maize. Moreover, a link between rainfall and displacement was found only for the upper-middle income countries of the regions. This supports the findings from other studies that migration can be an adaptation strategy to climate change only in those contexts where people have the economic means to migrate.

INDIVIDUAL PERCEPTIONS OF CLIMATE CHANGE AND DESIRE TO MIGRATE

As stressed in part of the migration literature, it is overly simplistic to analyse the relation between climate change and the complex pathways leading to migration decisions exclusively by looking at macro demographic patterns. To address this gap, we explore how intentions to migrate relate to perceptions on climate change using recent Afrobarometer surveys.

More than half of the survey respondents have heard about climate change and this awareness is highest in urban areas. Overall, in Africa, about half of the respondents think that climate conditions for agricultural production in their area has gotten worse or much worse. However, only 0.16% of those who declare they would like to emigrate report natural disasters as the most important reason for leaving the country.

Based on sociodemographic characteristics, we see that negative perception about the climate increases the desire to migrate particularly among people with secondary or higher education. This final finding can be read in conjunction with the estimates of vulnerability of populations with low level of education, provided in the chapter on projections. In particular, it supports the notion that people with low education who are expected to be more vulnerable to climate change impacts, are also less likely to consider migration as an adaptation strategy to climate change.

LIMITATIONS AND POLICY RECOMMENDATIONS

Any attempt to tackle the complex topic of climate change induced migration through an explicit quantification exercise faces two opposite challenges. On one side, when directly attributing migration to climate change, the estimates of climate change migrants tend to be limited to forced displacement due to climate emergencies, natural disasters (e.g., floods, hurricanes, severe exceptional droughts) and sea level rise. On the other side, a focus on longer term effects of climate change entail difficulties to disentangle the role of climate change from other factors that influence the movement of populations such as urbanisation or economic drivers.

After a thorough examination of recent evidence of climate change, we were not able to find a strong consistent relation between medium to long-term climate change (i.e., time scale of up to 50 years) and population movements. The actual complexity and context specificity of such relations hinders the attempts to translate the projections of exposure and vulnerability to a number of migrants and even more the subsequent step of establishing if these migrations would take place within countries or internationally.

The limitations and uncertainties in quantifying the impacts of climate change on migration, which are also stressed in the scientific literature, should not represent a justification for remaining inactive in the face of the potentially large consequences of climate change on human systems. As indicated in the chapter on exposure and vulnerability, there is a high probability that large populations will suffer from drops in agricultural productivity. Some pathways for socioeconomic development imply also that large segments of these populations will be in conditions of vulnerability especially in Africa.

These conclusions highlight the importance of orienting the focus of the policy discourse from a possible threat of an incoming exodus induced by climate change to the needs for adaptation. In addition, they stress the need for a joint effort in migration, climate adaptation and development policies to cater for the needs of those who will be trapped in conditions of extreme environmental degradation, without having necessarily the means to revert to migration as an adaption strategy.

1. EU AND INTERNATIONAL POLICIES ON CLIMATE CHANGE AND MIGRATION

Simon MCMAHON, Guido TINTORI, Marta PEREZ FERNANDEZ

Climate change is generally understood as 'a change in climate patterns due to human activities, going beyond the natural variability in the climate'.[3] Some of the most visible implications include rising of the temperature of the earth's atmosphere, rising sea levels, shifts in weather cycles and increasing frequency of extreme weather events such as droughts and floods. These events have significant implications for the ecosystems and populations directly affected by them. But climate change also encompasses a much wider range of processes and consequences which will condition all aspects of human health, economy and society. This report contributes to understanding, and responding to, some of these broader consequences with a focus on migration and displacement.

Often, contributions to public and policy debates have been concerned with the impact of climate change on migration, and in particular warned of a forthcoming crisis of sudden, large-scale and unplanned movements of people. Many international organisations have described future waves of 'environmental migrants'[4] or 'climate refugees' (Ida 2021) and sought to quantify the scale of their future displacement. Estimates suggest that there will be anywhere between 25 million and one billion environmental migrants by 2050 within countries and across borders (Myers 2005; Brown 2008; Kamal 2017; Rigaud et al. 2018). The United Nations High Commissioner for Refugees (UNHCR) has similarly stated that 'climate change is the defining crisis of our time and disaster displacement one of its most devastating consequences'.[5] The international media has taken a similar approach, such as when the New York Times writes that 'the result (of climate change) will almost certainly be the greatest wave of global migration the world has seen [...] it will amount to a vast remapping of the world's populations' (Lustgarten 2020).

The crisis narrative described above underlines the urgency of addressing the implications of climate change for migration. But it offers a limited understanding of the changes at hand. In particular, it often adopts a narrow view of migration which focuses primarily on displacement and the potential threats posed by it. Mass displacement in contexts of climate change will be a major challenge in the not-to-distant future, but there is more to the climate-migration nexus. However, while it may be relatively straightforward to find a correlation between extreme weather and the sudden displacement of an exposed population, it is much more challenging to appraise the extent to which all forms of migration, both across and within national borders around the world, have been induced in some way by climate change. This is because migration drivers and processes are

3 This definition comes from Eurostat, see here for more information: https://ec.europa.eu/eurostat/web/climate-change
4 See for example the webpage from International Organisation for Migration on 'Environmental Migration' https://environmentalmigration.iom.int/environmental-migration-1
5 See for example the webpage on 'Climate change and disasters', https://www.unhcr.org/climate-change-and-disasters.html

complex and multifaceted, responding to causes, incentives and determinants that intervene at levels that are both structural/institutional and individual/personal.

Environmental changes can interact with existing migration patterns or create new ones. Although it is true that climate change will increase the frequency of sudden crises from which people will flee, most emigration from areas of climate change so far has tended to increase in a gradual way over time, and many people have continued to migrate to locations affected by some of the worst implications of climate change. In this way, the relationship between climate change and migration is highly varied according to local contexts and their histories of migration.

In this chapter, we look beyond the crisis narrative in public and political debate and describe the general evolution of European Union (EU) and international policies on the climate change-migration nexus. Doing so shows that, although displacement is a key concern in policy frameworks on the topic, there have also been examples of a broader mainstreaming of climate change into migration policies and, vice versa, migration into climate change responses. This integration is important due to the complex, multifaceted and highly localised nature of both climate change dynamics and migration decision-making. Climate change and environmental degradation are a core concern of the EU today, and tackling them has been described as the current generation's 'defining task' (COM(2019) 640 final). As noted by European Commission Executive Vice-President Timmermans, 'anyone who wants to deny the urgency of the climate crisis should look again. And we certainly don't have the luxury of denying it [...] Yes, it is difficult. Yes, it is hard. But it's also an obligation. Because if we would renounce our obligation to help humanity live within planetary boundaries, we would fail' (European Commission 2021).

This concern is echoed around the world. The UN has called climate change 'the defining issue of our time and the greatest challenge to sustainable development'.[6] In 2015, 196 parties signed up to the Paris Agreement on climate change, seeking to limit global warming to below 2 deg Celsius compared to pre-industrial levels,[7] and the UN's Sustainable Development Goal 13 aims to 'take urgent action to combat climate change and its impacts', including by strengthening the capacity of all countries to respond and adapt to climate change and integrating climate change measures into national policies, strategies and planning.[8] These general statements have been accompanied by an expanding array of policy frameworks and actions which will be shown below.

MIGRATION AND CLIMATE CHANGE IN EU POLICIES

European institutions had already recognised that 'the protection of the environment belongs to the essential tasks of the Community' as far back as 1973 (Hey 2005). Since then, they have increasingly emphasised the significance and urgency of addressing climate change, such as by establishing multi-annual action programmes on the environment and defining practical policy measures such as emissions targets and funding for initiatives increasing sustainability. There is insufficient space here to comprehensively cover the

6 For more information see: https://www.un.org/development/desa/undesavoice/more-from-undesa/2019/08/46020.html
7 For more information see: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
8 For more information see: https://www.un.org/sustainabledevelopment/climate-change/

history of climate change-related developments in the EU, but in general it should be noted that the over-arching trend has seen evolution from piecemeal initiatives towards a more holistic and integrated approach. This recognises how climate change impacts cannot be addressed in isolation because they stretch across and interact with a range of other policy fields, institutional boundaries and geographic areas. Action against climate change has increasingly been mainstreamed across the spectrum of EU policymaking areas, including migration.

The current keystone of the EU's response to climate change is the European Green Deal, which sets out 'a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use'. The Green Deal also states that 'all EU actions and policies will have to contribute to the European Green Deal objectives' and climate policy will become 'an integral part of the EU's thinking and action on external issues'. For example, the Joint Communication to the European Parliament and the Council Towards a comprehensive Strategy with Africa (JOIN(2020) 4 final) places the green transition as the first partnership to pursue with African partners, stating that 'the EU and Africa alike need to opt for a low-carbon, resource efficient and climate-resilient future'. 25 per cent of the Neighbourhood, Development and International Cooperation Instrument upcoming budget will be allocated to climate-related objectives.[9]

In terms of EU migration policy frameworks, the significance of climate change has been recognised in two main ways. On one hand, linkages between the two have underlined the role of climate change as a driver of forced migration and displacement. For example, the report Climate Change and International Security, published by the High Representative for Common Foreign and Security Policy and the European Commission in 2008, referred to migration within its examination of the impact of climate change on international security. In doing so, it defined migration and climate change as 'threat multipliers' as climate change acts on existing drivers to cause more migration, it can in turn cause increased 'migratory pressure', insecurity and conflict in places of transit and destination. Similar can be found in the Green Deal, which states that 'global climate and environmental challenges are a significant threat multiplier and a source of instability … the EU will work with all partners to increase climate and environmental resilience to prevent these challenges from becoming sources of conflict, food insecurity, population displacement and forced migration, and support a just transition globally.'

On the other hand, however, there have been moves to integrate climate change within migration policymaking on migration which looks beyond displacement. In this vein, in 2011 the Global Approach to Migration and Mobility (GAMM) (COM/2011/0743 final) stated that 'Addressing environmentally induced migration, also by means of adaptation to the adverse effects of climate change, should be considered part of the Global Approach'. In 2013, the EU Strategy on Adaptation to Climate Change (COM/2013/0216 final) also stated that 'Migration in the context of environmental change is a complex issue that requires comprehensive responses involving a broad range of issues and policies: climate change mitigation, disaster risk reduction, urban planning, education,

9 For more information on The Green Deal, see https://ec.europa.eu/info/publications/delivering-european-green-deal_en

social policy, asylum and migration policies, development policies and humanitarian and civil protection policies'.[10] The updated EU Climate Adaptation Strategy from 2021 (COM/2021/82 final) also states that 'Adaptation is a crosscutting element in the EU's and Member States' external action, spanning international cooperation, migration, trade, agriculture and security' and highlights a need to 'better understand and manage the interconnections between climate change, security and mobility'.

INTERNATIONAL POLICIES ON THE CLIMATE CHANGE-MIGRATION NEXUS

The evolution of the EU policy context described above has broadly mirrored similarly shifts in international policy frameworks. These include historic developments in responses to climate change, such as the Paris Climate Conference in 2015 and The Paris Agreement on Climate Change in 2016, which was the first legally binding international agreement on climate change. The Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2° C and pursuing efforts to limit it to 1.5°C. It also aims to strengthen countries' ability to deal with the impacts of climate change and support them in their efforts. The significance of climate change for migration has also repeatedly been recognised in the international arena, but this has led to a complicated array of separate and often overlapping consultations, agreements and guidelines.
A predominant concern at the international level has been on providing protection for populations displaced by natural disasters. For example, in 2010 the UNFCCC Cancun Agreements called for better knowledge and collaboration regarding climate change and displacement and in 2011 the Nansen Conference on Climate Change and Displacement and the UNHCR Ministerial Conference committed to working towards a more coordinated approach to addressing the protection needs of those displaced across borders due to disasters and climate change. Outputs from these and other international processes include the IASC Operational Guidelines on the Protection of Persons in Situations of Natural Disasters in 2011, the Agenda for the Protection of Cross-Border Displaced Persons in the Context of Disasters and Climate Change in 2015, and the non-binding Guidelines to Protect Migrants in Countries Experiencing Conflict or Natural Disaster resulting from the Migrants in Countries in Crisis Initiative in 2016.

Although at times disconnected from one another, the processes described above lay the groundwork for the incorporation of migration and displacement into the major international frameworks for responding to climate change. The Paris Agreement recognises that responses to climate change should respect the rights of migrants alongside other particular populations, for example. The Paris Conference also called for the creation of a Task Force on Displacement to develop recommendations on responding to climate change-related displacement. Furthermore, climate change has also been incorporated into key frameworks for the global governance of migration. In 2016, The New York Declaration for Refugees and Migrants recognised climate change, natural disasters and other environmental factors as drivers of migration. In 2018, the Global

10 See in particular the Staff Working Document accompanying the strategy (SWD/2013/0138 final)

Compact on Safe, Regular and Orderly Migration (GCM) [11] also included environmental migration under Objective Two on addressing root causes of migration in the context of natural disasters, climate change and environmental degradation and Objective Five on ways to strengthen opportunities for regular migration for those impacted by slow-onset natural disasters.

Alongside and incorporated within many of the policy developments listed above has been a search for an appropriate terminology and legal framework to refer to people who migrate as a result of climate change. Some organisations refer to 'environmental migrants' and 'environmental displacement', for example. Others speak of 'climate refugees'. As already noted above, estimates of the number of future 'environmental migrants' have been produced based on calculations of how many people will be exposed to climate change in the future. The search for environmental migrants suggests a simple, linear relationship between migration flows and changes in climate and environment. It also posits that these changes can be clearly identified as the main factor driving people to migrate. But to do so is problematic. Although changes in climate and environment can shape how, when and where people move, just being exposed to them is unlikely to be the only reason why people migrate. As research has shown, multiple drivers interact to shape peoples' decisions to migrate (Carling and Schewel 2018; Migali et al. 2018; McMahon and Sigona 2018). Those who emigrate tend to have some prior knowledge, resources and opportunities to do so. They are also likely to have a range of personal, economic, social and other motivations and aspirations which shape their decision of where, when and how to move. In contrast, people who do not have the same resources are less likely to be able to move. When faced with environmental shifts associated with climate change, some people will be able to adapt by migrating elsewhere, but that will not necessarily be the case for everyone.

CONCLUSION

This chapter has described the general contours of EU and international policy frameworks regarding climate change and migration. In doing so, it has highlighted the development of an increasingly holistic approach to the climate change-migration nexus. Although displacement has been a key focus of many initiatives over the past few decades, steps have also been taken towards a more comprehensive integration of climate change in migration policies and, vice versa, of migration and mobility in climate change policies. As well as support for those displaced by severe weather and disasters, the varied, complex and locally-specific nature of the relationship between much migration and climate change also calls for broader and contextually-sensitive adaptation strategies.

11 See https://www.iom.int/global-compact-migration

2. PROJECTING POPULATIONS EXPOSED AND VULNERABLE TO CLIMATE CHANGE

Fabrizio NATALE, Alfredo ALESSANDRINI, Anne GOUJON, Daniela GHIO,Thomas PETROLIAGKIS

INTRODUCTION

This chapter addresses the question of how many people in Africa could be exposed and vulnerable to climate change by 2070. To answer this question, the chapter combines different sets of scenarios on the socio-economic evolution of societies and on climate change impacts with a focus on changes in agricultural productivity.

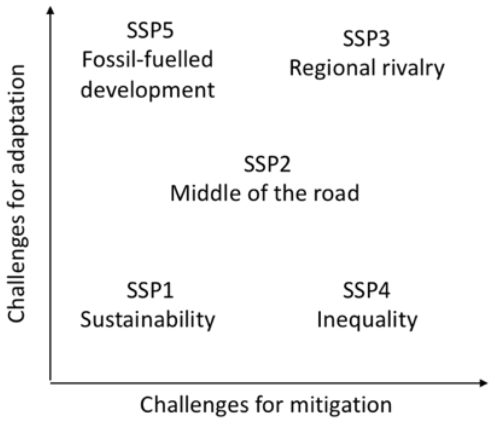
The concepts of exposure and vulnerability are borrowed from the framework adopted by the IPCC (Intergovernmental Panel on Climate Change) to assess the impacts of climate change on environmental and human systems (IPCC 2012; Turner et al. 2003). According to this framework, the severity of climate change impacts is determined by the interaction between extreme weather events and climate hazards on the one side, and the exposure and vulnerability of environmental and population systems, on the other. In relation to human systems, exposure is resulting from the spatial overlaying of the presence of populations and the local manifestation of impacts from climate change. Instead, vulnerability refers to the populations' capacity to cope with the adverse consequences of climate change. Since both the severity of climate change impacts and population dynamics vary geographically, exposure and vulnerability are best assessed by taking into account the interplay between climate change, population growth, urbanisation, and socio-economic conditions at local level.

To assess population exposure and vulnerability, this chapter relies on the state-of-the-art research and projections of populations and climate impacts at high geographical granularity. These projections consist in the quantification of scenarios on the possible future patterns of societal and climate transformations adopted by the international research community (O'Neill et al. 2020) (Figure 1).

In particular, two sets of scenarios are adopted and combined: Shared Socioeconomic Pathways (SSPs), and Representative Concentration Pathways (RCPs).

The SSPs are qualitative narratives describing the plausible future changes at global level in 'demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources' (O'Neill et al. 2017) (see Appendix for the original formulation of the narratives). These narratives reflect the possible socio-

FIGURE 1. Conceptual framework for socio-economic and emission pathways.
Source: O'Neill et al. (2017). *Note*: Shaded cells in the picture on the right indicate combinations considered in this study.



	SSP1	SSP2	SSP3	SSP4	SSP5
RCP8.5					
RCP6.0					
RCP4.5					
RCP2.6					
RCP1.6					

economic challenges that societies could face in adapting to climate change and mitigating its impacts. Some of the key variables in the SSPs, such as population and education (KC and Lutz 2017), urbanisation (Jiang and O'Neill 2017), economic growth (Crespo Cuaresma 2017; Dellink et al. 2017), and income inequality (Rao et al. 2019), have been quantified at national level.[12] Furthermore, the country-level projections of population corresponding to the SSPs have been downscaled at high geographical granularity (Jones 2016).

On the side of climate change, Representative Concentration Pathways (RCPs) are scenarios on different trajectories of greenhouse gas concentration (van Vuuren et al. 2011). More specifically, the RCPs represent changes in the energy balance of the earth system which can be linked to increases in anthropogenic greenhouse gas.[13] For instance, RCP1.9 corresponds to a pathway of global warming below 1.5° C by 2100. Instead, RCP2.6 corresponds to a global temperature rise below 2° C by the end of the century, in line with the Paris Agreement.

The two sets of SSP and RCP scenarios are intentionally designed to be independent from one another. In other words, the SSPs look at the societal challenges of mitigation and adaptation to climate change without taking into account the influence of climate change policies. Symmetrically, the RCPs consider only greenhouse gas emissions patterns and targets. The independence between the two sets of scenarios allows an intersection of the resulting projections avoiding feedback effects (see right panel in Figure 1). This, in turn, allows an exploration of how climate mitigation and adaptation challenges and opportunities are related to different targets of greenhouse gas emissions.

In the analyses in this chapter, projections of demographic and socio-economic indicators based on the SSPs are geographically overlaid on projections of changes in agricultural

12 The SPPs have also been incorporated in Integrated assessment models evaluating the possible change in land use, energy and agricultural systems and their impact in terms of GHG (greenhouse gases) emissions under different SSPs and climate policy assumptions.

13 Respectively: 1.9, 3.4, 2.6, 4.5, 6, 7, and 8.5 W/m2.

productivity stemming from the RCP2.6 and RCP6.0 climate scenarios. These two scenarios are chosen to represent the two extremes of possible future emissions.[14]

Exposed populations are then estimated as the number of people living in territories where agricultural productivity is expected to reduce by more than 20% in comparison to historical trends. Furthermore, estimates on the share of vulnerable populations are also provided. More specifically, vulnerability – that is, the capacity of populations to cope with climate change impacts – encompasses the following dimensions: residing in rural areas, living below the poverty line, holding a level of primary education or less.

The emphasis on agriculture – instead of climate change per se – is founded on the following considerations. Firstly, agriculture is usually more dependent on the natural systems than other economic sectors. Hence, it is among the sectors most exposed.[15] Secondly, agriculture is a key source of GDP and employment in most African countries, particularly in the case of subsistence agriculture systems. Farmers may be able adapt to drought by changing crops, management practices, planting seasons and introducing new irrigation systems. However, these possibilities are limited in low-technology farming systems, especially in subtropical and tropical areas. Moreover, the trade of food commodities to compensate for the decline in agricultural productivity will not solve local livelihood issues, especially for populations relying on subsistence farming. For these communities, several consecutive years of reduced harvests leave few alternatives other than land abandonment and migration to other areas (Morton 2007). Thirdly,[16] a growing body of studies recognises agriculture as one of the main channels through which climate change shapes migration. In other words, especially in developing countries, the main impacts of climate change on migration will be channelled by a disruption of local agricultural productivity.

The chapter is structured as follows. Section 2 describes the projections of population size and its socio-economic characteristics (education and poverty), as derived from the SSP scenarios. Section 3 outlines the impacts of climate change on the agricultural productivity of four major crops. Section 4 shows the estimates of exposed and vulnerable populations in African regions. The concluding section discusses the possible implications of such estimates for migration, displacement and trapped population.

PROJECTIONS OF POPULATION SIZE, URBANISATION, EDUCATION AND POVERTY

This section illustrates the possible alternative trajectories of four population and socio-economic indicators, as derived from the narratives of the SSP scenarios. In particular, the following projections are presented: firstly, the size of the total population and its spatial redistribution within countries; then, the poverty levels measured by the share of

14 In fact, RCP8.5 is the most extreme emission scenario, but this is considered by several authors too extreme to be used as baseline and 'business-as-usual' scenarios. Although many studies still rely on RCP8.5 to indicate the most extreme consequences of climate change its assumptions may lead to unrealistic combinations with SSPs (Pielke and Ritchie 2021).

15 For a detailed discussion on the effects of climate change on ecosystems vs managed systems, see the work by 2018 Nobel laureate for economics Nordhaus (Nordhaus 2013).

16 For a detailed discussion on the effects of climate change on ecosystems vs managed systems, see the work by 2018 Nobel laureate for economics Nordhaus (Nordhaus 2013).

the population living with $1.9 per day or less; lastly, the levels of educational attainment measured by the share of people with primary-level education or less. The results are presented by African macro-regions[17] to facilitate the comparison of trends across areas and over time. It should be stressed that the projections used in the chapter combine two dimensions: the country level, and a more granular geographical level.[18] The fact that the population projections used in the analysis not only take into account the absolute population trajectories in the country, but also its geographical distribution within the country will be crucial for the estimation of exposed populations, when considering spatial interaction with climate impacts, in the subsequent sections.

PROJECTED POPULATION SIZE

The SSP1 scenario (Sustainability) envisages increased well-being for the world which is evolving on a sustainable path, with substantial educational and health investments, with medium migration assumptions. The SSP1 scenario reflects the implementation of Sustainable Development Goal (SDG) 4 and SDG 5. While the former calls for equitable quality education and promotes lifelong learning opportunities for all, the latter aims at achieving gender equality and the empowerment of women and girls. The increase in well-being leads to an accelerated pace in the demographic transition to low birth and mortality rates and, ultimately, to declining global populations, from 8.7 billion in 2050 to 7.2 billion in 2100. For example, under the SSP1 scenario, Niger and Mozambique – both high-fertility countries – would experience a fast fertility decline, rapidly dropping from 7.4 and 5.5 children per woman in 2010-2015 to 1.7 and 1.4 children in 2045-2050 (and, ultimately, 1.3 and 1.2 children in 2095-2100). The life expectancy of women is projected to increase from levels below 60 years of age in 2010-2015 up to 88 years in Niger and 86 years in Mozambique, respectively, by the end of the century. According to the SSP1 scenario, low-income countries typically achieve the SDGs. The African population will be around 1.8 billion by mid-century (and 1.7 billion by 2100), and fertility will fall to less than two births per woman. Assuming SSP1, Africa is projected to experience a substantial increase in school enrolment and, consequently, a significant growth in the share of the population with secondary-level education or above. Actually, by 2100, all young men and women would have at least a lower secondary level of education (Wittgenstein Centre Human Capital Data Explorer 2018).

The SSP2 (Continuation) scenario models a business-as-usual trajectory, characterised by the continuation of recent trends, with some progress towards achieving development goals in terms of education and health, and following a medium trend in terms of migration assumptions. The global fertility decline is quite rapid, to 2.6 children in 2045-2050 and 1.7 by 2100. For example, it would imply a total fertility rate (TFR) of 4 children per woman in 2045-2050 in Niger, and approximately 2.3 children in Mozambique. By the end of the century, both countries would have below replacement fertility levels, corresponding to 1.9 and 1.7 children in Niger and Mozambique, respectively. The female life expectancy would also increase in both countries and reach above 76 years of age by 2095-2100. Africa's population would total 2.3 billion by mid-century and 2.9 by 2100.

17 Henceforth, the UN geographical classification of macro-regions is adopted: https://unstats.un.org/unsd/methodology/m49/
18 In particular, the geographical resolution of the analysis is 0.5 deg x 0.5 deg.

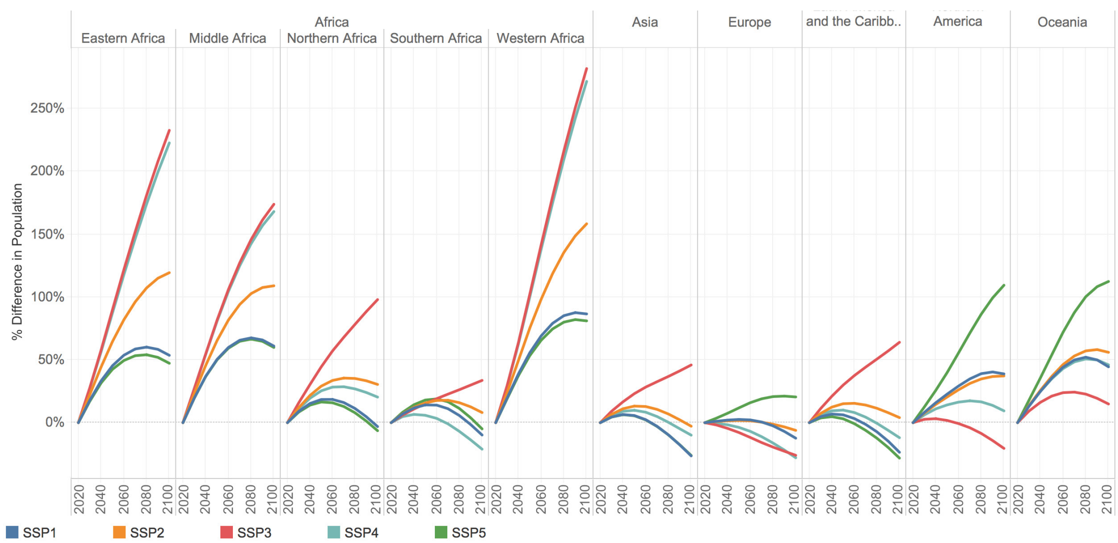
The SSP3 (Fragmentation) scenario imagines a world where low-income countries would experience slow decline in fertility and mortality rates; many countries would struggle to maintain their living standards due to rapidly growing populations. Migration patterns would be lower compared to SSP1 and SSP2. The diffusion of education would be almost stopped without a further increase in enrolment rates. Under that scenario, Africa's population will reach 2.7 billion by 2050 (4.9 in 2100), recording a fertility rate around 3.5 children (2.5 in 2095-2100). Due to the lack of progress in school enrolment, the share of young people aged 15-24 years with primary-level education and below would be as high as 54% among men, and 60% among women by mid-century and stable at that level until 2100. For example, the low level of education implies that the TFR of Niger and Mozambique would still be high in 2045-50 (5.4 and 3.0 children, respectively) and above replacement level in 2095-2100 (2.6 and 2.4 children, respectively). This development goes hand in hand with little progress in mortality reduction and life expectancy for women at the end of the century in the two countries would therefore be 66 and 64 years.

It should be noted that SSP1-SSP3 are the main diverging paths demographically. SSP4 (Inequality) resembles SSP3, except for the fact that the inequalities observed at macro-level are also present within countries, and that the migration assumptions follow a medium path. SSP5 (fossil fuelled conventional development) is close to SSP1 for Africa, but it entails more migration.

As shown in Figure 2, in three out of five SSP scenarios, Africa's population would not peak by the end of the century, contrary to what would happen in most world regions, including Asia, Europe and Latin America.

According to SSP2, the trend scenario, Africa's population would increase from 1.3 billion to 2.9 billion by 2100. The increase would be particularly strong in the two most populous regions of Western Africa and Eastern Africa. In the former, the number of inhabitants would grow from 401 million in 2020 to 1066 million in 2100. Western Africa would host around 37% of the African population (compared to 30% today). In Eastern Africa,

FIGURE 2. Projections of total population according to five SSP scenarios, expressed in terms of percentage change in respect of the population in 2020.



where the population would also increase substantially from 457 million in 2020 to 1043 million in 2100. East Africa would host 36% of African population (compared to 34% today). Middle Africa would also experience more than a doubling over the period 2020-2100, growing from 177 million to 400 million. Southern Africa and Northern Africa, more advanced in the demographic transition, would see their populations peak in the second half of the century: in 2065 in Southern Africa – largely dominated by the demographic path of South Africa – and in 2075 in Northern Africa.

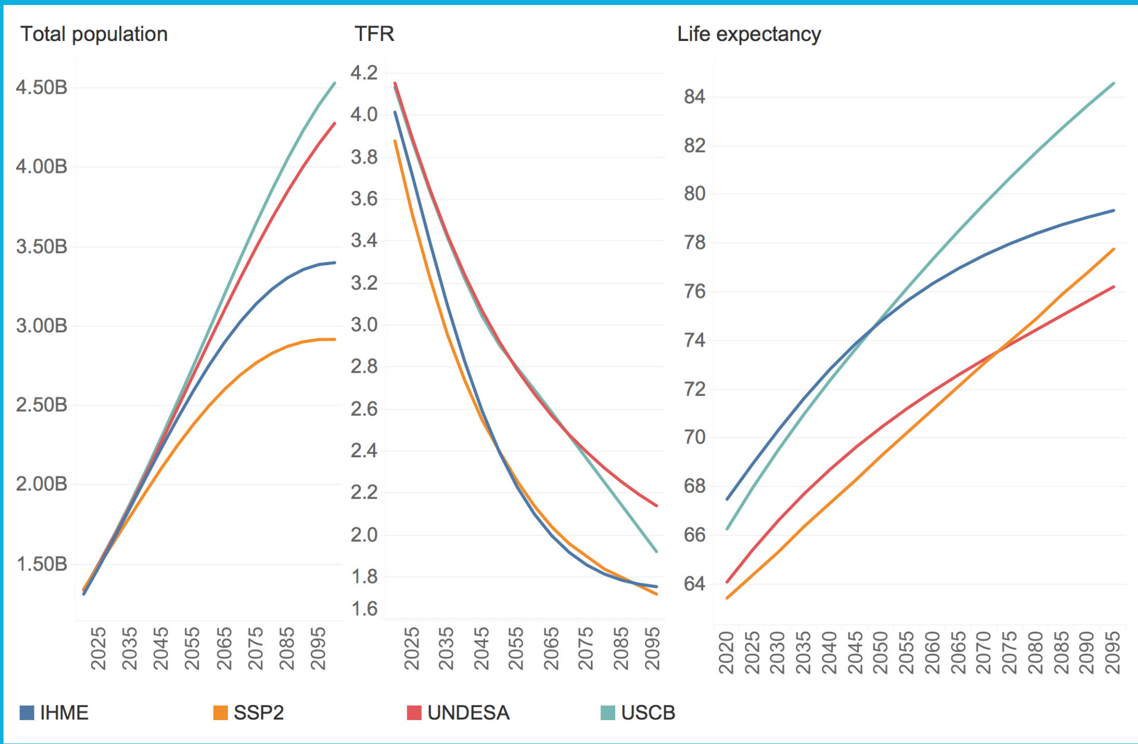
The other four scenarios show different perspectives. SSP3 – with its slow progress in human development and stalled demographic transition – would result in a population explosion in Africa, which would reach almost 5 billion inhabitants in 2100. The populations of Western Africa and Eastern Africa would increase four-fold or more from their present level and that of Middle Africa, three-fold. According to the SSP3 scenario, 36% of the global population would reside in Africa in 2100 compared to 17% today (and 31% according to the SSP2 scenario). At the opposite end, the SSP1 scenario would allow the population of Africa to peak in 2070 with 1.9 billion inhabitants and decline thereafter to reach 1.7 billion in 2100. All sub-African regions would peak within the second half of the century: Southern Africa in 2060, Northern Africa and Eastern Africa in 2065, Middle Africa in 2070 and Western Africa in 2080. According to SSP1, one quarter of the world's population would reside in Africa.

BOX 1 Africa's future population level: different opinions

The number of humans will be key in influencing the fate of planetary resources. The latter will be largely influenced by their behaviour. The population explosion is already behind us, when the world population more than tripled between 1950 and 2020, from 2.5 billion people to 7.8 billion in 2020. This is unlikely to happen again as the demographic transition is underway all over the planet, meaning that all societies are following a process of reducing fertility and mortality that will eventually and most likely lead the world population to peak within the century (or shortly thereafter) and fall afterwards. However, at the same time, the 2-3 billion people who will be added to the global population will overwhelmingly be born in low-income countries where they are at high risk of being vulnerable.
Long-range global population projections by several organizations such as the United Nations Population Division (UNDESA), the US Census Bureau (USCB) and the Institute for Health Metrics and Evaluation (IHME) differ in their projected number of people who will be inhabiting Africa in the future to 2100, also from the SSP scenarios used in this chapter (Figure 3). If we compare the population in 2100 resulting from the middle of the road[19] scenario of each organisation for Africa, it varies from 3.5 billion for IHME, to 4.3 billion for UNDESA and 4.5 billion for the USCB. SSP2, as the medium scenario within the SSPs, provides the lowest population numbers with 2.9 billion. Depending on these scenarios, the continent would represent 31% according to SSP2, 39% for UNDESA, 40% for IHME and 42% for USCB of the world population. The divergence in population trajectories largely depends on fertility and mortality assumptions. While the SSP2 scenario tends to foresee a rapid decline in the total fertility rate together with substantial improvements in life expectancies, with the spread of mass education in particular, the UNDESA and USCB projections assume that the decline of both determinants will be slower. The assumptions of the IHME provide a mix with rapid fertility decline not accompanied with commensurate mortality reductions, which would predominantly impact the size of the working age population (15-64), expected to reach 1.8 billion in 2100 for IHME and 2.8 billion according to UNDESA. An interesting result is that the countries start differing after 2050, while at mid-century the difference is barely visible, from 2.25 billion for SSP2 to 2.53 billion for the USCB (a difference of 277 million people).

19 These scenarios are usually labelled as the most likely at the time they were developed.

FIGURE 3. Total population (in billion), total fertility rate (in number of children) and life expectancy (in years) of Africa according to the four global scenarios.

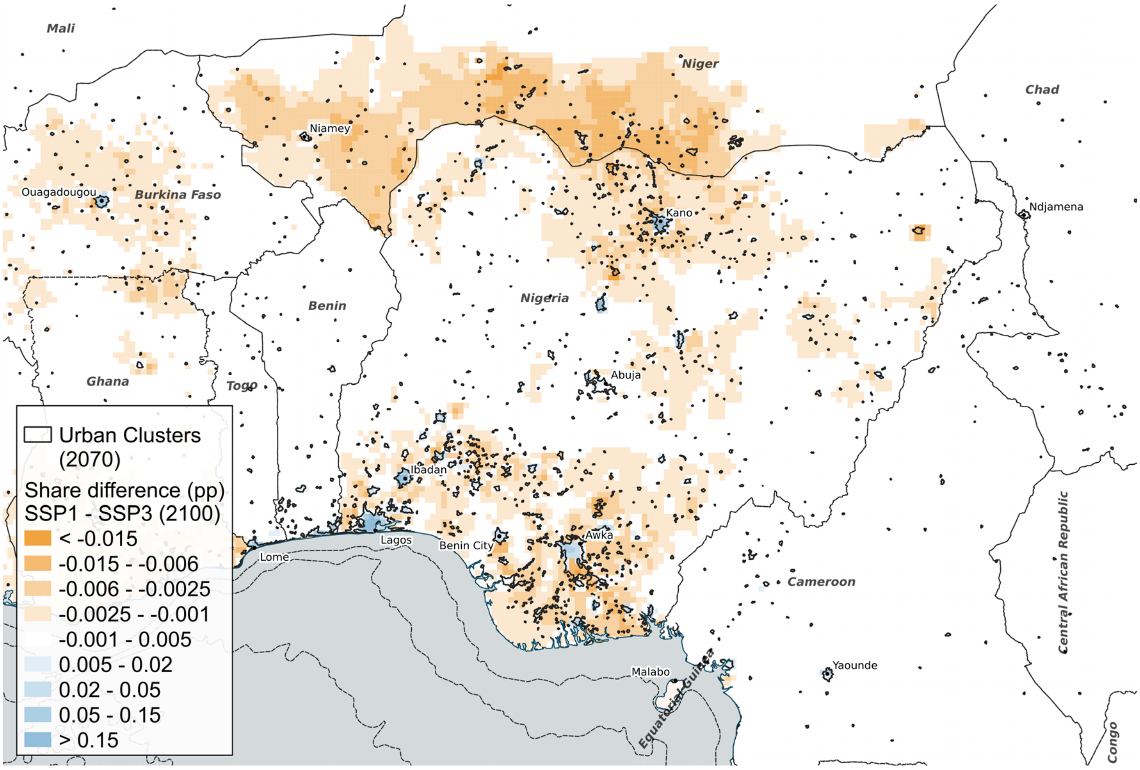


URBANISATION AND POPULATION GEOGRAPHICAL DISTRIBUTION

The SSP scenarios provide the ideal framework to estimate population exposure and vulnerability following possible future environmental and societal developments for each country. However, country patterns could hide the impact of climate change at a more detailed geographical level. As mentioned above, the projections combine both the country dimension and a more granular geographical one. In other words, our analysis is influenced not only by assumptions on the total country population parameters (such as fertility, mortality and migration), but also by scenarios in which the population will be distributed within countries. The allocation of the country population on the high spatial resolution grid is determined by two sets of assumptions. One set regulates the share of urban and rural populations at country level. A second set relates to the distribution of these totals within countries and represents different trends on how population will gravitate towards existing high-population-density urban clusters rather than being more uniformly redistributed in emerging settlements and fringes of expanding cities.

In terms of totals for urban and rural populations, the SSP1 and SSP5 scenarios forecast a fast demographic transition and a fast urbanisation process in low-income countries. Alternatively, in these countries, SSP3 and SPP4 envisage a slow demographic transition, accompanied by a slow urbanisation process in SSP3, and a fast urbanisation process in SSP4.
In terms of agglomeration, SSP1 is characterised by urban densification – that is, a pattern of increasing shares of the population in pre-existing urban cells, SSP3 intermediate levels of agglomeration and SSP5 marked sprawling into new areas.

FIGURE 4. Geographical distribution of the population according to SSP1 and SSP3 in Nigeria (2010). *Note*: The values in each cell correspond to the difference between the share of the population in the cell and the total country population in 2100 according to the SSP1 and SSP3 scenarios.

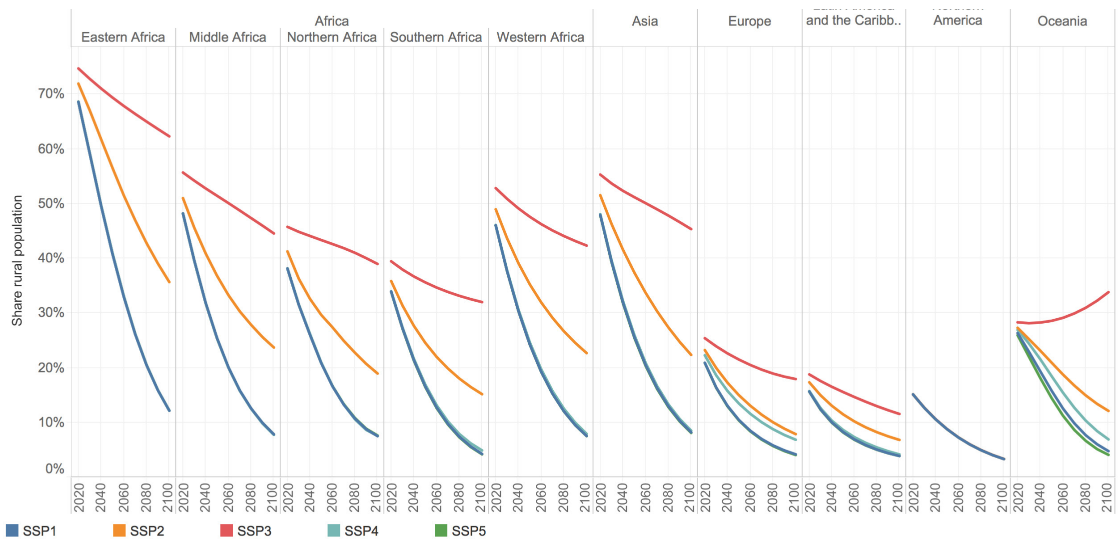


To exemplify the different outcomes of these scenarios in terms of the spatial distribution of the population in Figure 4 we consider the case of Nigeria. In particular, the figure shows the difference between shares of the total population in each cell according to the SSP1 and SSP3 scenarios in 2100. Positive values indicate that the proportion of the population in the cell would be higher when considering the SSP1 rather than the SSP3 scenario. On the map it is possible to identify that the SSP1 scenario foresees a higher population concentration in almost all main urban centres and a lower concentration in rural areas.

Figure 5 shows final outcomes at aggregate level of the two projections of rural-urban totals and their downscaling within countries.
Nowadays, the majority of the world population lives in urban areas and the share of rural population, at 44% in 2020, is projected to shrink in all world regions and under all scenarios, with the exception of SSP3 in Oceania. While Africa has seen a rapid urbanisation process in the recent past (for a more detailed discussion see Box 2), the continent remains the most rural worldwide, with around 55% of its population living in rural areas.[20] This is particularly evident in the most populated sub-regions, where the majority of the population lives in rural areas - around 51% in Middle Africa, 49% in Western Africa and 72% in Eastern Africa. According to all scenarios, the rural population as a share of the total population is projected to decline, though at a very different speed. For example, under SSP2 the share of the rural population would halve to 20-25% in

20 For the sake of comparison, the share of population living in rural areas is currently 23% in Europe.

FIGURE 5. Projections of the share of the rural population according to five SSP scenarios.



all African sub-regions.

It should be noted that, despite the decrease in relative terms, the absolute rural population would still moderately increase under the SSP3 scenario.[21] The SSP1 scenario assumptions lead to a highly urbanised world with less than 10% of the population in all African regions residing in rural areas. According to the SSP3 scenario, despite the increase in the population, the share of people living in urban areas is not projected to increase. Moreover, according to the slower urbanisation prospects of this scenario, the share of the rural population in all African regions would remain at the high levels of 62% in Eastern Africa and 42% in Western Africa by 2100, thus implying a substantial increase in the number of people residing in rural settlements. Only in SSP1, SSP4 and SSP5 is Africa expected to reach the current levels of urbanisation in Europe or in Northern America by 2060. As demonstrated in the next section, these patterns are expected to bear important implications in terms of vulnerability to climate change impacts on agricultural productivity.

FUTURE EDUCATIONAL ATTAINMENT

According to the IPCC framework on population vulnerability to climate change followed in this chapter, education is one of the dimensions influencing a population's capacity to cope with climate change. Indeed, the levels of education are at the same time drivers of socio-economic and demographic developments. Hence, they can determine the adaptive capacity in the face of environmental change (Muttarak and Lutz 2014) and reduce vulnerability, at both individual and aggregate level, while bringing large segments of the population out of poverty. The process of mass education that started in the late 19th century in the Global North and, after the end of colonial times, in the Global South, was delayed in Africa, especially in sub-Saharan Africa. Indeed, 17% of today's 15-19-year-olds in sub-Saharan

21 From 320.5 million in 2020 to 887.5 million in 2100 in Eastern Africa; from 209.2 million to 640.3 million in Western Africa; from 93.5 million to 204.8 million in Middle Africa, from 108.9 million to 183.6 million in 2100 and in Northern Africa and from 24.6 million to 26.6 million in 2100 in Southern Africa.

BOX 2 Urbanisation in Africa: a few insights

Several studies have underlined the peculiar patterns and characteristics of the urbanisation processes in Africa. In comparison to European countries during the first half of the 20th century, urbanisation in Africa has not always been driven by economic growth (Dyson 2011; Potts 2009, 2016).

As overall, African urbanisation is not a merely economic process with a linear development, but it should be considered in broader terms as a demo-economic phenomenon (Dyson 2011). Therefore, urban and rural areas present different consumption and production structures (Jiang and O'Neill 2017) due to the variety of spatial and population patterns across African regions.

Looking at past trends, urbanisation has been driven by a combination of factors, including the surplus of births over deaths and migration from rural to urban areas (Lerch 2017). When the quality of life improves, urban population growth tends to accelerate.

Nevertheless, in some sub-Saharan Africa regions, mortality rates tend to remain higher than fertility rates in densely populated urban surroundings, where infectious diseases spread rapidly due to poor sanitation and health conditions.

Menashe-Oren and Bocquier (2021), using data from the United Nations on urban and rural populations (URPAS) in 129 countries from 1980 to 2015, demonstrated that urbanisation processes in low- and middle-income countries can to a large extent be attributed to the population natural increase.

Moreover, the observed slackening of urbanisation rates in sub-Saharan Africa in the last 30-years would result from both the shrinking of population movements from rural to urban areas and reclassification of boundaries in urban settlements. Additionally, return migration from urban to rural sectors seems to become more frequent (Cattaneo and Robinson 2020).

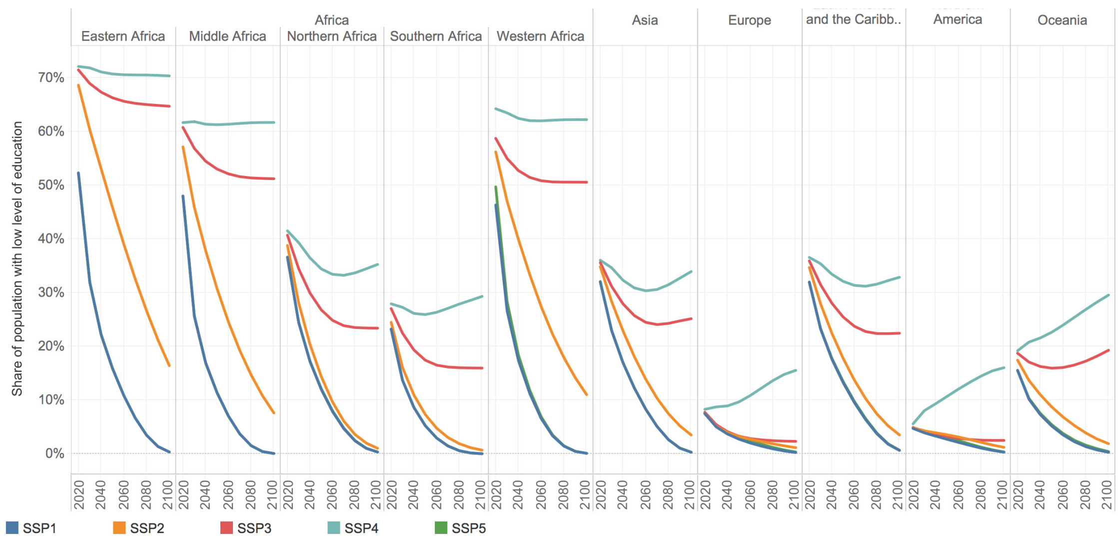
According to the World Urbanization Prospects (2018), the population living in urban settlements would rise from 4.2 billion in 2018 to 6.7 billion in 2050. Specifically, Africa would reach the largest number of dwellers, accounting with Asia for 88 per cent of all new urban inhabitants between 2018 and 2050, even when it could remain one of the least urbanised regions in the world. Different levels of urbanisation can be foreseen across regions: consistently with SSP1, SPP4 and SSP5 scenarios' narrative, Jiang and O'Neill (2017) forecast that Africa would reach the current European level of urbanisation only after 2050. However, projections are linked to wide ranges of uncertainly in defining future determinants and their related impacts on urbanisation pathways by region.

These urbanisation patterns and the interlinkages between demographic and economic development are crucial not only to assess population vulnerability to climate change, but also to interpret the climate change - migration nexus by considering the peculiarities of the African context (see Chapter 3).

Africa have never attended any school (Wittgenstein Centre for Demography and Global Human Capital 2018). Rapid population growth in sub-Saharan Africa poses several challenges. Besides putting pressure on food supplies and other resources, a consistent rise in the number of children may strongly affect the potential of many sub-Saharan African countries to achieve universal education as envisaged by SDG 4 – which is 'to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all'[22] (Lutz et al. 2021). The latter point is illustrated by SSP4: in this scenario, countries are not able to increase enrolment rates at all schooling levels. This results in most African sub-regions having more than 60% of the 15+ population with low levels of education, except for Northern and Southern Africa where the share would be 35% and 30% in 2100, respectively. These proportions hide a huge increase in the population aged 15 years and above with primary-level education or less, from 700 million to 2.2 billion in all regions. The SSP2 scenario foresees quite some decline in the share and the number of individuals in the population with a primary level of education or less: the share would range from

22 https://sdgs.un.org/goals/goal4

FIGURE 6. Projections of the share of the population with a low level of education according to five SSP scenarios.



16% in Eastern Africa to 1% in Southern and Northern Africa, with an intermediate value of 11% in Western Africa. However, it is worth noting that these positive outcomes that are foreseen at the end of the century are less visible in 2050. For instance, in 2050 there would still be 46% of the population with primary-level education or less in Eastern Africa and 31% in Middle Africa. Education diffusion is very fast under SSP1 leading to all people aged 15 years and above to have at least a secondary level education.

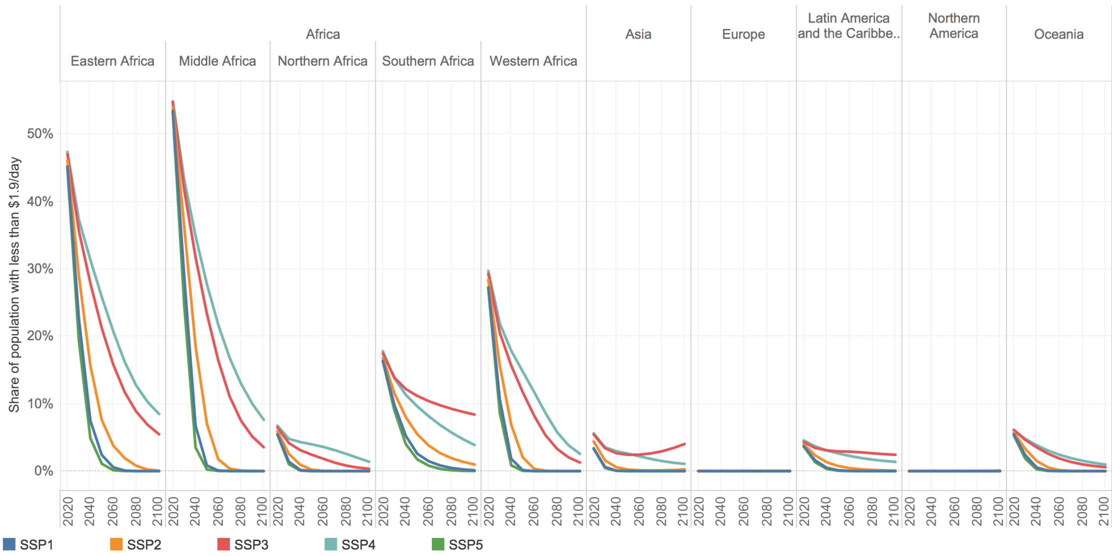
FUTURE POVERTY LEVELS

Similar to educational attainment, poverty levels are recognised proxies of individual and aggregate poverty. With 29 out of 32 countries listed under the low Human Development Index (UNDP 2020) belonging to sub-Saharan Africa, 'the big bulk of the poverty reduction challenge is expected to be in Africa' (Crespo Cuaresma et al. 2018).
Sub-Saharan Africa exhibits the largest differences in poverty rates, approximated by the share of the population living with less than $1.9 a day[23] aacross scenarios, compared to other world regions.

Paradoxically, it is the sub-continent where poverty reductions would be more drastic. The share would be at least halved across all sub-regions except for Southern Africa and Northern Africa. In Southern Africa, the poverty levels are estimated at about 18% in 2020 a relatively low share when compared to Eastern Africa (47%) and Middle Africa (55%). Despite the reduction in poverty levels expected in the coming decades, the share of Africa's population in poverty is projected to remain higher by end of the century when compared to other areas of the world. According to the SSP4 scenario, the share of the population living with less than $1.9 per day would be around 8% in Eastern and Middle Africa, corresponding to 117 million and 34 million people, respectively.

23 The poverty thresholds are expressed in purchasing power parity (in $) for 2015, using World Bank definitions. The data are generated for the five SSPs from projections of GDP (Dellink et al. 2015), population (KC & Lutz 2014) and Gini index (Rao et al. 2019).

FIGURE 7. Projections of the share of the population with income below $1.9 per capita/day according to five SSP scenarios..



FUTURE IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTIVITY

In this section we present the projections of expected changes to agricultural productivity according to the RCP scenarios, in particular RCP2.6 and RCP6.0. Indeed, the existing literature on climate change impacts suggests that tropical and sub-tropical regions in Africa will suffer the worst consequences in terms of reduced agricultural productivity worldwide, despite variations in the timing and intensity of the impacts across African regions (see Box 3 for details).

The analysis of this chapter is based on the results from two major international climate change impacts modelling initiatives: the Inter-Sectoral Impact Model Inter-comparison Project (ISIMIP) (Warszawski et al. 2014), and the Agricultural Model Inter-comparison and Improvement Project (AgMIP) (Rosenzweig et al. 2013). For each RCP scenario we constructed an ensemble of outputs from four general circulation models and two impact models each with CO2 fertilisation and two options for irrigation (full irrigation/no irrigation).[24] By combining the outputs of these models through simple averages, we obtained estimates of agricultural productivity for each of the four main crops of soybean, rice, maize and wheat. These estimates include historical simulations for the period 1975-2015 and projections for the period 2020-2070[25] according to each RCP scenario and for each cell. To derive anomalies in the future we calculated mean deviations from past trends over 5-year intervals.[26] The maps in Figure 8 show the projected changes in

24 The models for irrigation and no irrigation were aggregated through a weighted average on the basis of the shares of irrigated and rainfed crop areas in each cell in the period around 2000 (MIRCA2000) (Portman et al. 2010). We assume that the availability of irrigation for each crop in the future remains as in 2000. This crude assumption implies an underestimation of impacts in areas which are likely to experience water scarcity and an overestimation in cases where there will be no scarcity in irrigation water.

25 While the demographic trends in previous section are presented until 2100, we restrict to 2070 the description of changes in agricultural productivity and exposure given the increasing uncertainties in the projections until 2100.

26 For details on the methodology see the Appendix.

yields for the four main crops under the RCP6.0 scenario by the end of 2070. It can be observed that projected impacts on crop yields will be more pronounced for maize and wheat especially across Africa, in line with findings by Zhao et al. (2017).

Figure 9 shows the trends for the RCP6.0 scenarios over the period 2020-2070 aggregated by African region. In particular, it plots the median change in productivity for each of

FIGURE 8. Projected changes in productivity of four main crops (rice, soybean, wheat and maize) by 2070 according to the RCP6.0 scenario.

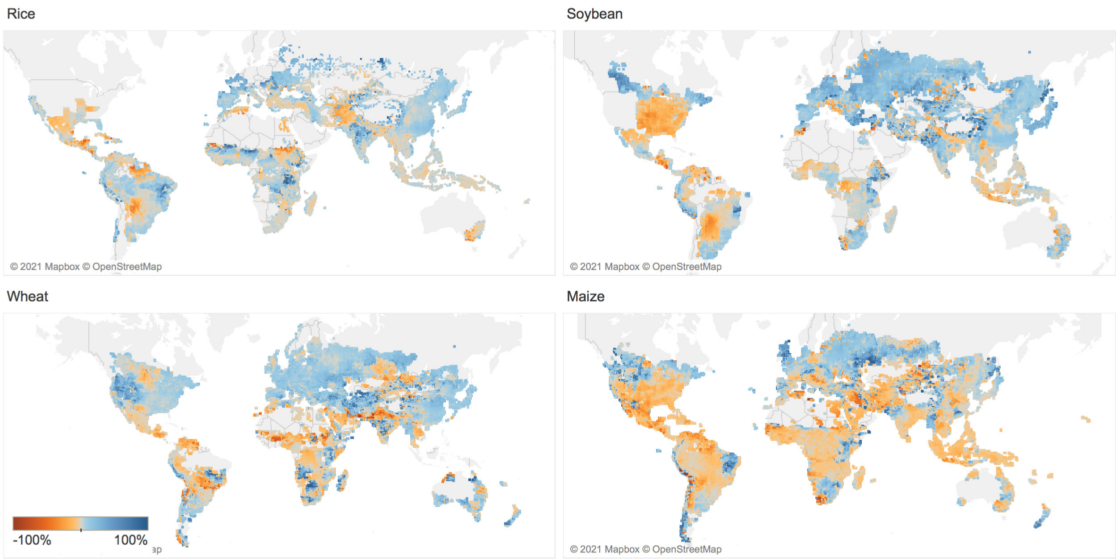
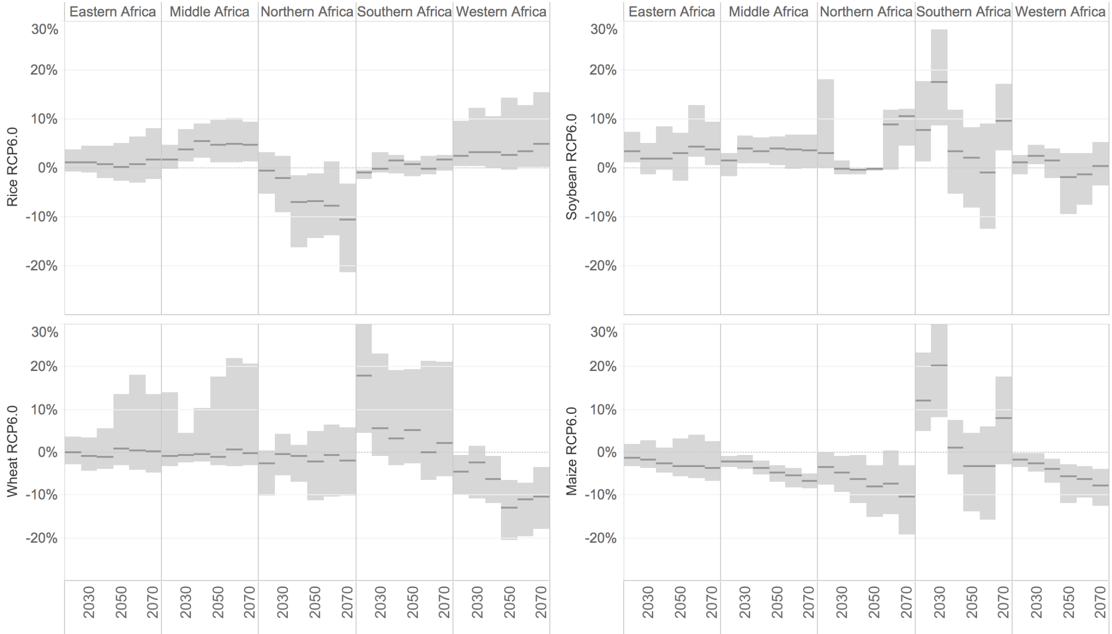


FIGURE 9. Anticipated percentage change in the median productivity according to the RCP2.6 and RCP6.0 scenarios for the period 2020-2070 for the four main crops.
Note: the median (horizontal line) is calculated across all cells in each region and shaded bars represent the quartiles of the distribution across cells in each region.



the main crops across all cells in each region (shaded areas are the quartiles of the distribution across cells in each region). The regions which are expected to experience the worst impacts in terms of crop yields are Western Africa with a change by 2070, of -7% for maize and -10% for wheat, Northern Africa with a change of -11% for rice and -10% for wheat, and Middle Africa with a change of -8% for maize. Such trends have high geographical variability within regions as shown by the large range of shaded bars and should be considered with caution. The results from the models on agricultural productivity are based on the assumption that no adaptation measures will be adopted (i.e., same crop varieties, planting dates, fertilisers and water management systems). Furthermore, model assumptions are often considered optimal as default, which is not very realistic for most African countries, where there is a large gap between potential yields and actual yields.

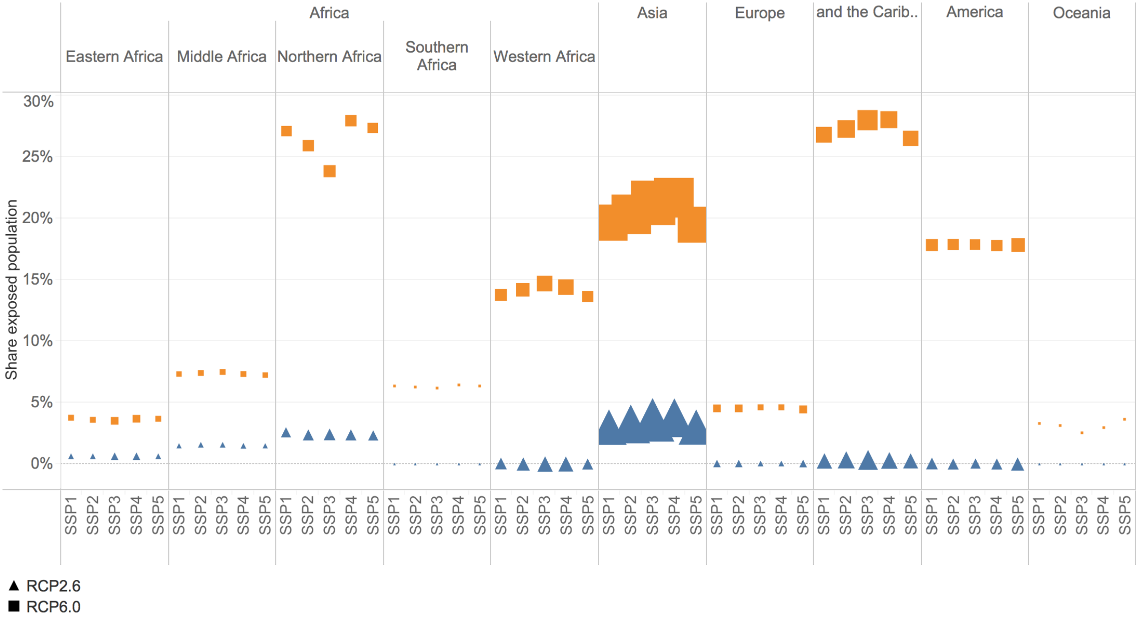
ESTIMATING POPULATION EXPOSURE AND VULNERABILITY TO CLIMATE CHANGE

This section presents the results of the analysis of populations exposed and populations vulnerable to climate change. To assess population exposure and vulnerability, two sets of data are overlaid: firstly, the population projections under the different SSP scenarios; secondly, the climate change impacts projections on agriculture under the RCP2.6 and RCP6.0 scenarios. In this way, we are able to provide a quantification of the population exposed to a reduction in agricultural productivity triggered by climate change. As a further step, the other dimensions of vulnerability described in Section 2 – projections of the

BOX 3 Climate change impacts on agriculture across African regions evidence from the literature

The impact of climate change on yield is expected to differ not only between crops, but also between regions. In particular, the impact will be largely negative in Eastern Africa (Adhikari et al. 2015). Among the grain crops, wheat is considered as the most vulnerable to climate change, with up to 72% yield reductions expected by 2100 in this region. For the other grain crops – such as maize, rice and soybean – yield reductions up to 45% are expected (Adhikari et al. 2015). The projected impacts in Eastern Africa vary considerably; without climate change adaptation, the region could lose about two thirds of its wheat productivity by the end of the 21st century. Climate change could also cause maize reduction of up to 40% by 2100, despite large variations in projected impacts on this yield.
Similar results have been documented for Middle Africa (Stuch et al. 2021), where the projected decrease of harvested maize areas could pose risks to food security. In Northern Africa, rising temperatures associated with climate change are expected to reduce the land areas suitable for agriculture, shorten the length of growing seasons and diminish crop yields. In addition, in Southern Africa maize yields are projected to decline by 18% on average. Estimations for this region also suggest declining crop yields in the 21st century: in particular, -18% for 2050, and -30% for late century. When considering Western Africa, increasing temperature and changing rainfall patterns are projected to increase crop yield production average and variability. For instance, across the majority of Western Africa, maize, millet and sorghum yields are shown to fall (Parkes et al. 2018). Furthermore, Roudier et al. (2011) stress that despite a large dispersion of yield changes ranging from -50% to +90%, the median yield loss lies at around -11% over the 21st century. The predicted impact is larger in north Western Africa (Sudano-Sahelian countries, -18%) than in south Western Africa (-13%). This is probably due to projections of increasingly drier and warmer climate in the northern part of Western Africa. Moreover, negative impacts on crop productivity increase in severity as warming intensifies, with a median yield loss close to -5% for the most intense warming scenarios.

FIGURE 10. Share of the exposed population according to SSP and RCP scenarios in African sub-regions and other continents, 2070.
Note: The size of the symbols is proportional to the absolute number of people exposed.



population residing in rural areas, with a primary level of education or below, living below the poverty line – are added to the analysis. In this way, we provide a quantification of those who are expected to be exposed and vulnerable to the impacts of climate change.

The results for exposure are summarised in Figure 10 which shows the exposed population in 2070 as a share of the total population and in absolute terms (size of the symbols). The exposed population is calculated considering the number of people in each cell where there is an expected reduction in agricultural productivity of more than 20% for any of the four major crops. It should be noted that the figures presented are the result of the aggregation across territories in higher geographical detail within each region. Hence, the estimates of exposure are affected not only by different assumptions on the evolution of the total population of the country, but also by its geographical redistribution within each territory. Furthermore, agricultural productivity impacted in those cells and the presence of the crops is also crucial for the final results.

The key findings of the analysis are the following. When considering the SSP1 scenario, in 2070, there would be around 212 million exposed people (11% of total population) in the entire African continent, 853 million (20% of total population) in Asia and 169 million (27% of total population) in Latin America and the Caribbean. Within the African continent, the largest exposed populations would be in Western Africa and Northern Africa. In Western Africa according to SSP3 and RCP6.0 scenarios, about 162 million people (15% of total population) would experience a reduction in agricultural productivity of more than 20% by 2070. In Northern Africa, the exposed population would reach the highest level in terms of shares according to the SSP4 and RCP6.0 scenario (28%) and in absolute terms according to the SSP3 scenario (95 million). It should be noted that the share of exposed population is more affected by scenarios concerning levels of emissions than by socio-economic and demographic scenarios. In the case of Western Africa and SSP3, there would be an increase of 15 percentage points in the share of the exposed population when considering the more pessimistic RCP6.0 scenario in comparison to RCP2.6. Keeping the RPC6.0 climate scenario fixed and changing socio-economics assumptions between SSP1 and SSP3 leads to an increase of only 1 percentage point in the share of the exposed population.

The results shown in Figure 10 refer to 2070. Throughout the entire projection, the share

FIGURE 11. Evolution of exposure according to according to SSP3 and RCP scenarios in Africa, 2020-2070.

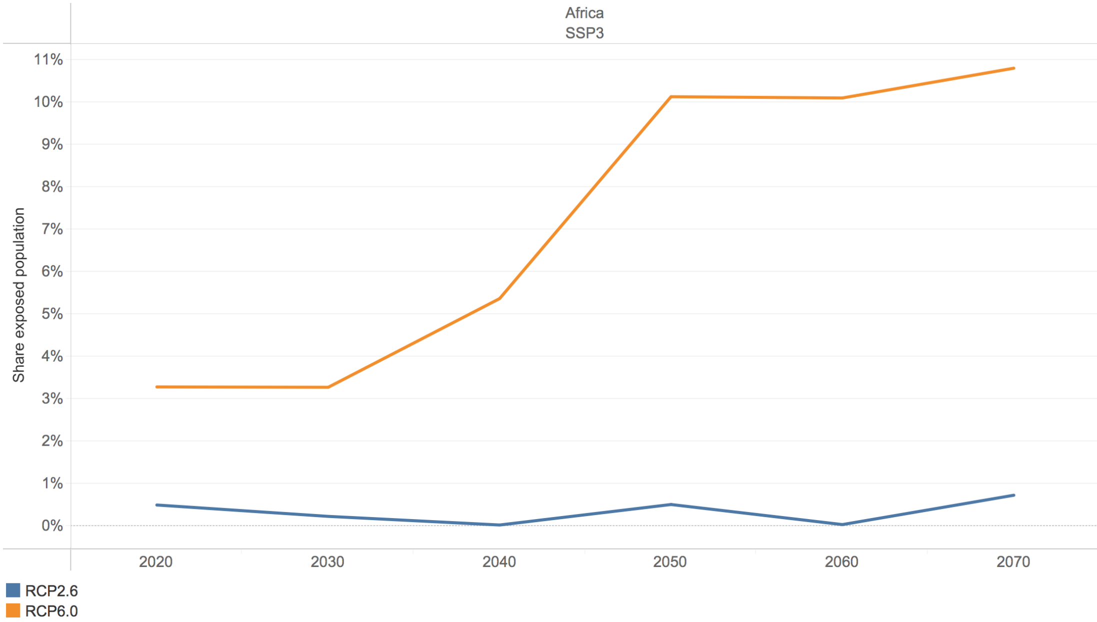


FIGURE 12. Share (in per cent) of the exposed rural population according to SSPs and RCP scenarios in African sub-regions and other continents, 2070
Note: The size of the symbols is proportional to the absolute number of people exposed.

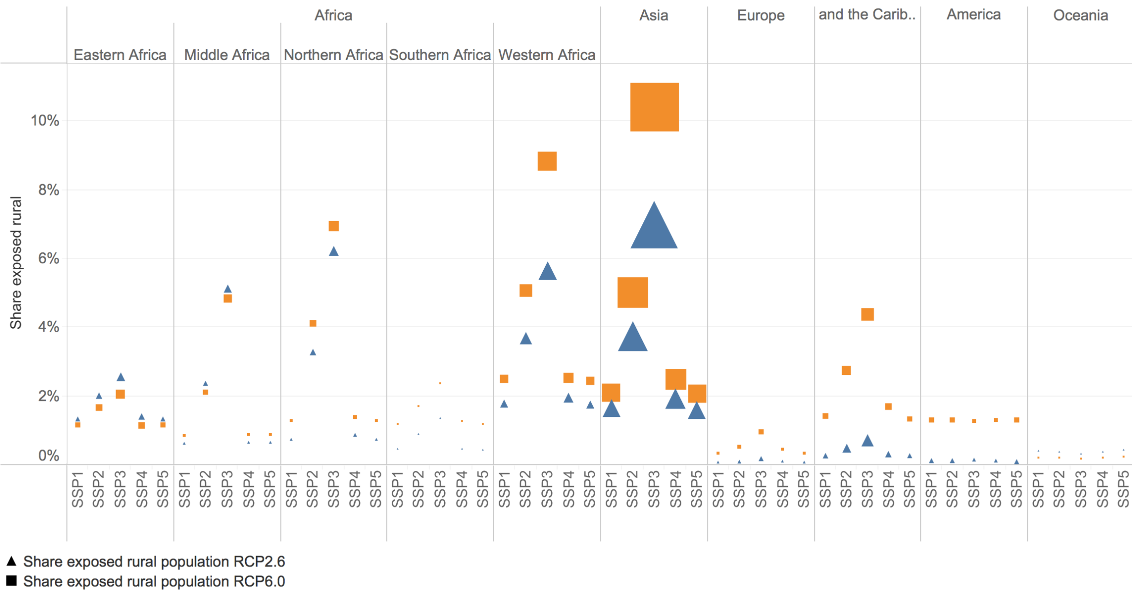
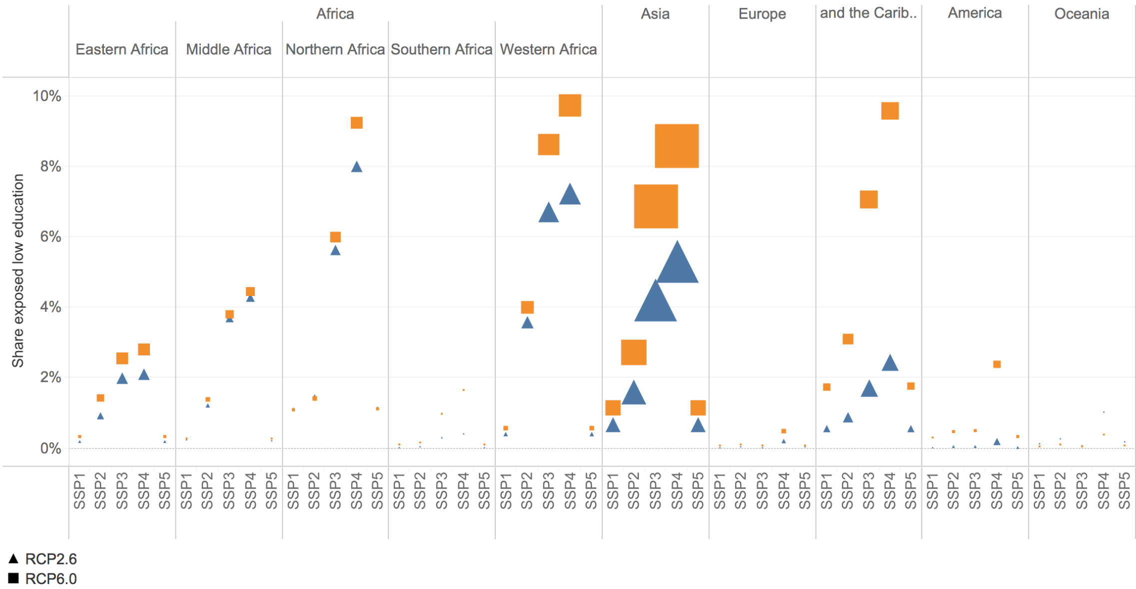


FIGURE 13. Share (in per cent) of exposed population with a low level of education (with primary education or less) over the age of 15 years according to SSPs and RCP2.6 and RCP6.0 by African sub-regions and major world region, 2070
Note: The size of the symbols is proportional to the absolute number of people exposed.

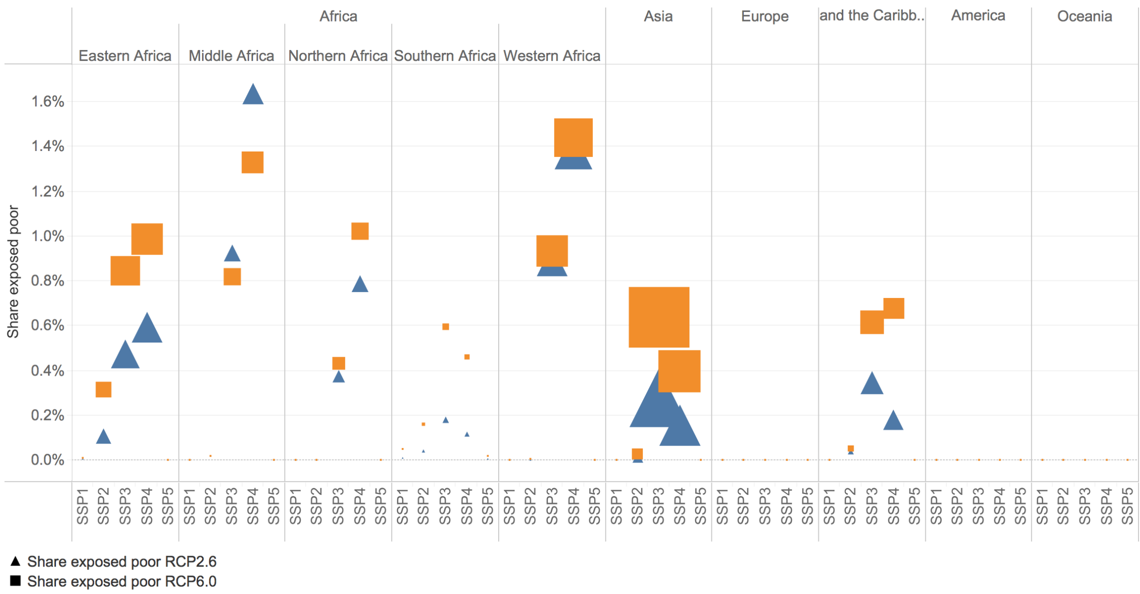


of the exposed population in Africa is projected to rapidly increase expanding in the case of the RCP6.0 and SSP3 scenarios from 3% in 2030 to almost 11% in 2070 (Figure 11).

Figure 12 shows the share of the exposed and rural population in the total population. In most SSP scenarios and under both RCP2.6 and RCP6.0, the shares in all the continents – except Africa – remain below 8%. This is most likely due to the urbanisation transition process that is foreseen at global level. However, Figure 12 also shows increased exposure under the RCP6.0 scenario, especially for SSP3. According to this scenario, within the African continent, the share of exposed population living in rural areas would reach the highest value of 9% in Western Africa (approximately 98 million people). This is in line with the literature, which indicates that Western Africa, particularly in areas with a semi-arid Sahelian climate, is vulnerable to the impact of climate-change, especially regarding food security (Defrance et al. 2020). While most differences in exposure are determined by climate scenarios for the total population, when considering the share of the rural population, vulnerability is also greatly influenced by assumptions about socio-economic development and urbanisation. In the case of Western Africa, the slow urbanisation foreseen by the SSP3 scenario compared to SSP1 produces an increase of 6 percentage points in the share of the rural population vulnerable to climate change impacts. This is 3 percentage points more than the increase due to the two RCPs climate assumptions under SSP3.

As mentioned earlier, education has been shown to enhance the adaptive capacity of people to climate change (Feinstein and Mach 2020; Striessnig and Lutz 2016). The share of exposed population with low education in 2070 (Figure 13) is particularly high for SSP3 and SSP4 that envisage a world with slow education progress – mostly penalising those countries that are lagging behind in terms of education diffusion at present, particularly in Africa. In Western Africa, the exposed population with low levels of education, would account for almost 10% of the total population, meaning 105 million people in 2070,

FIGURE 14. Share of exposed poor population (living with $1.9 per day or less) according to SSPs and RCP2.6 and RCP6.0 by African sub-regions and major world regions, 2070.
Note: The size of the symbols is proportional to the absolute number of people exposed.

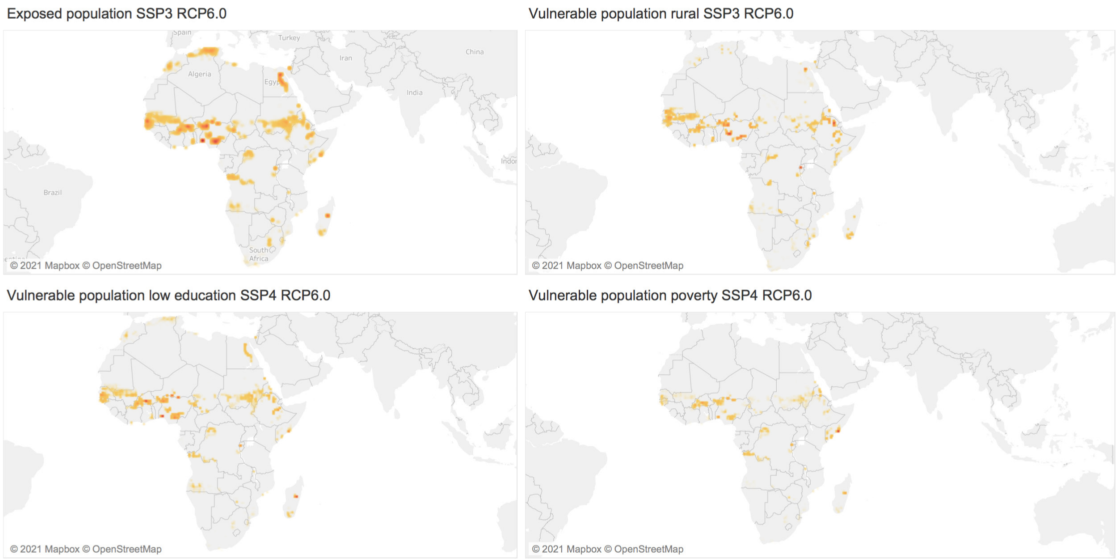


according to the combined SSP4-RCP6.0 scenario. These populations are likely to be remote, geographically or socio-economically and difficult to reach and will be highly vulnerable to radical changes in their environment. The effect in terms of increases in vulnerability linked to changes in socio-economic rather than climate scenarios is even more evident in the case of education with an increase of almost 9 pp between SSP1 and SSP4 in the case of Western Africa and RCP6.0.

The extreme poverty that is present in sub-Saharan Africa, if not resolved, is susceptible to make millions of Africans particularly vulnerable to climate change. The SSP scenarios devote special attention to the distribution of wealth within the different narratives. According to SSP3 and SSP4, wealth inequalities remain (SSP3) or are even accentuated (SSP4). This is clearly visible in Figure 14 showing the percentage of the exposed population living below the poverty threshold of $1.9 per capita-day. This share would be highest under the SSP4 scenario combined with RCP6.0, particularly in Western Africa (1.5% corresponding to 15.6 million people).

The figures above show aggregates at the level of regions within Africa, however a key element in our analyses lies in the possibility of exploring geographical patterns within regions and countries and identify hotspots of exposure and vulnerability at a more granular level.
Figure 15 shows the shares of exposed and vulnerable populations at this granular level in 2070 and according to the worst combinations of RCPs and SSPs. The maps indicate several hotspots of exposure in Northern Africa (Algeria, Morocco, Egypt) and in sub-equatorial zones (Senegal, the northern part of Mali, Burkina Faso, Nigeria, southern part of Chad, Sudan, northern part of Ethiopia, western part of DRC, Rwanda and south-eastern part of Somalia). These hotspots of exposure largely correspond to hotspots of vulnerability according to the three dimensions considered, with the exception of Northern Africa where there are no hotspots of population exposed and living in rural areas and in poverty.

FIGURE 15. Hotspots of exposure and vulnerability according to the worst combination of SSPs and RCPs scenarios..
Note: colours represent absolute values of exposed and vulnerable populations.



Overall, the analysis of exposure and vulnerability indicates that under all climate and socio-economic scenarios, the level of vulnerability would be higher in African sub-regions than in other continents. Within Africa, Western Africa stands out for high level of exposure in absolute terms and vulnerability in relation to population living in rural areas and with low education and in poverty.
High levels of exposure are mostly determined by changes in assumptions about climate change from the RCP2.6 to RCP6.0 scenario. The SSP scenarios have a prominent role in determining different level of vulnerability. In particular, SSP3 leads to increase in the share of exposed population living in rural areas, while the SSP4 scenario is affecting the exposed population in poverty and with low levels of education.

CONCLUSION

Several studies have estimated exposure to climate change extreme events such as heat (Batibeniz et al. 2020; Dosio et al. 2018; Jones et al. 2018; Rohat et al. 2019), hydro-meteorological extremes (Farinosi et al. 2020), and sea level rise (McMichael et al. 2020). This has been made possible by the availability of data at high geographical granularity. More recently, the development of harmonised climate impact simulations (e.g. from ISIMIP) allows the analysis of several phenomena within a unified framework - such as drought intensity and water stress, cooling demand and heat events, habitat degradation and crop yield (Byers et al. 2018; Lange et al. 2020).

In this chapter we expanded this growing literature by estimating the exposed and vulnerable populations in Africa according to a combination of RCPs and SSPs scenarios. We considered in particular impacts in terms of reductions in agricultural productivity and the three dimensions of vulnerability of population in rural areas, in poverty and with low levels of education.

The results indicate that up 162 million people in Western Africa, could be affected by 2070 by changes in agricultural productivity of more than -20%. Within the African continent, Western Africa would be particularly affected in terms of vulnerability.

The different outcomes on exposure and vulnerability emerging when changing climate and socio-economic scenarios underline the need to address the adverse consequences of climate change through both climate and development policies. A reduction of emissions can result in a reduction in exposure. However, when not accompanied by improvements in socio economic conditions, these improvements could be contrasted by the large effects on the size of vulnerable populations.

The large numbers of exposed and vulnerable populations do not necessarily translate into an equivalent number of people who will migrate. Attempts to translate estimates of exposed populations into predictions of the number of international migrants have been criticised for excessive determinism and alarmism. In particular, migration scholars are stressing the need to disentangle climate change from other migration drivers (Black et al. 2011).
Rather, the figures on exposure developed in this chapter should be interpreted as upper-bound estimates of those populations that will need to adapt to climate change impacts. While absolute figures may change and depend on the uncertainties concerning the projections of demographic data, climate impacts and socio-economic conditions, our results help to identify geographical hotspots of exposure and vulnerability which will require the special targeting of adaptation measures.

Adaptation to climate change could initially occur through the introduction of technological solutions in agriculture or through diversification in other economic sectors less influenced by environmental conditions (Collier et al. 2008). Should these adaptation strategies not be viable, the exposed population may abandon their territories as an extreme adaptation strategy and undertake the more costly and difficult solution of migrating internationally.

Looking at migration in these terms corresponds to a shift in perspective whereby mobility is seen as a solution to a problem of localised impacts caused by climate change rather than an issue to be solved (Kraler 2020). This shift in perspective is especially important when starting to realise – as is apparent in this chapter – that impacts of climate change are extremely well differentiated at local level. While some areas especially in tropical and subtropical latitudes are expected to experience dramatic reductions in agricultural productivity, in many other areas and in a large portion of the northern hemisphere, increases in temperature combined with the availability of irrigation are expected to bring increases in productivity. In this context of the geographical differentiation of impacts, openness to trade of food commodities could help to mitigate issues on food security at global level, while the possibility for population to redistribute spatially or diversify economic activities could contribute to lower the local impacts.

At individual level, aspirations and possibilities to migrate internationally will not even emerge for populations living in poverty, in rural areas and with a low level of education. Since international migration normally occurs through step-wise moves passing through world cities connected through international trade and communication networks (Czaika and de Haas 2014; Massey et al. 1993), populations in rural areas face additional limitations in terms of reverting to international migration as an adaptation strategy.

Some of the SSP scenarios indicate that the population in Africa, especially in Western Africa, will be not only be more exposed to the impacts of climate change but also more vulnerable given the still high share of the population in rural area, low education and in poverty. Moving from population exposure to vulnerability, allows us to recognise the importance of socio-economic and demographic drivers in shaping future adaptation strategies.

Under the SSP3 scenario, in particular, the high level of vulnerability in some parts of Africa could be exacerbated by a pathway of resurgent nationalism which would most likely pose further barriers to international mobility (O'Neill et al. 2017). Under these conditions of vulnerability and lack of migration governance, it will be unlikely that the large numbers of exposed populations in some parts of Africa will have the means to adapt by migrating. This would leave to climate adaptation policy the difficult and challenging task of foreseeing specific measures to cater for the needs of those who will be trapped in conditions of extreme environmental degradation and disruption of agricultural activities.

The next step would be to quantify the number of migrants within exposed and vulnerable populations. However, this is a complex task that faces two main challenges. The first lies in the definition of who should be considered a climate change or environmental migrant in the first place. Movements linked to climate change may be permanent or temporary, they could take place locally, within countries or across international borders; they may be linked to sudden onset events such as floods and hurricanes or derive from the slow and progressive degradation of environmental conditions. The lack of definition poses problems for the identification of the boundaries of the phenomenon, and hence for the attempts at quantification of the number of possible migrants. Moreover, the lack of a definition has significant policy and legal implications, as documented by the contentious discussions on the inclusion of climate refugees under the 1951 Refugee Convention. The second difficulty is linked to the uncertainty of estimates of climate impacts models, especially for sectors and activities that could more directly influence migration decisions (Foresight 2011). Given these challenges, it should not come as a surprise that – despite the urgent demand at policy level – scientific results on the quantification of climate migrants are still mixed and debates are constantly shifting between alarmistic predictions of mass exodus and strong criticisms of any attempt at quantification (Kelman 2019).

Despite the difficulty in quantifying climate migrants in the future, some lessons on the climate change – migration nexus can be learnt from past climate trends and migration patterns. One of the main challenges in isolating the link between climate change and migration is to disentangle climate change from other migration drivers, such as individual aspirations, poverty, conflicts, demographic transitions and urbanisation. The link between climate change and migration is indeed mediated by all of these other factors (Hoffmann et al. 2020). Moreover, climate change may either incentivise or hinder migrations. While increasing the need to migrate, climate change may reduce the possibilities to undertake costly international movements and keep the most vulnerable populations in areas subject to environmental degradation. Despite these many challenges, the next chapter will attempt to shed new light on past population responses – in terms of migration – to climate change.

3. FROM EXPOSURE AND VULNERABILITY TO MIGRATION: THE NEXUS BETWEEN CLIMATE CHANGE AND NET MIGRATION IN THE RECENT PAST

Silvia MIGALI, Thomas PETROLIAGKIS, Alfredo ALESSANDRINI, Daniela GHIO, Alessandra CONTE, Umberto MINORA

INTRODUCTION

Africa will be unequally affected by climate change and its impacts. As highlighted in the previous chapter, populations in African sub-regions will be not only among the most exposed to climate change globally, but also the most vulnerable to its negative impacts. In Western Africa living in rural areas, poverty and low education levels will likely exacerbate the negative impacts of climate change. A question that remained unanswered in previous chapter is whether exposed and vulnerable populations will be more likely to migrate or stay in their place of residence.

In the effort to move from the concepts of population exposure and vulnerability to migration, this chapter addresses the following questions.

- In which areas populations have (not) responded to climate change in terms of migration?
- How is the response mediated by other migration drivers?
- Which climatic events tend to be most associated with population mobility?

To answer these questions, the chapter looks at the relation between climate and net migration trends over the period 1975-2015. This relation is explored through a series of regression models using data at high spatial resolution. The models consider indicators for drought, temperatures and precipitation as explanatory variables. In addition to these climatic variables, the models look at the role of population density and agricultural productivity as possible contextual factors influencing the relation between climate and net migration. Besides models covering Africa as a whole, separate models are considered for the main macro region of Northern, Western, Eastern, Central and Southern Africa and for groupings of regions by climatic zones and level of income of countries.

The climate change - migration nexus is mediated by other migration drivers - such as economic development, demographic dynamics and urbanisation processes, the presence of conflicts or other forms of violence, agricultural productivity, food security and the scarcity of resources. Hence, disentangling the nexus between climate change and migration is a complex task. Indeed, the empirical evidence on the relationship between climate change and migration is mixed and offers different results, thus hampering 'policy efforts to address the challenges related to potential increases in global migration flows due to environmental change' (Hoffmann et al. 2020).
The pieces of evidence provided in this chapter make an effort to isolate effects linked to climate change from other migration drivers and from context specific factors affecting population redistributions in Africa.

EVIDENCE AND GAPS FROM EXISTING STUDIES

The nexus between climate change and migration has been studied in the last decades, by scholars from different fields (for recent reviews of the large body of knowledge and empirical evidence on the subject see Hoffmann et al. 2020; Kaczan and Orgill-Meyer 2020; Borderon et al. 2019; Cattaneo et al. 2019).

In addition to studies considering the individual and meso-scales of households and communities, there are macro-level analyses at different geographical scales. The majority of macro-level studies in the last 15 years have attempted to assess how climate change is related to changes in international migration flows, while only a small number has focused on how climate change tends to influence internal migration patterns. In both cases, almost all studies find that climate change is among the drivers of migration (Hoffmann et al. 2020). In particular, climate change tends to be directly linked to migration when it involves health and well-being, while indirectly when it involves socio-economic and political conditions. In other words, the influence of climate change and migration is mediated by other migration drivers - mainly agriculture and income but also socio-political ad cultural factors - and in a non-linear manner (Kaczan and Orgill-Meyer 2020). For instance, Cattaneo and Peri (2016), in a study using emigration rates of non-OECD countries for the period 1960-2000, find that agricultural productivity is the main channel of influence of temperatures on emigration. They conclude that while losses in agricultural productivity, due to increasing temperatures, are associated with increased emigration from middle-income countries, in poor countries these impacts reduce the ability of rural populations to emigrate since they aggravate their liquidity constraints.

A common finding in macro-level studies is that weather shocks tend to result in long-term within-country migration, rather than short-term or international migration; slow-onset events more often result in migration than fast-onset events (Kaczan and Orgill-Meyer 2020). Overall, migration tends to respond more strongly to changes in temperature levels and precipitation (Hoffmann et al. 2020). This could be explained by the fact that while changes in temperature levels tend to have negative impact on migration, changes in precipitation levels may have either positive or negative impacts on migration, depending on its timing. For example, precipitation after a period of drought is beneficial, while an excess of rainfall in a normal period may lead to floods. The magnitude of the relationship between climate change and migration is influenced by the other factors considered in macro-level studies, thus suggesting strong interactions between climate change and the other migration drivers. Moreover, the relationship is weaker when using measures of climate and migration with 5- or 10-year frequency than in the case of annual data. Finally, the size of the relationship is influenced by the form of internal migration considered (such as rural-urban, rural-rural or urban-urban). Indeed, climate change may have not only a push but also a pull effect, possibly influencing the choice of the destination country (Hoffmann et al. 2020).

Existing macro-level empirical evidence suggests that the strongest relationship between climate change and migration is in Latin America and the Caribbean and sub-Saharan Africa, in middle-income countries and agriculture dependent countries (Hoffmann et al. 2020). Recent research also identifies environmental migration hotspots worldwide – i.e., regions particularly vulnerable to current and future impacts of climate change (de Sherbinin 2014) - especially in Latin America and the Caribbean, sub-Saharan Africa, the Sahel, East Africa, West Africa, part of South Africa and East Asia (Hoffmann et al. 2020; de Sherbinin 2014). When focusing on sub-Saharan Africa, most of the existing country-level studies cover the period from the 1960 to 2000, by using annual data, or five- or ten-year frequency data. All the studies find positive[27] and significant associations of both temperature and precipitation with emigration from sub-Saharan areas. Despite Africa being among the continents most exposed to climate change, several analyses indicate that climate is not likely to generate mass migration and that populations may be trapped and migration of no avail as one of the possible adaptation strategies to changing climatic conditions (Borderon et al. 2019; Black et al. 2011).

Despite the growing number of studies, disciplines and approaches to study the climate change migration nexus, the knowledge gaps and uncertainties on the subject do not allow generalised conclusions to be drawn (Borderon et al. 2019). One problem frequently highlighted in analyses at country level is that they do not recognise effects from climate change which are differentiated in space and highly contextual.
One of the largest exercises trying to address this gap by using data at high geographical resolution is constituted by the World Bank's Groundswell Report (Rigaud et al. 2018). This has been possible thanks to the recent development of population and migration data at high geographical detail (de Sherbinin 2015). In particular, the Groundswell Report has proposed projections for populations and areas most exposed to climate change and tried to quantify internal climate migrants, by downscaling national projections of population from the country to territories at higher spatial resolution, on the basis of the work of Jones and O'Neill (2013, 2016). As one of the main findings, the report suggests an increasing trend of internal climate migration in sub-Saharan Africa, South Asia and Latin America by 2050, across all the scenarios considered. In particular, the report estimates around 86 million internal migrants in sub-Saharan Africa under the more pessimistic scenario. Climate change impacts – especially on crops, and in terms of sea level rise and water stress – are likely to become drivers of internal migration of growing importance. However, this will not be the case for the poorest populations who are trapped in their territories due to the lack of opportunities to move to other areas (Rigaud et al. 2018).

27 Naude 2010; Ruyssen and Rayp 2014; Damette and Gittard 2017; Marchiori et al. 2012, 2017; Bruckner et al. 2014; Henderson et al. 2017.

A recent contribution analysing the climate change migration nexus worldwide on the basis of high spatial resolution data is in Peri and Sasahara (2019). More specifically, the authors carry-out an empirical analysis of the relationship between climate change and migration using historical decennial data, from 1970 to 2000, at high spatial resolution. The main result of this study is that increasing temperature tends to diminish rural income, thus increasing the income differential between rural and urban areas. In poor countries, a reduction of rural income decreases out-migration from rural areas since it makes the cost of migration prohibitive (poverty trap). Instead, in middle-income countries, lower rural income tends to push out-migration from rural to urban areas. Additionally, the study develops a projection exercise which suggests that emigration from rural areas in poor countries will continue to decrease, thus increasing the populations trapped in rural poverty.

METHODOLOGY

The analyses in this chapter move along the most recent literature making use of spatially detailed data on population distributions. In particular, they rely on historical data on net migration and climate change at high spatial resolution. The relation between these two set of variables is explored through a series of regression models characterised by the following methodological choices (see Appendix for more details).

- **High geographical detail & long-term patterns.** The data on net migration, population dynamics, and climatic events used in the regression models refer to grid cells of 0.5 deg resolution. Such granularity allows us to capture migration and climatic patterns that could be masked when using more aggregated country-level data.

- **Which migration?** The dependent variable in the models is represented by net migration estimates at high spatial resolution developed by Alessandrini et al. (2020). Net migration is calculated for each territory (or cell) considering changes in population over time, after taking into account natural population changes linked to fertility and mortality. The main population data is obtained from high resolution population estimates from the JRC Global Human Settlement Layer (Pesaresi et al. 2019; Corbane et al. 2018) and the demographic components of fertility and mortality are from UN/DESA. Negative net migration corresponds to more emigration than immigration in the territory. Vice-versa, positive net migration is indicative of attractiveness of the area which results in more immigration than emigration.[28] It should be stressed that net migration does not provide information neither on the origin of the immigrants, nor the destination of the emigrants (for details, see Box 4).

- **Slow-onset climatic events.** In terms of time, the models cover the period from 1975 to 2015, with 5-year frequency.[29] This implies a focus on medium-long term effects of slow onset climate changes. In particular, the regression models tested, separately, more than 90 climatic indicators from several data sources, described in Petroliagkis and Alessandrini (2021). In the following sections, only few of the 90

28 Details on net migration estimates can be found in (Alessandrini, Ghio, and Migali 2020) and the interpretation, strengths and limitations of the net migration are described in Box 4.

29 It should be noted that developing short-term forecasts or early warning analyses is beyond the scope of this report.

climatic indicators are reported - that is, those best describing the main climatic patterns and being significantly associated with the net migration.

- **Climate induced migration and population demographic dynamics.** Besides natural population change, the other factor affecting net migration is represented by urbanisation. To disentangle changes in net migration attributable to urbanisation from those that could be explained by climate change, the models include population density as a control variable (i.e., as a proxy to measure urbanisation). As a further step, the models consider interactions between climatic variables and population density. This serves to explore whether the association between climatic change and net migration is mediated by local demographic processes. In other words, through the interaction terms, the models attempt to detect if, for example, an increase in temperature is associated with more net migration in areas which are also experiencing stronger expansion in the population.

- **Macro-regional vs continental approach?** The chapter presents the model results for each African macro-region separately.[30] The analysis is also performed by looking at the entire African continent.[31] However, the preferred model specifications – reported and discussed in the rest of this chapter – are those focusing on each macro-region separately.[32] The main reason for this methodological choice is that when pooling data for the entire African continent, significant results that are specific of a particular area or set of countries could be masked.[33] In other words, the results are context specific, as also suggested by qualitative studies and analyses (Borderon et al. 2019).

- **Caveats.** It should be mentioned that the models are not able to provide information on migration in-flow or out-flows. As already noted, the only migration indicator available at such a high geographically detailed level is net migration. As a further caveat, it should be mentioned that it is difficult to disentangle the climate change-migration nexus from other migration drivers. Hence, the results of the regression models developed in this chapter are interpreted as associations – rather than causal relations. Lastly, other technical caveats related to the modelling approach are listed in the Appendix.

30 In particular, the chapter follows the geographical classification provided by the United Nations Statistics Division: https://unstats.un.org/unsd/methodology/m49/.

31 The results are reported in the Appendix.

32 We also run the same models using different sub-samples: the income level group of the countries; the agro-ecological classifications of cells. Almost none of these models yielded significant results (see Table 3A and Table 3B in the Appendix).

33 The model results for all of Africa does not provide clear indications on the association between climatic indicators and net migration (see Table 3 in the Appendix). In particular, 5-year average temperatures and precipitation are not associated with net migration. It is also tested whether the relationship between net migration and climate indicators changes across different African macro-regions. This is done by using an interaction term between the climatic indicators and an indicator of the African macro-region. This model specification allows us to test whether the relationship between climatic indicators and net migration varies between macro-regions. However, this specification does not allow us to estimate a specific coefficient of the climatic indicators for each macro-region, as it is done in the models presented in the rest of the chapter. The results suggest a negative association between average temperature and precipitation with net migration in Northern Africa only.

BOX 4 Net migration

Net migration is defined as the difference between the number of immigrants and the number of emigrants. Territories with positive net migration (i.e., where the number of immigrants is higher than the number of emigrants) experience population gains. Symmetrically, territories with negative net migration (number of immigrants lower than the number of emigrants) experience population losses. When data on migration flows are not available, net migration can be derived from the population change over the given period of time, using the demographic equation, in which population change is equal to the starting population minus the ending population plus natural increase (births minus deaths) and net migration. However, in doing so, the estimated net migration may be affected by inaccuracies of data on population change and its related components. Demographers have explained limitations in the use of net migration (Rogers 2008, Termote 1993). For instance, it should be noted that the net migration results from the migratory balance between populations immigrated in the targeted territory and populations emigrated towards other territories. Hence, it is not possible to distinguish neither the origin of the immigrants, nor the destination of the emigrants. Similarly, no distinction can be made by type of movements, such as internal (within the country), international (across countries) circular or return migration. Despite all of its limitations, nowadays the net migration remains often the only applicable indicator, which maximises the use of available official statistics and accounts for the spatial distribution of populations.

NORTHERN AFRICA

OVERVIEW OF DEMOGRAPHIC AND CLIMATE CHANGE TRENDS IN THE REGION

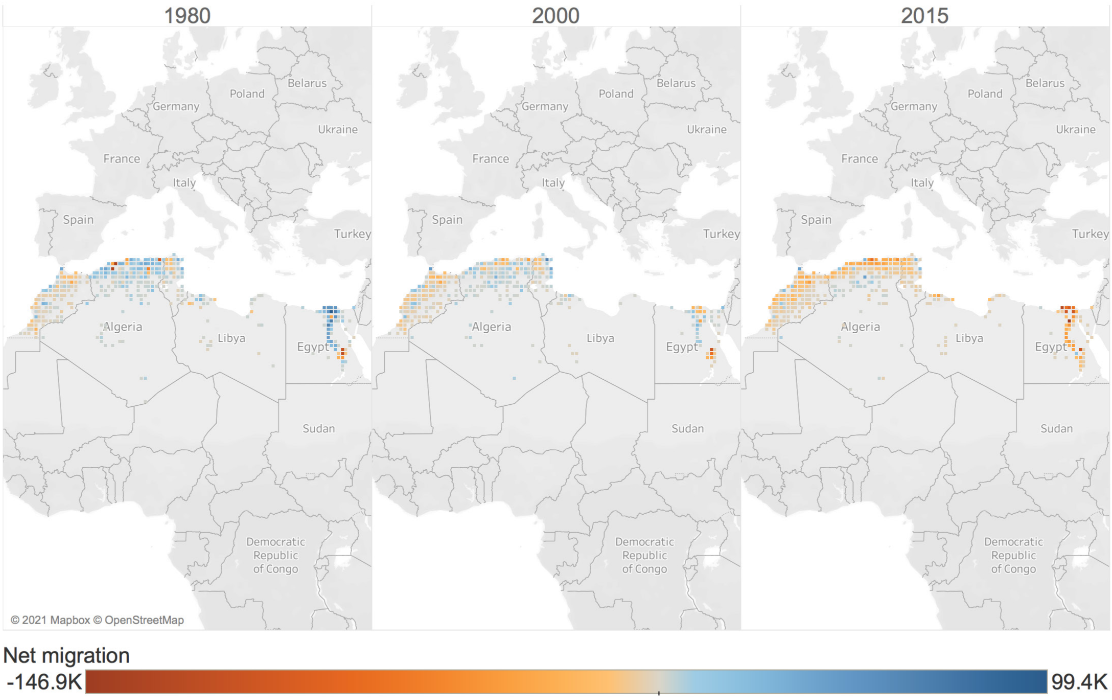
According to the UN World Population Prospects, the population in Northern Africa[34] amounted to approximately 223.9 million in 2015. It has increased by 130.4 million over the last 35 years, corresponding to a 139% relative change. According to UN/DESA estimates, the share of people born in Northern Africa living abroad is above 4% since 2005 and the majority of Northern Africans' moves overseas. Two main migration patterns can be identified in the region: from Maghreb countries to Europe, and from Egypt to the Gulf states and Jordan (Natale et al. 2018).

In Northern Africa, the 5-year net migration rate is always negative over the period 1975-2015 - i.e., the number of immigrants is lower than the number of emigrants (United Nations 2019). This qualifies the Northern Africa as an emigration region. Additionally, Northern Africans have higher probability of moving abroad than people born in sub-Saharan Africa (Natale et al. 2018). A similar pattern emerges when focusing on net migration at high spatial resolution (Figure 16). It can be observed that coastal territories in Morocco and Algeria tend to have negative net migration in the latest period (2010-15). In the same period, most territories in Egypt have negative net migration especially in the areas in the lower and upper Nile Delta.

In 2010-15, the most densely populated areas correspond to the major cities (such as Cairo, Algiers, Tunis and Casablanca). Population density in each grid cell – which is, on

34 In the UN geographical classification, the region of Northern Africa includes Western Sahara, Egypt, Libya, Tunisia, Algeria, Morocco and Sudan.

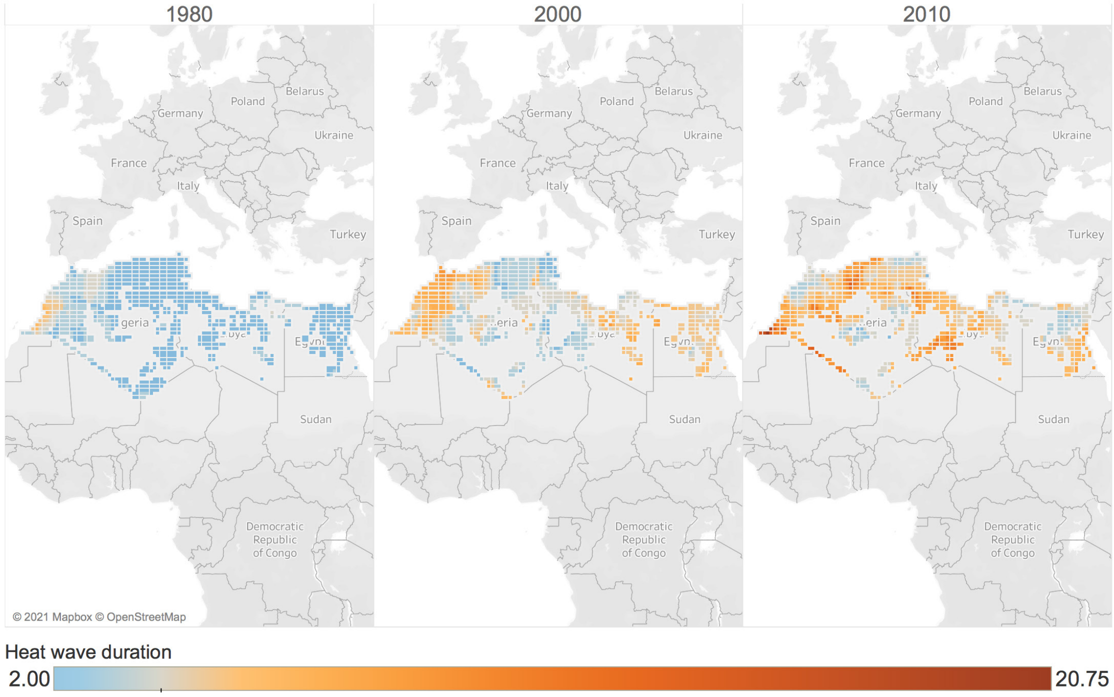
FIGURE 16. Net migration at high geographical resolution, Northern Africa.
Note: Estimates of 5-year net migration per 0.5 deg resolution cells (Alessandrini et al. 2020). Year refers to the end of the 5-year period.



average, the highest when compared to other macro-regions - has increased over time from around 25 inhabitants per square kilometre in 1975-1980 to 54 in 2010-2015. According to the IPCC AR5 report (Niang et al. 2014), in recent decades, North African annual and seasonal observed trends in mean near surface temperature indicate an overall warming that is significantly beyond the range of changes due to natural (internal) variability. During the warm seasons (March-April-May, June-July-August) in particular, anomalous increases in near surface temperature have been recorded in northern Algeria and Morocco. Further to the positive trends in temperature, Fontaine et al. (2013) reported an increased occurrence of hot days and heat waves in Northern Africa, associated with specific atmospheric anomalies over Morocco and the Western Sahara. Several areas in Northern Africa recorded increases in the duration of heat waves from 1995-2000 to 2005-10. The latter period seems, on average, the most affected, with an average duration of 6 days and a maximum value of 24 days (Figure 17). These findings are consistent with recent analyses (Ceccherini et al. 2017) carried out for all African regions, assessing the link between heat wave indicators and climate change in the past and envisaging its persistency in the near future (Russo et al. 2019).

With regard to precipitation, over the last few decades, the northern regions of North Africa (north of the Atlas Mountains and along the Mediterranean coast of Algeria and Tunisia) have experienced a sharp decline in the amount of precipitation received in winter and early spring. The observed records indicate more than 330 dry days (with less than 1 mm/day rainfall) per year over the 1997–2008 period. However, in autumn (September-October- November) observations show a positive trend in precipitation in some parts of northern Algeria and Morocco. The Sahara Desert, which receives less than 25 mm/year, shows little seasonal change.

FIGURE 17. Heat wave duration indicator.
Note: Heat wave duration indicator (5-year average) at high geographical detail (0.5 deg resolution) for 1975-1980, 1995-2000, 2005-2010. Details on the indicator are provided in Petroliagkis and Alessandrini (2021). Data source: Mistry, Malcolm Noshir (2019).



RELATION BETWEEN CLIMATE CHANGE AND NET MIGRATION

The results of the baseline model applied to Northern African region[35] suggest that heat wave duration and frequency are negatively associated with net migration over the period 1975-2015, whereas associations with heat wave amplitude and magnitude are less clear[36] (Table 4 in the Appendix).[37] The negative association means that if heat wave duration would increase, net migration is expected to decrease. In other words, the territory is expected to become less attractive or experience population losses (either due to an increase of emigration or a decrease of immigration, or both).

As discussed in Section 3, one of the objectives of the empirical analysis is to understand if the association between climate change and net migration is mediated by interactions with demographic processes. Model results suggest that the increase in heat wave duration is associated with smaller population losses in areas experiencing higher increases in population density. This would indicate that while the increase of heat waves duration

35 It should be mentioned that when including all Northern African countries, we do not get significant results. When excluding Sudan from the sample, the heat wave indicators are significantly associated with net migration. This provides us a valid argumentation to model Sudan separately from the rest of the Northern African region.

36 More precisely, net migration is negatively associated with heat wave amplitude and magnitude only when using standard errors clustered at regional or at country level – while not significant when using standard errors clustered at the level of agro-ecological class. While the latter model specifications are reported in Table 4 in the Appendix, the former are not reported in this report due to space constraints.

37 Heat waves can be related to other demographic indicators besides net migration. For instance, Mora et al. (2019) have provided a global threshold beyond which the daily mean surface air temperature and relative humidity can increase mortality. Recent studies have also underlined the differences in vulnerability to heat waves between gender and age groups, and how heat waves – in combination with contextual social economic factors – generate additional vulnerability for trapped populations (Cattaneo and Bosetti 2017).

is related, in general, to the loss of attractiveness, this association is less pronounced in areas experiencing underlying processes of population expansion, either linked to population natural increase or urbanisation. Instead, increasing heat wave duration may accelerate emigration from areas already subject to lower population increases.
This type of interaction proves one of the main difficulties in examining the effects of climate change in a spatial context, which consists in disentangling variations in population distributions attributable to demographic and urbanisation transitions from those related to environmental factors.

An apparent contradiction in all model specifications is that population density is negatively associated with net migration: territories with increasing population density – attributable either to urbanisation or natural population increase - tend to lose population, probably because they are experiencing emigrations. This is a counterintuitive finding since we would expect that higher population density is related to an increase in the attractiveness of the territory. This finding may be explained from the fact that, particularly in the African context, a natural population increase represents still a major driver of population growth. High emigration may coexist with population expansion, especially in rural areas, due to their higher fertility levels in respect of cities. Overall, these results show that urbanisation and/or population growth are prevailing forces influencing emigration from the Northern African territories. In this region, climate change appears (only) as a minor factor mediating such demographic processes. Climate change may on the one hand reinforce the exodus from depopulating areas and, on the other hand, overlap with demographic expansions.

According to the 2015 World Bank income level classification, countries in the Northern African regions are lower-middle income countries, except for Algeria and Libya which are classified as upper-middle income countries. When splitting the analysis across these two groups of countries, the association between heat wave duration and net migration continues to hold for the group of lower-middle income countries only. Similarly, when modelling subtropical and tropical regions separately, the negative association between net migration and heat wave duration is confirmed.The agricultural sector constitutes an important part of the economy of the macro-region, although its importance has decreased over the period considered. Indeed, the share of employment in the agricultural sector as aper cent of total employment has declined from 36% in 1990-1995 to 25% in 2010-2015 (World Bank, 2020). Similarly, the sectoral contribution of agriculture, forestry and fishing to the value added has decreased from 23% of GDP in 1980-85 to 18% in 2010-2015, though with some differences between countries. Whether the association between net migration and heat waves continues to hold once taking crop yield productivity into account, cannot be tested in the model for the entire Northern African region due to missing observations at high spatial resolution for the region (Iizumi and Sakai 2020) - except for Egypt. A focus on this country is provided in Box 5 below.

BOX 5 A focus on Egypt

We focus here on Egypt to provide an example of the complex link between population dynamics, climate change and agriculture. The model results for Egypt are reported in the Appendix (Table 5). Overall, the results suggest that: (i) heat wave duration and frequency are negatively associated with net migration and the association is less pronounced in areas with increasing population density; (ii) the relationship between heat waves and net migration continues to hold even when taking into account crop productivity (rice, wheat, and maize).

These results need to be framed in the general development process that Northern African countries are experiencing. Figure 18 visualises the evolution of population density in Cairo's surrounding areas from 1980 to 2015 Cairo is not only the capital of Egypt but also its economic, social, service, and administrative centre, accounting for more than 20 million inhabitants in 2018. Due to the rapid population growth, the government has attempted to both decentralise population and activities from Cairo and to reorganise the national, regional, and local institutional structures (Yousry and Atta 1997). The expansion of cities into agricultural areas is seen as a serious issue in Egypt; the construction of new buildings on farmland is forbidden by law and needs to be licensed by the Ministry of Agriculture and Land Reclamation.

The enlargement of densely populated areas is visible over the observed period (the colour gradient of urban grids varies from brown, corresponding to low levels of population density to blue, corresponding to high levels of population density). As in the general model for Northern Africa, also in the Egyptian case, an increase in population density would make net migration lower. Moreover, results for Egypt confirm that the negative association between heat wave duration and frequency and net migration is less pronounced in areas with higher increases in population density. As argued above, this would indicate that the expansion of cities is happening independently of climate change.

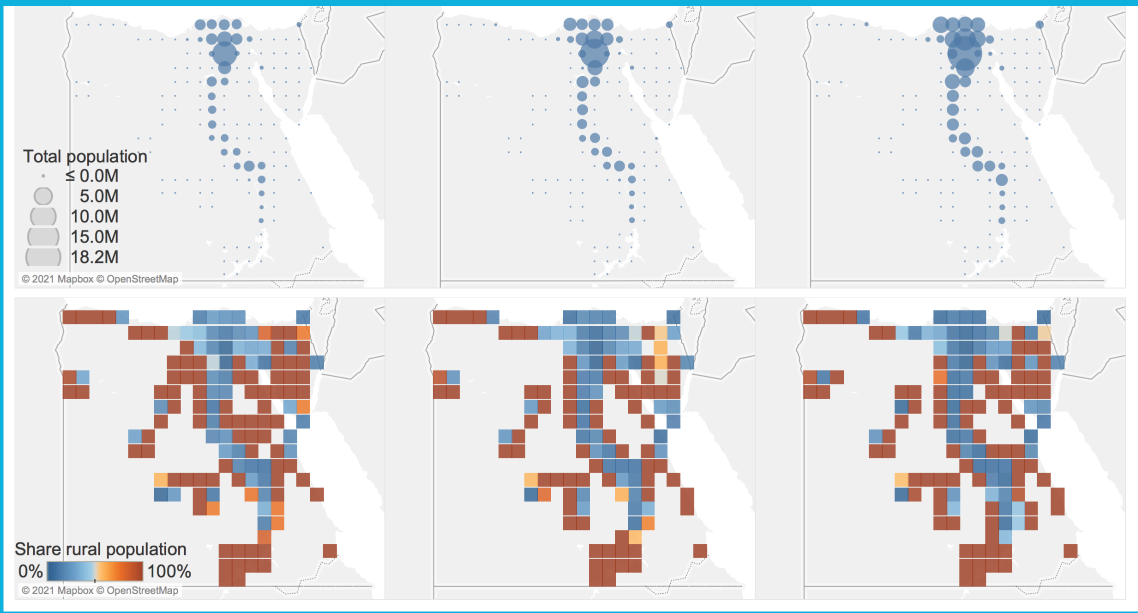
In Egypt, agriculture is concentrated in the Nile valley and its delta, with a few oases and some arable lands in Sinai, and rice is the major field crop for exportations after cotton (FAO 1997; AQUASTAT 2016) growing mainly in the delta zones. Figure 18 displays the high concentration of population in such areas where agricultural production is dominant.

Smallholdings characterise Egyptian agriculture, with about 50 per cent of holdings having an area less than 0.42 ha (AQUASTAT 2016). Agriculture is still a major economic activity in Egypt, as it plays an important role for population sustenance (AQUASTAT 2016). Since 1992, farmers have been able to select crops while in the past the government selected the cropping patterns (Gersfelt 2007).

In our models, rice productivity is positively associated with net migration. This positive association confirms that the most productive farmland is subject to a demographic pressure. As indicated above, this has led the Egyptian government to introduce specific measures to protect agricultural productivity from rapid urbanisation.

The positive association persists in the models considering the heat wave duration. This seems to indicate that demographic pressure on productive land is not reduced by climate change.

FIGURE 18. Cairo's population dynamics from 1980 to 2015.
Data source: Alessandrini et al. (2020).



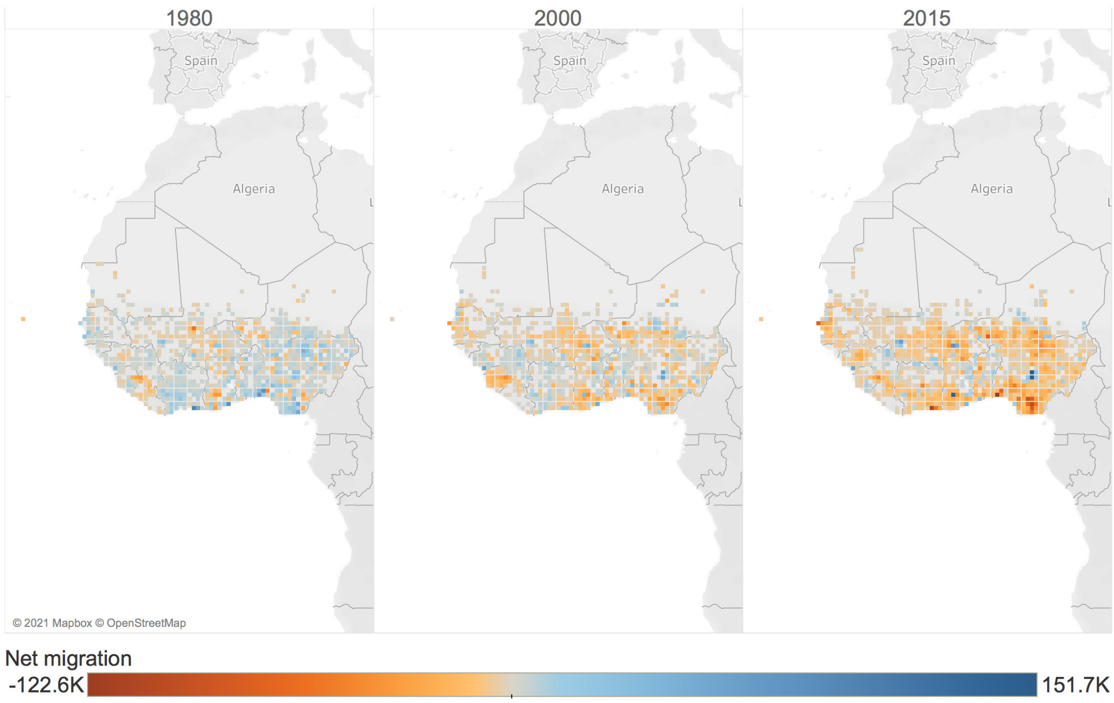
WESTERN AFRICA

OVERVIEW OF DEMOGRAPHIC AND CLIMATE CHANGE TRENDS IN THE REGION

According to UN data, population in Western Africa[38] amounted to 402 million in 2020 (United Nations 2019). From 1975 to 2015, population experienced a relative change of about 200% - second only to Middle Africa in terms of relative change over the same period - from about 120 million in 1975 to 352 million in 2015. Western Africa primarily hosts immigrants born in another Western African country. This intra-regional mobility is related to the Economic Community of West African States (ECOWAS), whose citizens have the right to move and settle in another ECOWAS country. Besides intra-regional migration, the other main migration pattern is constituted by immigrants moving to Europe (Natale et al. 2018).

The net migration rate in Western Africa, despite considerable fluctuations, has always been negative since the 1970s (United Nations 2019). This indicates that, overall, the region is producing more emigrants than immigrants. The same picture also emerges when focusing on net migration at high geographical detail (Figure 19). The territories with the highest net migration values are those corresponding to capital cities or urban areas that are attracting population. This is the case of, for instance, Abuja in Nigeria, Ouagadougou in Burkina Faso, Bamako in Mali, Accra in Ghana and Dakar in Senegal. The majority of Western African

FIGURE 19. Net migration at high geographical resolution, Western Africa.
Note: Estimates of 5-year net migration per 0.5 deg resolution cells – from (Alessandrini et al. 2020). Year refers to the end of the 5-year period.



38 In the UN classification, Western Africa includes Benin, Burkina Faso, Ivory Coast, Cabo Verde, Ghana, Guinea, Gambia, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo.

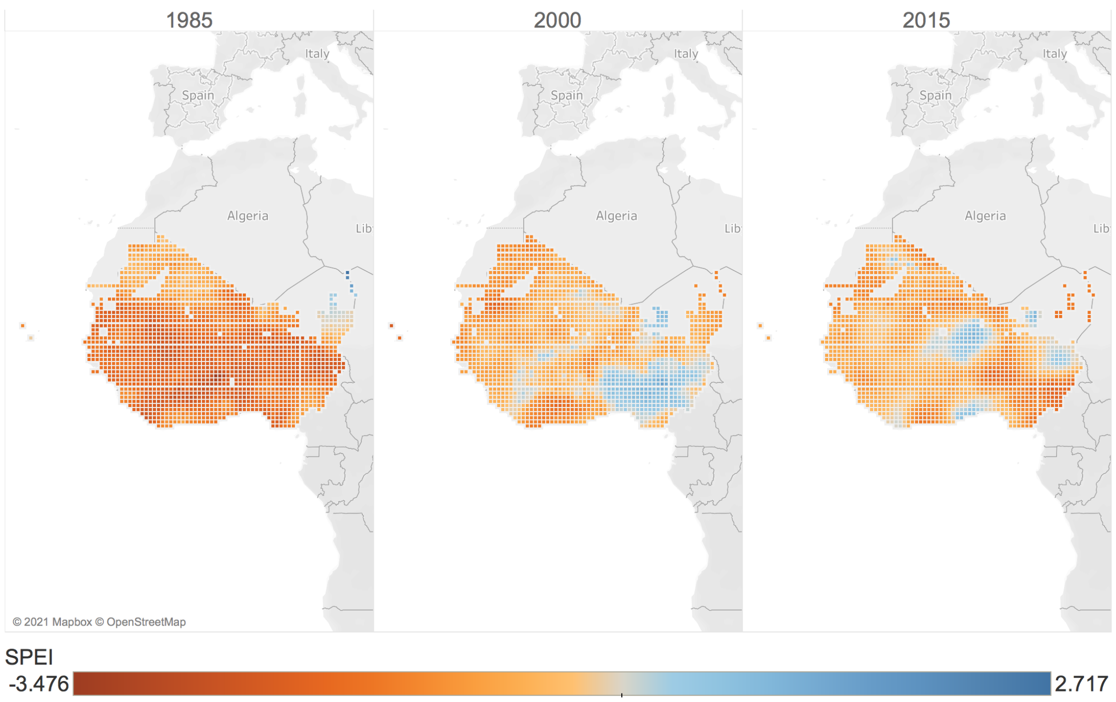
territories have low population density even though population density has increased over the period considered. Indeed, it has grown from an average of about 22 to inhabitants per square kilometre in 1975-1980 to about 60 in 2010-2015.

Since the 1970s, climate observations have indicated significant changes in the region's climate, particularly in relation to temperature and precipitation. The high dependence of Western African communities and sectors on natural resources makes them vulnerable to climate change impacts such as rises in temperature, changes in annual rainfall, more frequent and intense rainfall events, and sea level rise. Pre-existing physical, ecological, and socio-economic characteristics and stressors increase the region's vulnerability to extreme events such as storms, flooding, and drought, which are anticipated to become more frequent and intense due to climate change.

Over Western Africa and the Sahel near surface temperatures have increased over the last 50 years (Niang et al. 2014). Using indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), it has been estimated that the number of cold days and cold nights have decreased, and the number of warm days and warm nights increased between 1961 and 2000. A statistically significant warming of between 0.5° C and 0.8° C between 1970 and 2010 over the region has been documented using remotely sensed data with a greater magnitude of change in the latter 20 years of the period.

Rainfall over the Sahel has experienced an overall reduction over the course of the 20th century, with a recovery towards the last 20 years of the century. The occurrence of a considerable number of droughts in the Sahel during the 1970s and 1980s has been well documented and understood. On the other hand, the gradual recovery of the rains may be due to natural variability or a forced response to increased greenhouse gases or even reduced aerosols.

FIGURE 20. SPEI mean values over 5-yearly time intervals.
Note: SPEI mean values at high geographical detail (0.5 deg resolution). Data source: Vicente-Serrano et al. (2010). Negative values (in red) indicate extreme drought conditions, while positive values (in blue) indicate wet conditions.



BOX 6 How is drought measured?

Climate experts hardly agree on indices to measure drought. Droughts usually become evident after long periods without precipitation although it is difficult to establish their onset, extent, and end (Vicente-Serrano et al. 2010). Different indexes have been developed to assess and monitor drought, such as the Palmer Drought Severity Sndex (PDSI), the Standardised Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). The PDSI is based on the concepts of water demand and supply and it is calculated by considering precipitation, moisture and evaporation (Vicente-Serrano et al. 2010). The SPI and SPEI are multi-scalar indexes of drought; while the former takes into account precipitation, the latter takes into account both precipitation and temperatures. Despite being the most used tools to assess and monitor droughts, these indexes have some caveats; for instance, different rankings of the intensity of drought can be obtained depending on the indexes used and their characteristics; for a discussion, see Riede et al. (2016).

In this report, we use the SPEI. This is a multi-scalar index which combines information on temperature variability and precipitation to assess the severity of drought (Vicente-Serrano et al. 2010). The SPEI is based on climatic water balance, given by the difference between precipitation and evapotranspiration. Negative values of the SPEI indicate water deficits and positive values water surpluses. In this report, we refer to the classification of drought intensity (Li et al. 2015). In particular, SPEI values less than -2 indicates extreme drought; values between -1.99 and -1.50 severe drought; values from -1.49 to -1 moderate drought; values between -0.99 and 0.99 normal hydrological conditions. Symmetrically, positive values indicate moderate wet conditions (from 1 to 1.49), severe wet conditions (from 1.50 to 1.9) and equal or above 2 extreme wet conditions. The SPEI can be calculated by referring to different time scales over which water deficits or surpluses accumulates – usually from 3 to 48 months (Vicente-Serrano et al. 2010). We use the SPEI calculated for 48 months since we are interested in how long-term variations in water balance affects net migration over 5-year periods.

In the empirical analysis, several indicators of temperature and precipitation are included. In addition to these, the analysis also uses the Standardized Evapotranspiration Precipitation Index (SPEI), an indicator commonly employed to measure drought (for details, see Box 6). As it can be observed from the SPEI plotted in Figure 20 - where territories in red correspond to extreme drought while blue territories to wet conditions - the 1980s were the most affected by drought.

RELATIONSHIP BETWEEN CLIMATE CHANGE AND NET MIGRATION

Overall, the models considering the entire Western Africa region do not indicate clear associations between climate extremes and net migration. There is no significant association independent of from the climate indicator used (precipitation, temperature trends or temperature extremes such as daily temperature range indicator, drought severity through the SPEI indicator) and, also after considering, in several model specifications, the productivity of main crops as additional controls (Table 6 in the Appendix).

There could be several explanations for this. From the more technical point of view, the model may not be able to capture any significant association between climate indicators and net migration since data refers to 5-year intervals. Hence, they may mask some variability of extreme climatic events over time. Furthermore, the regression model used are not able to fully capture non-linear relations between climatic variables and net migration.[39]

39 More details on the limitations of the models are reported in the Appendix.

The fact that no association is found for the Western African region should not be surprising for two reasons. Firstly, this could be interpreted as a sign of populations being trapped because of vulnerability like poverty, low education and residence in rural areas (see previous chapter). Secondly, migration is only one of the possible adaptation strategies to changing climatic conditions (Black et al. 2011) and population response to climate change may be highly dependent on socio-economic and environmental specific characteristics.

In an attempt to understand whether a significant association may emerge in specific contexts, in Box 7 the focus is restricted to the smaller area of the Sahel region.

BOX 7 Relationship between climate change and net migration in Sahel

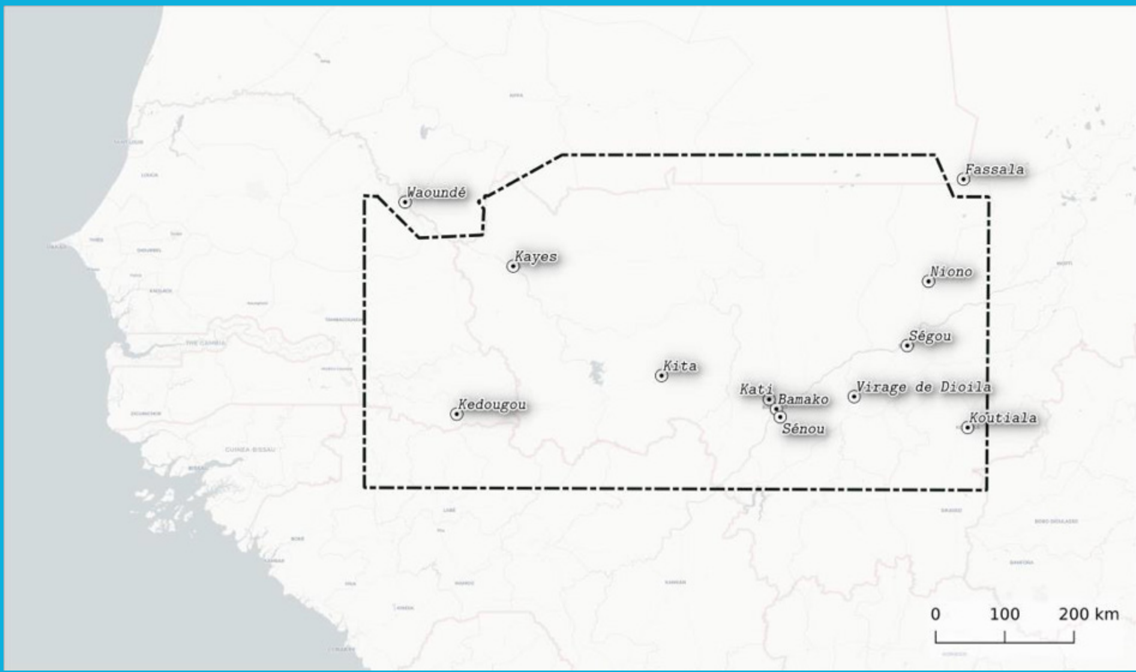
The Sahel is a region between Mali (region of Kayes), Senegal and Mauritania (Figure 21) mainly composed of rural territories, except for the towns of Bakel in Senegal, Yélimané, Kayes and the Mali capital of Bamako. The main crops in this region are cereals, in particular maize, rice, millet, sorghum (FAO/GIEWS, 2020a, 2020b). The region has been hit by prolonged and intense droughts between the late 1970s and the 1980s. Previous qualitative and quantitative studies for this region documented that migration and mobility strategies were adopted to face the scarcity of food supply during prolonged periods of drought (a review of selected studies and more details on this case study can be found in (European Commission. Joint Research Centre., 2021).

Two elements are of particular importance to this case study. First, out-migration from this area tends to follow established migratory routes and migration networks with selected destination regions. Before the droughts in the late 1970s and 1980s, this area was characterised by out-migration, which originated as seasonal migration of Soninke people in the colonial period. This seasonal migration has then transformed into long-term international out- migration, mainly directed to France (Gonin and Lassailly-Jacob 2002). Even though there is no consensus among scholars on whether out-migration after the droughts was mainly long- or short-term phenomenon, there is a recognised association between drought and out-migration, contributing to reinforcing traditional migration patterns. The second crucial element identified by literature on this area is that out-migration is one of the possible individuals' adaptation strategies to cope with food shortages related to drought and water scarcity. Indeed, in a period of prolonged drought, the traditional household adaptation strategies, such as the use of substitution food, may not be sufficient to satisfy the demand for food. In addition, food shortages, combined with increasing demographic pressure and other migration drivers, such as previous migration networks would push family members to move to other areas, either neighbouring or abroad.[40]

When analysing the relationship between climate change and net migration at high geographical detail (see Table 7 in the Appendix) our models find a negative association between extreme minimum temperatures as well as drought severity and net migration. Moreover, in territories with smaller increases in population density the response – in terms of loss of population – to extreme climatic slow-onset events tend to be more pronounced than in territories experiencing higher population growth. Overall, these results suggest that while it was not possible to find a generalised association between climate change and net-migration for the whole of Western Africa, this association is clearly emerging in the context of Sahel region, where there are well-established migration processes and recurrent drought conditions resulting in food shortages.

40 This is the case, for instance, of the Soninke population (Gonin & Lassailly-Jacob, 2002).

FIGURE 21. Case study selected area in Sahel.



EASTERN AFRICA

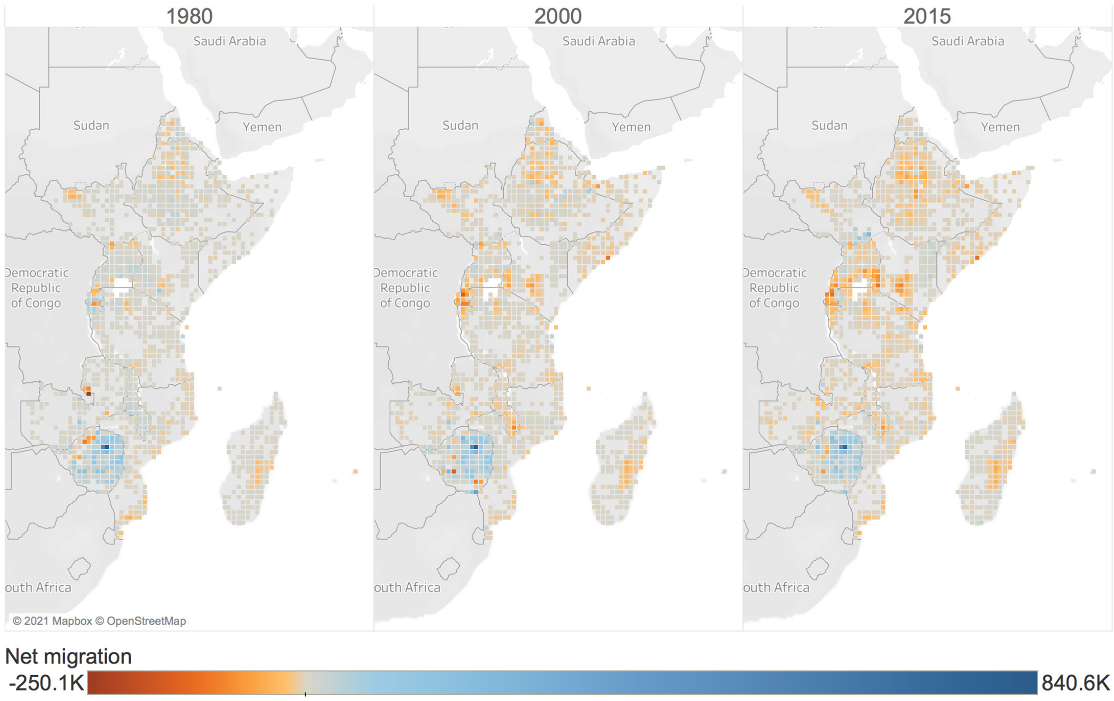
OVERVIEW OF DEMOGRAPHIC AND CLIMATE CHANGE TRENDS IN THE REGION

In 2020, the UN World Population Prospects estimated a population of about 444 million in Eastern Africa.[41] The relative population change from 1970 to 2015 is, together with Central and Western Africa regions, among the highest in the continent (208%). Indeed, the population grew from 106 million in 1970 to 388 million in 2015. In 2019, Eastern Africa hosted 7.7 million immigrants, 93% of which born in an African country. Since the 1980s, no less than 90% of African immigrants living in Eastern Africa are born in another Eastern African country. Intra-regional migration (i.e., within Eastern Africa), is undoubtely one of the main migration patterns – together with movements 'from Eastern Africa to the Gulf States (mostly temporary workers) and to neighbouring countries (mostly refugees)' (Natale et al. 2018).

UN estimates indicate that the 5-year net migration rate in Eastern Africa is negative for the entire period 1975-2015 (United Nations 2019). Net migration data at high spatial resolution suggests a more complex situation (Figure 22). The region with the highest net migration is in the area of Harare. Regions in Uganda and Kenya (areas around the Lake Victoria), areas Eastern of Nairobi are those with the lowest (negative) values of

41 According to the UN classification, Eastern Africa includes Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mozambique, Mauritius, Malawi, Rwanda, Somalia, South Sudan, Tanzania, Uganda, Zambia, Zimbabwe.

FIGURE 22. Net migration at high geographical resolution, Eastern Africa.
Note: estimates of 5-year net migration per 0.5 deg resolution cells - from Alessandrini et al. (2020). Year refers to the end of the 5-year period.



net migration. Most of the territories are low densely populated areas. Indeed, average population density in the cell has moved from 20 inhabitants per square kilometres in 1975-1980 to 53 in 2010-2015. Given the slowing down of urbanisation processes, this pattern is mostly likely driven by a population natural increase (Potts 2009).

The climate of Eastern Africa is generally tropical, though average temperatures tend to be reduced by the region's high elevations (Marcus and Low, 2021). Precipitation is also affected by varying elevation: Uganda, Tanzania, and western Kenya receive plentiful rainfall, while Somalia, eastern Ethiopia, and north-eastern Kenya receive far less. The equatorial and southern parts of eastern Africa have experienced a significant increase in temperature since the early 1980s (Araujo et al. 2016). Seasonal average temperatures have risen in many parts of the region over the past 50 years. Rainfall in the region is extremely variable across time and space. Several physical processes, including the El Niño Southern Oscillation, affect rainfall. Countries bordering the western Indian Ocean experienced a trend towards more frequent heatwaves, droughts, and storms between 1961 and 2008.
According to the IPCC AR5 report (Niang et al. 2014), the equatorial and southern parts of eastern Africa have experienced a significant increase in temperature since the beginning of the early 1980s. Similarly, recent reports from the Famine Early Warning Systems Network (FEWS NET) indicate that there has been an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan, and Uganda over the last 50 years. In addition, warming of the near surface temperature and an increase in the frequency of extreme warm events have been observed for countries bordering the western Indian Ocean between 1961 and 2008. Furthermore, there is a lack of

evidence of observed trends in extreme temperature, extreme rainfall, and drought in Eastern Africa. Changes in the Indo-Pacific oceans appear to have contributed to more frequent drought during the 'long rains' (from March to May) over the past 30 years. It is not clear whether these changes are due to human-caused climate change, or to natural climatic variability.

RELATIONSHIP BETWEEN CLIMATE CHANGE AND NET MIGRATION

The model results do not indicate any significant relationship between average temperature, average precipitation and net migration (Table 8 in the Appendix). Clearer patterns emerge when focusing on indicators of temperature trends, although not in all model specifications. Similar to the work of Peri & Sasahara (2019), temperature trends[42] are negatively associated with net migration. The results also indicate that the relationship between temperature and net migration differs depending on population density in each territory. In particular, and consistently with the results for other African macro-regions, areas with higher variations in population density seem less negatively affected than areas with lower population density variations – in terms of net migration – by changes in temperature. When focusing on the heavy precipitation day index,[43] no significant association with net migration emerges.

Most of the countries in the Eastern African region are classified as low income, according to the 2015 World Bank classification, except for Kenya and Zambia – classified as lower-middle income countries – and Mauritius (upper-middle income country).[44] Increasing temperature tends to make territories less attractive, especially in the case of low-income countries in the macro region. The economy of the region largely depends on the agricultural sector. Indeed, the contribution of agriculture amounted to 23% of GDP in 2010-2015, although it gradually decreased since the mid-1980s. Similarly, the employment in the agricultural sector – despite decreasing over time – represented more than 70% from the 1990s to 2005-10 (World Bank 2020). National statistics indicate that maize – cultivated by half of the population in Sub-Saharan Africa – is the main food crop and agricultural product among poor smallholder farmers where it is considered as both cash and subsistence crop (Maggio et al. 2018). Maize productivity in Eastern Africa is low as compared to global standards, due to different reasons such as degrading soil characteristics and conditions of low and variable rainfall (Maggio et al. 2018), despite an increase in maize productivity over the last decades. According to Iizumi and Sakai's (2020) estimates, rice productivity has been increasing – from an average of 2.1 tonnes per hectare in 1985-1990 to 3.3 tonnes per hectare in 2010-2015. Similarly, wheat productivity has increased from 6.4 tonnes per hectare in 1985-1990 to 8 tonnes in 2010-2015. In the regression model, we consider the three main crops mentioned in the region, both individually and with the indicators of temperature and

42 Temperature trends, defined as in (Peri and Sasahara 2019) and estimated over 5-year intervals, serve to capture long-term changes in temperature, attenuating annual fluctuations and only isolating a pentennial trend. Since 1990-95, estimates indicate increasing temperature trends in Eastern Africa.

43 The index of heavy precipitation counts the number of days with more than 10mm of (daily) precipitation (Mistry, Malcolm Noshir 2019; Petroliagkis and Alessandrini 2021). This index is associated with the wet part of the precipitation distribution but does not necessarily describe extreme precipitation. Results seem to indicate a high variability of this indicator over time.

44 Since the group of upper-middle income countries include only Mauritius, the model is not estimated in this case due to the low number of observations.

extreme precipitation trends. Contrary to our expectations, crop yield production is not associated with net migration, except for the case of rice. Territories with increasing rice production tend to be more attractive. However, in these areas, the negative association between temperature and net migration continue to hold, even after taking into account rice productivity.

The model for Eastern Africa is not able to isolate other significant associations between other climate change slow-onset extreme and net migration. The lack of a clear association between net migration and climate change may derive from the confounding of climatic effects with the high numbers of refugees and people displaced by recurring conflicts. Eastern Africa has a history of conflict and violence and its low resilience to climate change is exacerbated by the interaction between multiple stressors in the region. To assess the link between climate change and instability, in Box 8 we examine a case study of Sudan and South Sudan, focusing on the complex climate change-conflict-migration nexus

BOX 8 The interplay between local conflict and climate change - the case of Sudan and South Sudan

dynamics, by focusing on Sudan and South Sudan – , which are listed among the world's countries most vulnerable to climate change.[45] The two countries are indeed experiencing increases in the frequency and severity of climate-related floods, droughts and epidemics (UNEP 2018), which have damaged livelihoods and displaced large numbers of the population. These climate emergencies occur within a fragile security environment, marked by devastating wars, severe underdevelopment and a low capacity to mitigate and adapt to the changing climate.

Through qualitative and quantitative methods (Assal 2006; Chavunduka and Bromley 2011; Leff 2009; Rowhani et al. 2012), evidence for Sudan and South Sudan suggests that variations in the geographical distribution of water and vegetative resources (De Juan 2015) and temperature anomalies (Maystadt et al. 2015) are positively associated with the risk of violent conflict. Militia attacks have been found to be more common in villages near floodplains (Olsson and Siba 2013), and the drier season with the reduced flow of water from Lake Victoria coincided with an increase in fighting between the Dinka and Nuer ethnic groups in the wetlands of Sudan (Sosnowski et al. 2016). Despite the growing attention on the climate-conflict nexus, this remains a complex and context-specific phenomenon that requires close attention, also in relation to population dynamics. Recent quantitative evidence generally supports rising temperatures as a driving force behind violence. Nevertheless, quantifying the mechanisms through which climate change may drive violence remains a major challenge for quantitative analysts.

In this box, we follow the growing strand of empirical studies looking at the climate change– conflict nexus at sub-national level. In particular, we explore whether local temperature and rainfall are related to the occurrence of lethal organised violence in Sudan and South Sudan, focusing on the period from 1989 to 2015. We use data at high geographical detail on conflict events, climate indicators and population dynamics. Moreover, the granularity of the data allows us to consider whether conflict events occur in urban or rural territories, to hence identify a rural-urban divide in some violence patterns.

Organised violence in Sudan and South Sudan is explored using data from the Uppsala Conflict Data Program (UCDP).[46]

The UCDP dataset has information on three different forms of events of organised violence: state-based armed conflicts, non-state armed conflicts, and unilateral violence.[47] During the 1989-2015 period, approximately 14% of the territories considered

45 See https://thinkhazard.org/en/.

46 Specifically, the source of the data is the UCDP Georeferenced Event Dataset (GED) Global version 21.1 (Högbladh 2021)

47 UCDP defines an 'event' as 'the incidence of the use of armed force by an organized actor against another organized actor,

TABLE 1. Organised violence in Sudan and South Sudan by degree of urbanisation, 1990, 2000, 2015
Source: Our elaboration based on UCDP Georeferenced Event Dataset and (Alessandrini et al. 2020). We distinguish the presence of (total) violence measured by a dummy variable equal to 1 if at least one conflict event occurs in a cell of 0.5 deg x 0.5 deg resolution and 0 otherwise and by type of violence, according to the degree of urbanisation of each territory. For the definition of rural territories, see the link https://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf.

	Rural territory	Urban territory
Total violence	40%	60%
State-based armed conflict	37%	63%
Non-state armed conflict	35%	65%
One-sided violence	43%	57%

in the analysis recorded at least one violent event related to any form of violence.[48]

Overall, urban territories appear as the most violent settings both when considering total violence and disaggregated figures for the different types of violence.[49] Indeed, 60% of the total violence was recorded in urban areas and 40% in rural areas. The higher concentration of violence in urban territories can be explained by the fact that urban areas are strategic targets of organised violence due to the greater concentration of economic and political resources and the larger population competing for them (Raleigh and Hegre 2009).

Sudan and South Sudan are classified as tropical areas, consisting mainly of tropical shrubland, tropical forest and tropical desert (FAO 2012), and characterised by highly variable precipitation. Figure 23 illustrates the temporal and geographic variation of temperature and precipitation anomalies,[50] conflict events and the associated casualties, for the years between 1989 and 2015, aggregated over 5-year averages.[51]

Overall, we observe an increase in positive temperature anomalies over time, with maximum values over the central and western parts of the macro-region, and in the proximity of the extremely arid and desert areas in northern Sudan. Data on rainfall suggests stronger negative anomalies, i.e. less rainfall than normal, in south-western South Sudan, and stronger positive anomalies (more rainfall than average) in southern Sudan.

From these maps, it is possible to graphically identify an overlap of areas affected by at least one conflict event with areas denoting regions of temperature anomalies and, to a lesser extent, with areas denoting regions of rainfall anomalies.[52] These overlaps are further corroborated by a series of regression models

or against civilians, resulting in at least one direct death in either the best, low or high estimate categories at a specific location and for a specific temporal duration' (Sundberg and Melander 2013). State-based conflicts are violent events involving a state against another state or against a non-state actor as an opposing organisation. Non-state armed conflicts include communal conflicts, electoral violence, ethnic clashes and conflicts between rebel organisations, thus involving formally or informally organised non-state actors. Unilateral violence refers to episodes of violence in which the state or a criminal organisation targets civilians. Violence against civilians is commonly used by the rebel group as a strategy with the aim of antagonizing the population against the government, demonstrating that it cannot protect them. For the government, targeting civilians aims to weaken the rebel support base (Hultman 2012).

48 Among the numerous violent events that have affected the countries in the last decades, to name only some examples, the fighting that broke out in the western region of Darfur in 2003 between SLM/SLA, JEM and the government led to the spread of hunger, disease and violence with thousands of civilians killed. Many of the state-based conflicts were concentrated in the north/south corridor of the country. After its independence in January 2011, South Sudan was involved in a conflict with Sudan over the Heglig/Panthou border area in 2012. The state violence also involved confrontation between the new regime and the SSDM/A and SSLM/A rebel groups supported by the Sudanese government. Unilateral violence and communal conflicts were, however, the dominant types during the reporting period, with most deaths occurring in clashes between communities and ethnic groups.

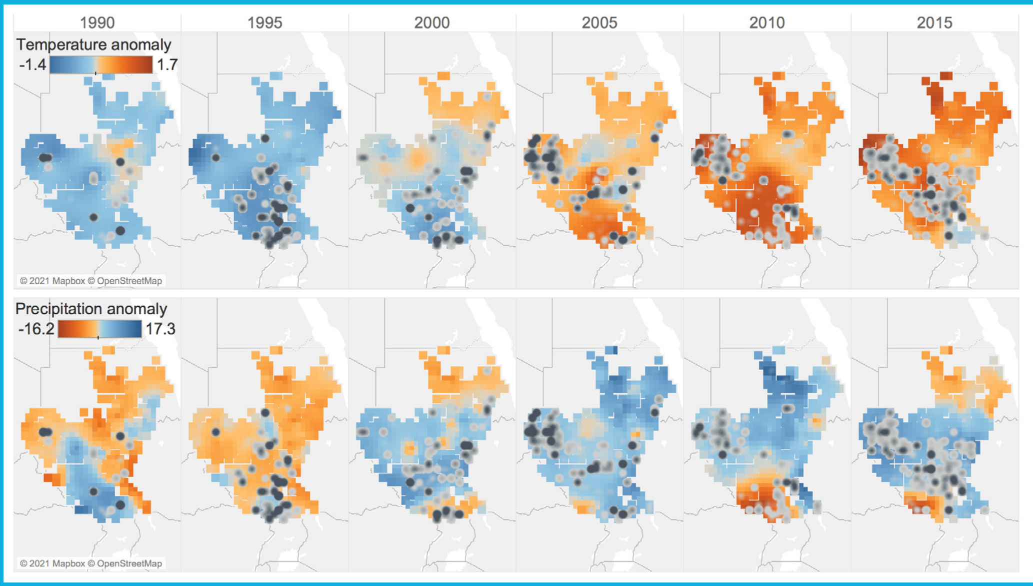
49 Similarly, the intensity of violence – measured by either the number of conflict events or the associated casualties – is higher in urban territories.

50 More precisely, a temperature (precipitation) anomaly is defined as the deviation of the temperature (precipitation) observed in one territory and time from the reference temperature (precipitation) value over the same territory measured as the average value over a 40-year period. For further details on the definition of anomalies and the data sources used, see (Petroliagkis and Alessandrini, 2021).

51 Each square on the map refers to a pixel of 0.5 deg x 0.5 deg resolution.. The available dataset covers the majority of the South Sudan territory (87%), while for Sudan around 58% is covered due to the presence of the desert.

52 A positive temperature anomaly means that the observed temperature was warmer than the average (red on the map), while a negative anomaly means that the observed temperature was colder than the average (blue on the map). For a detailed overview of these climate indicators, see (Petroliagkis and Alessandrini 2021)

FIGURE 23. Temperature and precipitation anomalies and density of deaths from organised violence (1990–2015).
Source: Our elaboration based on UCDP Georeferenced Event Dataset and Alessandrini et al. (2020). Notes: the grey shading represents the density of the absolute number of deaths.



which indicate positive associations with violence for temperature anomalies, extreme temperatures,[53] extreme precipitations, population density and net migration (see detailed results in Appendix). When considering rural and urban areas separately, results suggest that in rural areas only temperature and precipitation extremes tend to be associated with increasing local violence, while in urban areas the positive association is also present for temperature anomalies.

Net migration is positively associated with the risk of violence in the general model and the model for urban areas, albeit with a low coefficient.

Lastly, results confirm that areas already affected by violence tend to experience violent events over the years, thus suggesting a temporal dependence in the proliferation of violence.[54]

Overall, these results confirm, for Sudan and South Sudan, an association between the magnitude of positive climate anomalies and an increase in organised violence, in all its forms. The results are in line with the evidence that identifies temperature and precipitation as the climate events most associated with conflict risk. These events are also those that negatively affect agriculture, economic and human productivity, thus interacting in the relationship as a poverty multiplier (Schlenker and Roberts 2009; Lobell and Burke 2009, Hsiang 2010; Graff Zivin and Neidell 2013).

Despite the substantial presence of violence in both rural and urban areas, the analysis suggests a higher incidence of all types of armed violence in urban than in rural locations in line with studies indicating that more populated areas tend to be more prone to violence (Collier 2004; Raleigh and Hegre 2009). Finally, the positive relationship between net migration and violence shows that areas with conflicts also often experience higher immigration than emigration. This association supports the notion that climate-induced migration may increase competition for resources in the host areas and higher ethnic tensions with the host communities (van Baalen and Mobjörk 2018; Vesco et al. 2021).

53 We include the squared term of temperature (precipitation) anomalies to capture extreme temperature (precipitation) values and to estimate the potential non-linearity in the conflict-climate association. In addition, we tested the use of several extreme temperature indicators (Petroliagkis and Alessandrini 2021) and used a specific threshold for extreme temperatures. In all cases, we find a strong positive correlation between extreme and high temperatures and violence.

54 We replicate the models using the intensity of violence (instead of the occurrence/risk of violence), as displayed in column 7 of Table 11 in the Appendix. The intensity is measured as the number of events associated with any form of violence and observed in a territory. We confirm that temperature anomalies, high variability in precipitation, as well as demographic variables, correlate positively with more conflict events. The association between conflict events and temperature anomalies is confirmed to be the strongest link in our estimates.

MIDDLE AFRICA

OVERVIEW OF DEMOGRAPHIC AND CLIMATE CHANGE TRENDS IN THE REGION

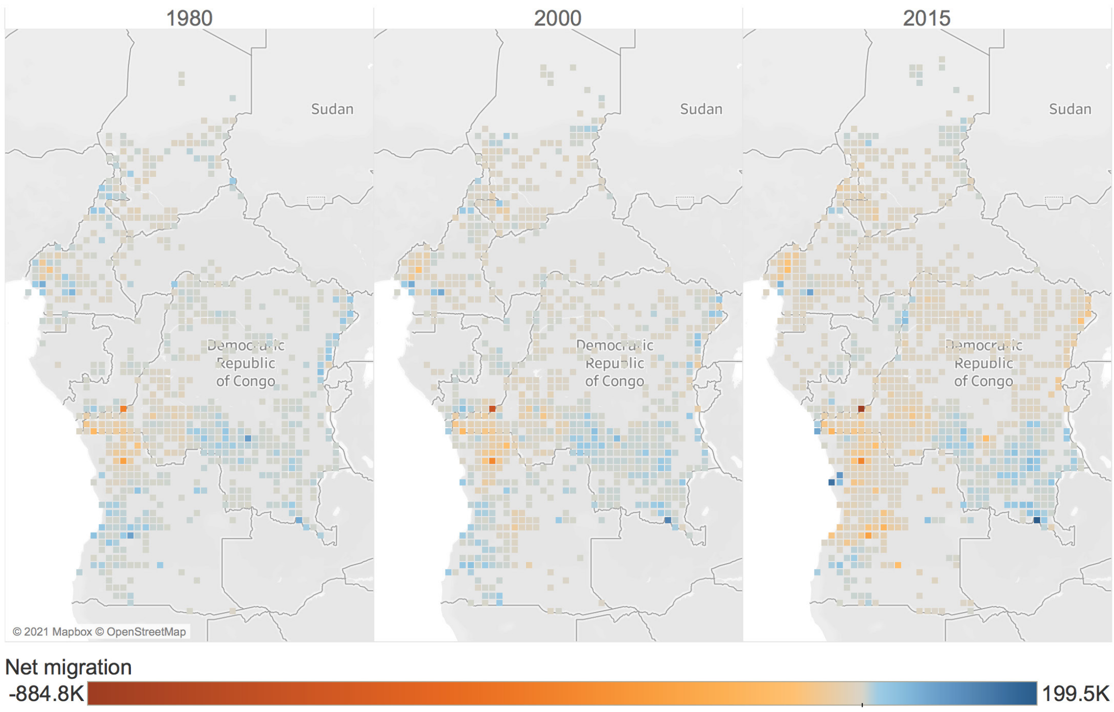
According to the UN World Population Prospects' estimates, population in Middle Africa[55] reached almost 180 million in 2020. It amounted to 45.9 million in 1975, thus experiencing the highest growth when compared to other regions in Africa – 236% relative change from 1975 to 2015, corresponding to an increase of 108 million. The share of Middle Africans living in another country fluctuated between 1.7% (in the 1970s and 1980s) and 2.7% in 1990. Since the 1960s, more than half of the immigrants in this region have been born in Africa. Indeed, most migration movements are directed from Middle Africa to neighbouring countries and they are mainly related to conflict and political instability – with the exception of Gabon, where is mostly related to work (Natale et al., 2018).
At the aggregate level, no clear patterns of net migration can be identified in Middle Africa over the period considered, except for Gabon which had a positive and increasing net migration rate since the 1970s (Lucas, 2015), Angola, Chad and Equatorial Guinea - also showing positive migration rates over the entire period. When considering net migration at high spatial resolution (Figure 24), a heterogeneous situation emerges. The highest net migration values in 2015 are estimated in the area of Luanda (Angola), in the western coastal part of the region – probably due to urbanisation processes. Across Middle Africa, the Democratic Republic of the Congo (southeast of the country) is the part with the highest positive net migration values. The areas with the lowest net migration values are Angola (Uige province) and the western part of Congo. Population density has increased over the time period considered. Indeed, the 5-year average population density in the cell was about 8.9 inhabitants per square kilometre in 1975-1980, it reached 15.82 inhabitants in 2000-2005 and is estimated at approximately 24 inhabitants per square kilometre in 2010-2015.

When considering climate change patterns, Figure 25 plots the SPEI in Middle Africa for three periods – 1975-1980, 1990-1995 and 2005-2010, with red values indicating extreme drought (or water deficits). As can be observed, high variability of water conditions, both in the geographical and time dimensions, emerges.
One climate change indicator used to capture extreme dry conditions is represented by the number of consecutive dry days (CDDs),[56] which is defined as the maximum number of days with precipitation less than 0.1 mm. In Middle Africa, the highest values for CDD are in (north-west) Cameroon, which also recorded the highest value of 220 consecutive dry days. On average, in Middle Africa, CDDs have fluctuated over time, decreasing from an average value of 35 consecutive dry days in 1975-1980 to 32 in 2005-2010, then increasing in the latest period to 34 days.

55 In the UN classification, Middle Africa includes Angola, Cameroon, the Central African Republic, Chad, the Democratic Republic of the Congo, Equatorial Guinea, Gabon, the Republic of Congo.

56 CDD can serve as a measure of extreme seasonal droughts. However, it should be noted that since drought is a complex phenomenon depending on various other factors besides lack of precipitation, the CDD parameter can only provide an indication for meteorological drought and should be interpreted in combination with other precipitation indices.

FIGURE 24. Net migration at high geographical resolution, Middle Africa.
Note: Estimates of 5-year net migration per 0.5 deg resolution cells - from (Alessandrini et al., 2020). Year refers to the end of the 5-year period.



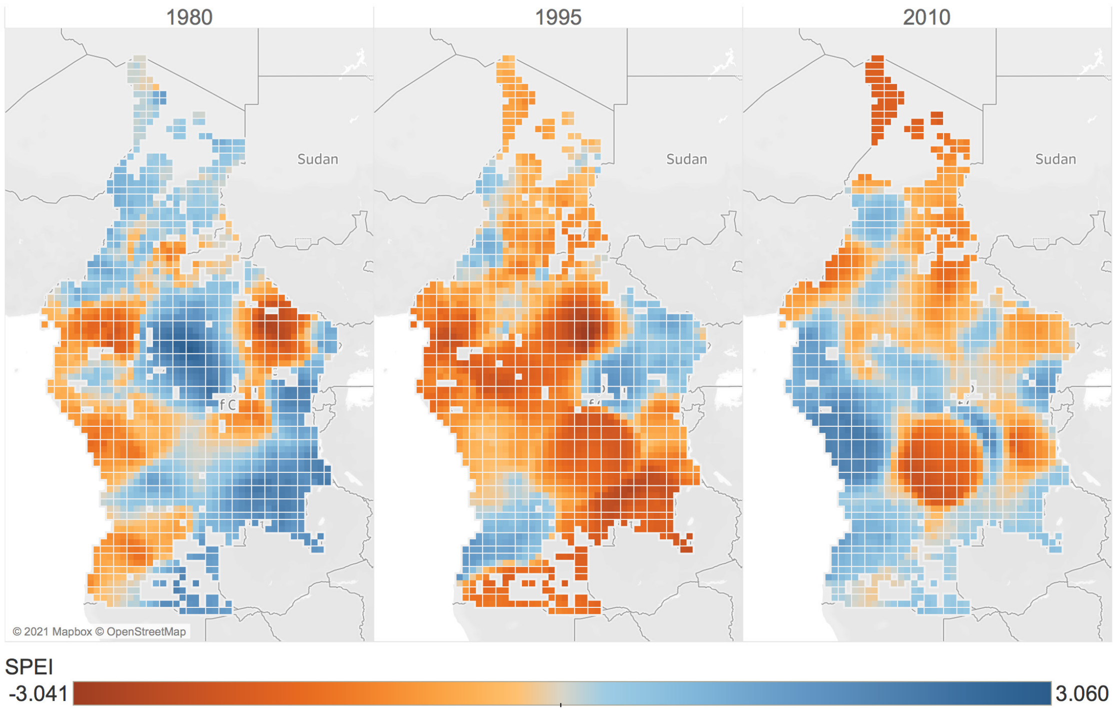
RELATIONSHIP BETWEEN CLIMATE CHANGE AND NET MIGRATION

The model results (reported in the Appendix, Table 9) suggest that neither average temperature nor average precipitation are associated with net migration. It is difficult to reconcile this finding with the existing knowledge on the climate change-migration nexus since no comprehensive analyses exist for the entire Middle Africa region.[57] Most of the studies for this region focus on areas where the interlinkages between climate change impacts and the changes in ecosystems, water, violence and migration are particularly relevant, such as the Lake Chad area – characterised by the shrinking of the lake, an important source of livelihoods (Pham-Duc et al. 2020) – and the Congo Basin forest. For instance, in the latter area, the forest ecosystem represents a vital source of livelihoods, goods and services (Sonwa et al. 2012); migration from north to south Cameroon – pushed by desertification (Brown et al. 2010) – tends to worsen the forest ecosystem and amplify the already negative impacts of climate change on the forest environment. This, in turn, exacerbates vulnerable sectors such as food, energy (fuelwood), health and water. Despite these case studies, the data coverage for Middle Africa has been determined to be insufficient to draw conclusions on temperature and precipitation trends. This could also explain why no comprehensive studies on the Middle Africa region exist.

When moving from average temperature and precipitation to extreme wetness conditions (precipitation) and drought, our regression models find evidence of an association

57 One exception is Njock (2010), who studied the main patterns of migration of fishing communities in coastal areas of Central and West Africa.

FIGURE 25. Mean values of SPEI for 1975-80, 1990-95, 2005-10.
Note: SPEI averaged over 5-years. Data source (Vicente-Serrano et al., 2010).



thereof between net migration and these slow-onset extreme events. In particular, the indicator of consecutive dry days (CDD) is negatively associated with net migration. This means that an increasing number of consecutive dry days tends to make territories less attractive. As is the case for the other African macro-regions, the negative impact of extreme conditions – measured using the CDD indicator – tends to be more pronounced in areas experiencing less population expansion. When exploring the association between net migration and drought severity through the SPEI,[58] territories experiencing more wet conditions have higher net migration (i.e., are more attractive) than territories with normal conditions.

As a next step, it is investigated whether there are differences in population responses to climate change - in terms of migration – between areas with different levels of economic development. It should be noted that the (5-year average) annual GDP growth rate in Middle Africa has been highly variable over the period considered: it was approximately 2-3% in the first periods considered, it dropped to -4% and recovered thereafter reaching its highest values in the 1990s and was attested at 2% in 2010-2015.

In the model, we group countries according to the 2015 World Bank income-level; the group of upper middle-income countries includes Angola, Gabon and Equatorial Guinea. Lower-middle income countries comprise Cameroon and the Republic of Congo while low-income countries include the Central African Republic, Democratic Republic of the Congo and Chad. The CDD indicator remains negatively associated with net migration in lower-middle income countries only.

Despite some heterogeneities between countries, Middle Africa relies heavily on the

58 We use the SPEI and classify the severity of drought following the definition and SPEI threshold values proposed by (Li et al. 2015). In particular, we have seven categories: extreme drought, severe drought, moderate drought, normal conditions, moderate wetness, severe wetness, and extreme wetness – and we use normal condition as the comparison category in the regression model.

agricultural sector. Indeed, the contribution of agriculture, forestry and fishing to the GDP is crucial in this region: it was around 27% in 1975-1980, increased in the late 1980s, then decreased to 20% in the latest period. Agriculture is also the most important source of livelihood, with the share of employment in agriculture above 60% throughout the period considered. According to Iizumi and Sakai's (2020) data, rice production per harvested area decreased in Middle Africa from the late 1980s until 2010, then increased thereafter (5-year average is 1.6 tonnes per hectare for each grid cell in 1985-90, down to 1.2 in 2005-10). Maize production increased in Middle Africa since the 1980s (5-year average was about 1 tonne per hectare for each grid cell in 1980-1985, up to 1.3 tonnes in 2010-2015). It should be mentioned that when including consecutive dry days in the model specifications together with crops yield production, the indicator extreme temperature loses significance. This could be explained by the fact that that crop production is significantly correlated with the CDD indicator, thus making it difficult to disentangle their relationships with the net migration.

SOUTHERN AFRICA

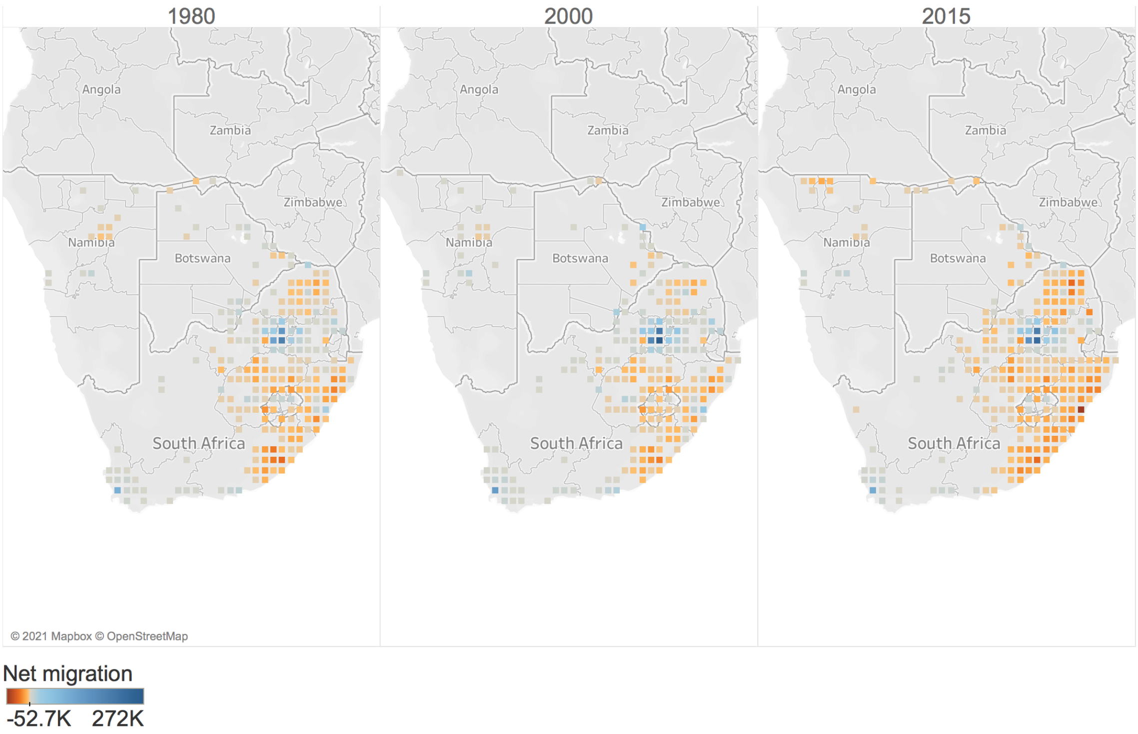
OVERVIEW OF DEMOGRAPHIC AND CLIMATE CHANGE TRENDS IN THE REGION

According to the UN World Population Prospect's estimates, population in Southern Africa[59] was about 29 million in 1975 and grew to 67.5 million in 2020. Approximately 2.4% of Southern Africans live in another country and this share has fluctuated around 2% throughout the period considered. Two main migration patterns characterize the region. The fisr is, intra-regional migration from other Southern African countries to neighbouring countries, with the Republic of South Africa as the main destination – especially since the late 1990s. The second pattern involves permanent migration to overseas destinations (Natale et al. 2018).
The UN Population Division estimates indicate that the net migration rate for the region fluctuated around zero from the mid-1970s to the late-1980s and peaked in 1990-1995. When focusing on net migration at high geographical resolution, the picture becomes more complex. In Figure 26, positive net migration can be noted in the areas of Johannesburg, Pretoria and Cape Town. On average, population density grew from 12 inhabitants per square kilometre in 1975-1980 to 23 inhabitants per square kilometre in 2010-2015. Whether such a growing population density should be attributed to urbanisation processes – fostered by mobility from rural to urban areas – or to population natural increase is still debated (Menashe-Oren and Bocquier 2021).

The climatic classification of the Southern Africa region is characterised by considerable variability comprising a wide range of both sub-tropical and tropical types of climates (FAO, 2012). Southern Africa's climate varies from arid to humid subtropical regions. It is influenced by topography and large-scale seasonal atmospheric patterns, such as sea surface temperatures in the Indian Ocean (through the Agulhas current bringing

59 According to the UN geographical classification, Southern Africa includes Botswana, Lesotho, Namibia, Eswatini and the Republic of South Africa.

FIGURE 26. Net migration at high geographical resolution, Southern Africa.
Note: Estimates of 5-year net migration per 0.5 deg resolution cells - from (Alessandrini et al., 2020). Year refers to the end of the 5-year period.

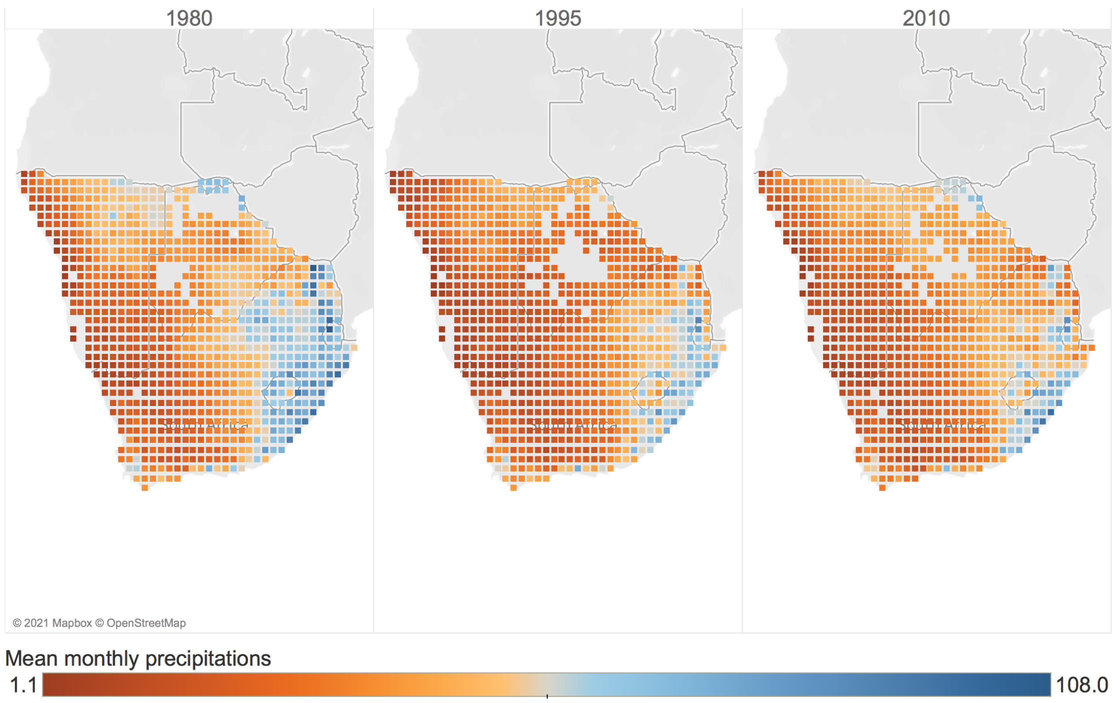


additional moisture to the east coast) and the South Atlantic Ocean (through the Benguela current).[60] Rainfall is mainly driven by the migration of the Intertropical Convergence Zone. Most of the region's rainfall comes during the summer months (November–March) apart from South Africa. Temperatures vary significantly, with the highest temperatures recorded in the Lesotho, South Africa and Zimbabwe highlands, Kalahari Desert (>40°C) and coastal regions of Mozambique.
]
Figure 27 shows monthly precipitation averaged over 5-years. The highest values can be observed in the eastern coastal territories of South Africa. The median of the precipitation indicator has varied over time – from approximately 39 mm in 1975-1980 to the lowest value of about 30 mm in 1990-1995 – and fluctuated around 31 mm thereafter.
One of the indicators for extreme temperatures included in the regression model is the median of the daily temperature range.[61] In Southern Africa this indicator has remained almost constant around 15° C with two peaks (local maximum values) in 1990-1995 (16° C) and 2005-2010 (16° C).

RELATIONSHIP BETWEEN CLIMATE CHANGE AND NET MIGRATION

60 https://pdf.usaid.gov/pdf_docs/pa00mtz6.pdf
61 Daily temperature range (5-year average) is defined as the difference between the daily maximum and minimum temperature of atmospheric air. Daily temperature range is more informative than average temperature since it is influenced by changes of either minimum temperature or maximum temperature, or both. Higher (lower) values of daily temperature ranges indicate that populations are exposed to more (less) temperature variability within the day which could affect agricultural production (Petroliagkis and Alessandrini 2021).

FIGURE 27. Mean monthly precipitation for 1975-80, 1990-95 and 2005-10.
Note: Mean monthly precipitation, averaged over 5-years. Details on the indicator are in Petroliagkis & Alessandrini, 2021).



As an initial step, the model aims at isolating the relationship between average precipitation, average temperature and net migration. It then moves to extreme climatic events, focusing on extreme temperatures and using the daily temperature range indicator (all the model results are reported in the Appendix, Table 10). First, the analysis suggests that monthly precipitation is negatively associated with net migration, consistently with previous country-level studies (Mastrorillo et al. 2016).[62] This means that territories experiencing increasing rainfall tend to lose population or become less attractive (either because they attract fewer immigrants or do not retain emigrants).[63] Furthermore, the model seeks evidence of the interlinkages between demographic dynamics and climate change. To do so, it investigates whether there are any interactions between precipitation and population density. This is indeed the case; results suggest that an increase in precipitation would make territories less attractive, especially those experiencing lower increases in population density. In line with the previous chapter, this would indicate that climate change is superimposed on prevailing underlying demographic processes. In particular, climate change is incentivising emigration from areas already subject to low population growth and not hindering immigration where population density is increasing. As recently noted by Mpandeli et al. (2020) in an analysis for Southern Africa, win-win strategies should be fostered for more and less densely populated areas . In other words, the authors envisage the so-called *'nexus planning perspective'* that considers

62 In particular, using a gravity model of migration for the Republic of South Africa for the periods 1997-2001 and 2011-2007, Mastrorillo et al. find that positive and negative rainfall excesses act as a push effect and boost out-migration.
63 It should be noted that net migration is defined as the balance (or difference) between immigration and emigration. Hence, it is not possible to distinguish whether a change in net migration is due to a change in immigration, emigration or both. See Box 4 for details and further explanations on the interpretation of the net migration.

the interlinkages between water, food and socio-economic conditions to tackle the issues related to climate change in Southern Africa. In particular, areas attracting migrants should be prepared and resilient to host them and should be transformed climate change adaptation centres. In parallel, in less densely populated areas, both climate mitigation and adaptation strategies should address the challenges related to livelihoods, income, water, energy and food security issues.

In comparison to Mastrorillo et al. (2016) – who find that increasing temperature tends to enhance out-migration – no association between average temperature and net migration is found. Hence, it is investigated whether extreme temperatures are associated with net migration. Results indeed show that the daily temperature range is negatively associated with net migration and agriculture may be the channel to explain this pattern. In reality, territories with an increasing daily temperature range may be less attractive, in terms of net migration, because of the negative response of crop yields to increased daily ranges. As noted by Lobell and Field (2007), crops such as maize tend to negatively respond to an increased daily temperature range 'which likely results from greater water and heat stress during hot days', production variability and economic stability (Petroliagkis and Alessandrini 2021). The negative response of crops may, in turn, affect food security – an issue particularly evident in Namibia, – a country facing 'lack of food access and dietary diversity' which, in turn, affects incomes and food pricing (Pendleton et al. 2014).

Overall, in the Southern African region the importance of agriculture has reduced over time: the share of employment in the agricultural sector as the per cent of total employment has declined from 23% (the 5-year average in 1990-1995) to 14% in 2010-2015. Similarly, the sectoral contribution of agriculture, forestry and fishing to the value added has decreased from 7% of GDP in 1980-1985 to 3.6% in 2010-2015, despite some differences existing between countries in the region. To check whether the results of the model are confirmed once considering agricultural productivity, estimates of crop yield production per harvested area at high spatial resolution[64] are included in the model. In particular, we use maize and wheat. When focusing on South Africa, in particular, maize is the most important grain crops which constitutes the main staple food of the population and the major contributor to the gross value of field crops in recent years, followed by sugar and wheat. When taking into account maize or wheat productivity in the model, precipitation and daily temperature range continue to be negatively associated with net migration.[65]

The economy of the Southern Africa region is quite heterogeneous (Ahmed and Cruz 2016), with Eswatini and Lesotho classified as lower-middle income countries and Botswana, Namibia and South Africa as upper-middle income countries (WB, 2015 classification). The GDP growth rate in the region has increased from the 1990s to 2000-05 from about 2% to 4.4%, then decreased in the period 2010-15 to 1.4%. To check if the relationship between climate change indicators and net migration differs across countries with different levels of economic development, the analysis is carried-out for the two groups

64 Productivity is expressed in tonnes per hectare for each grid cell. The source of the data is (Iizumi & Sakai, 2020).

65 It should be noted that these model specifications may be plagued by multi-collinearity issues (indeed, all the following correlations are statistically significant: the correlation between maize yield and precipitation is 0.59; between maize and daily temperature range is -0.2; between wheat and precipitation 0.37; between wheat and daily temperature range -0.4). Another caveat is that Iizumi and Sakai's data (2020) of production per unit harvested area have missing observations, hence the analysis is not able to cover all Southern African territories.

of lower-middle income and upper-middle income countries separately. The negative association between precipitation and net migration remains significant only in upper-middle income countries – while it loses significance in lower-middle income countries. This seems to confirm that the response of population, in terms of net migration, to climate change is related to economic development. Populations having the means to migrate in upper middle-income countries tend to adapt to changing precipitations by migrating. Instead, in lower middle-income countries, the relationship is not significant and this may be interpreted as a sing of trapped population.

CONCLUSION

The pieces of evidence provided in this chapter suggest that, when looking at the entire African continent, no clear relations between climate change and migration emerge. However, when focusing on the climate change-migration nexus in each African macro-region separately or in smaller geographical areas the following relationships, although scattered, can be identified. In Northern Africa, heat waves, and especially heat wave duration and frequency, are related to changing net migration patterns. Increasing duration and frequency of heat waves tend to make territories in the region less attractive and trigger population losses.In Southern Africa, precipitation and extreme temperature are negatively associated with net migration. The pieces of evidence for Middle Africa suggest that conditions related to extreme events (such as prolonged periods of dry days) are negatively associated with net migration. In Eastern Africa, the relationship between increasing temperature and net migration does not appear as clear-cut. Moreover, our modelling approach of the climate change-migration nexus for the Western African region does not provide any clear results. As highlighted in the previous chapter, this region is among the most vulnerable to climate change. This could hint that, overall, in Western Africa, populations have been trapped. When focusing on smaller areas in Sahel within the region, the model suggests a negative association between extreme temperature, drought and net migration.

The fact that the relationships between climate change and migration identified in this chapter appear scattered and diversified across regions should not come as a surprise. Indeed, the climate change-migration nexus depends on the local context and factors such as the resilience of the communities and the possible climate adaptation strategies alternative to the migration option. Moreover, the pieces of evidence provided in this chapter refer to long-term migration patterns and their relationship with variations in temperature or extreme temperature, precipitation and slow onset events such as drought. Since the analysis is based on data with 5-year frequency, it is not possible to capture neither short-term response or adaptation to climate change nor sudden displacements.

This chapter has tried to assess how climate change is related to and mediated by other migration drivers. For instance, in Northern Africa, the analysis has shown how demographic factors and climatic events like heat waves jointly influences migration. Specifically, the negative relation between heat waves and migration tends to be less pronounced in territories where population is expanding. This suggests that the level of urbanisation and/or population growth are the prevailing factors which influence out-migration, while climate change impacts appear less important in such demographic processes. The analyses have also confirmed that migration is an adaptation strategy to climate change in those contexts where population have the economic means to migrate. This is the case, for instance, of Southern Africa, where the relationship between precipitation and migration holds only in the group of upper-middle income countries of the region.

Conflicts, political instability and violence, are also linked to local climatic conditions. The case study of Sudan and South Sudan has indeed indicated increasing temperature and precipitation as climate events most associated with conflict risk, especially in urban territories. Areas with conflicts are also often experiencing higher immigration than emigration. This association support the notion that climate-induced migration may increase competition for resources in the host areas and higher ethnic tensions with the host communities. Finally, in Western Africa, an association between extreme temperatures, drought severity and displacement emerges when focusing on the specific context of the Sahel region, with its already established migration patterns often linked to recurrent food shortages.

A general consideration stemming from the analyses in this chapter is that the formulation of climate adaptation policies should not overlook demographic dynamics and urbanisation processes – which emerge as the main migration drivers especially in the Northern African region – and are, partly, mediated by climate change. Overall, the strong interlinkages between climate change and the other migration drivers support the implementation of comprehensive approaches and strategies that consider agriculture, vulnerability of rural areas, water management to address extreme dry conditions, as well as the necessity to make populated areas as organized centres of adaptation to climate change.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4. CLIMATE CHANGE PERCEPTION AND MIGRATION ASPIRATIONS IN AFRICA

Sona KALANTARYAN

INTRODUCTION

This chapter complements the geographical and macro perspective of the previous analyses – which have looked at population exposure, vulnerability and migration – with the individual perspective. In particular, the chapter focuses on what Africans think nowadays about climate change. Moving from population as a whole to individual perceptions is essential to expand our understanding of the complex concerns and motivations that – in addition to contextual demographic and socio-economic characteristics – could drive the decisions to migrate in the context of climate change.

The chapter first maps individual perceptions on climate change and its impacts. It then seeks to understand whether and how these perceptions are related to the individual desire to move abroad. Furthermore, it looks at the individual dimensions of vulnerability to climate change and their relationship with migration desire. As described in Chapter 2, vulnerability should be understood as the population's capacity to cope with the adverse impacts of climate change. Mirroring the previous macro-level analysis of population vulnerability, the focus here is on various dimensions of individual vulnerability to climate change: living in rural areas, with secondary-level education or lower, being employed in the agricultural sector and facing economic hardships.

The analysis is based on data from the 2016-2018 wave of the Afrobarometer public opinion survey.[66] This survey includes a broad set of questions related to climate change perceptions. For instance, survey respondents are asked whether climate conditions for agricultural production have changed when compared to the previous decade. Moreover, they are asked about their awareness of climate change, its meaning and causes, its impacts in their country and whether ordinary people can take actions to stop it. The knowledge of climate change perceptions in Africa – still recent and quite limited (Steynor et al. 2020) is a precious source of information on individual concerns and perceived risks and impacts of climate change.

In addition to climate change perceptions, the Afrobarometer survey includes questions on migration aspirations covering 34 African countries.[67] More specifically, survey

66 The Afrobarometer is a pan-African series of national public attitude surveys on democracy, governance and society. The survey is based on nationally representative samples of 1 200 observations per country. This ensures comparability between countries and over time. For more information, see the dedicated website here: https://afrobarometer.org/data.

67 For more information on the questions used here, see Table 12 in the Appendix.

respondents are asked whether they have considered moving to another country. This question, typically asked in public opinion surveys, is used by social scientists to understand how migration decisions are formed and to distinguish between the desire to move abroad, the concrete possibilities and the capabilities to do so (Carling and Collins 2017; de Haas 2010). How to interpret questions on migration aspirations as well as the determinants of the individual desire to migrate have been extensively studied. In this chapter, we focus on the possible influence of climate change perceptions on migration aspirations.

The rest of the chapter is structured as follows. Firstly, it examines the variation in the awareness and perception of climate change as well as migration aspirations across African countries. It then explores the relationship between climate change perception and migration aspirations at country and individual level. In the latter, in particular, the focus is on the individual dimensions of vulnerability and their relationship with the individual desire to migrate.

WHAT DO AFRICANS THINK ABOUT CLIMATE CHANGE?

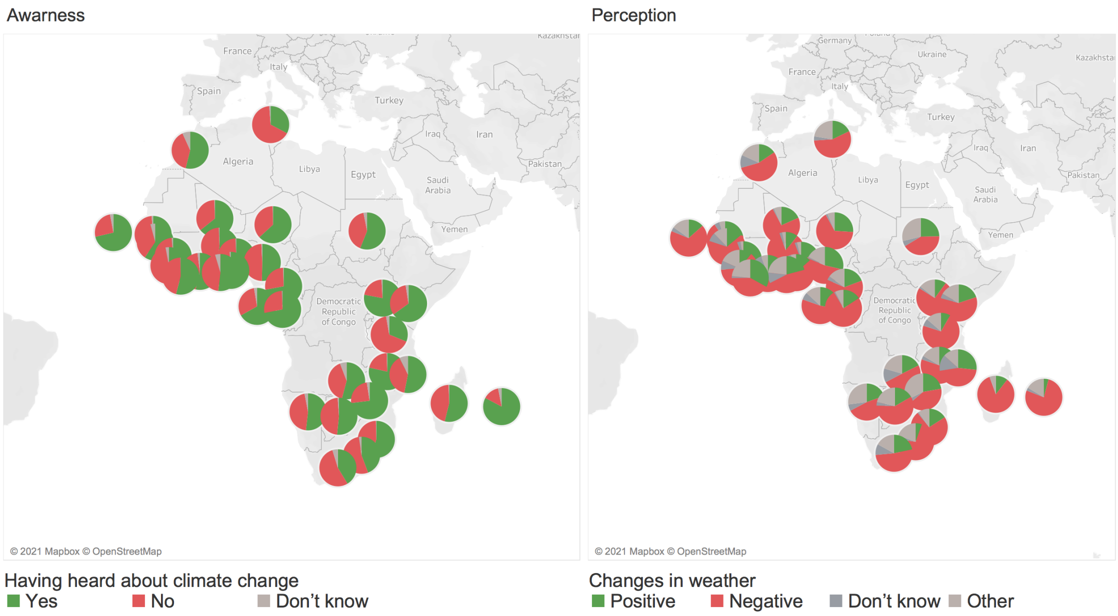
The Afrobarometer survey reveals the existence of disparities in the awareness of climate change and the perception of its impact across and within African countries. Overall, more than half of the respondents (58%) have heard about climate change. However, there is considerable variation between the 34 countries under consideration. The percentage of those who have heard about climate change is highest in Middle Africa (72%). At country level, in 8 out of 34 countries, at least two thirds of the respondents have heard about climate change. The figure is as high as 83% in Mauritius, followed by Malawi (79%), Uganda (78%), Zimbabwe (73%), Cameroon and Gabon (72% each), Cabo Verde (71%) and São Tomé and Príncipe (67%). On the contrary, in five countries, less than half of the respondents have heard about climate change. The lowest figures are observed for Tanzania (31%) and Tunisia (33%), followed by Sierra Leone and South Africa (41% each) and Lesotho (44%).

The awareness of climate change is systematically higher among those residing in urban areas. Except for Benin, in all countries included in the sample, the figures are higher for urban areas; the largest positive gap is observed in Botswana (29 pp), Burkina Faso (25 pp), Morocco (23 pp) and Lesotho (21 pp)..

Among those who have heard about climate change, 63% associate it with negative changes in the weather, while only 17% with positive ones; some 15% associate it with other changes in weather patterns. Furthermore, in this case the percentage of those who see climate change as negative changes in the weather varies significantly across the continent. The negative perception of climate change is most widespread in Middle Africa, where the percentage of those who have heard about climate change is also the highest. In 7 out of 34 countries, more than three quarters of the respondents associate climate change with negative changes in the weather. In Burkina Faso and Madagascar, the figure reaches 84%. In only 6 out of 34 countries – namely Zimbabwe, Liberia, Sudan, Mozambique, Ghana and Namibia – less than half of the respondents associate climate change with negative changes in the weather.

FIGURE 28. Population by awareness (having heard) about climate change and its perceived meaning (positive or negative)

Source: JRC elaboration of Afrobarometer survey data. *Notes:* The figure on the left is based on the whole sample of observation. The figure on the right on the subsample of those who have heard about climate change.



Contrary to the divide observed for the awareness of climate change, in the case of perceptions on changes in the weather, there is no difference between rural (63%) and urban (64%) areas. Moreover, the gap observed between urban and rural territories is not necessarily positive. It is positive (i.e., figures for urban are higher than for rural) in 19 countries, with a percentage point difference above 10 in eight countries and the greatest difference observed in Guinea (17 pp). There is no gap, in line with pan-African figures, in three countries – namely Benin, Malawi and Nigeria. The gap is negative (i.e., figures for urban are lower than for rural) in 12 countries, with the largest gap observed in Niger (7 pp).

The survey goes beyond measuring the awareness and perceived meaning of climate change. It contains questions related to its perceived impact on agricultural production and on life in the country (Figure 29). At aggregate level, around half (48%) of the respondents think that the climate conditions for agricultural production in their area over the last 10 years either got worse (25%) or much worse (23%). This is much higher than the percentage of those who think that the change was positive: better (16%) or much better (4%). Only 17% of the respondents think that the climate conditions stayed about the same. The percentage of those who think that the change was negative is higher in rural (54%) compared to urban (42%) areas. At country level, the top five countries with the most negative perception of changes in climate conditions are Uganda (85%), Malawi (81%), Lesotho (79%), Madagascar (74%) and Cabo Verde (71%).

More than one-third of the respondents (37%) think that climate change negatively affects life in the country (Figure 30). Only 10% are of the opposite opinion. In rural areas, the percentage of those thinking that climate change negatively affects life is higher

(35%) than urban areas (29%). In none of the countries included in the Afrobarometer sample is the share of those who consider the impact to be positive higher than of those who think it is negative. Moreover, in this case Uganda is the country with the highest figures on negative effect (73%), and Malawi (72%), together with Cabo Verde (59%) is still among the top five countries. The three countries where the figures are relatively low (less than one quarter of the respondents) are Morocco (23%), Tunisia (22%) and Mozambique (19%).

FIGURE 29. Climate conditions for agricultural production in your area compared to ten years ago
Source: JRC elaboration of Afrobarometer survey data.

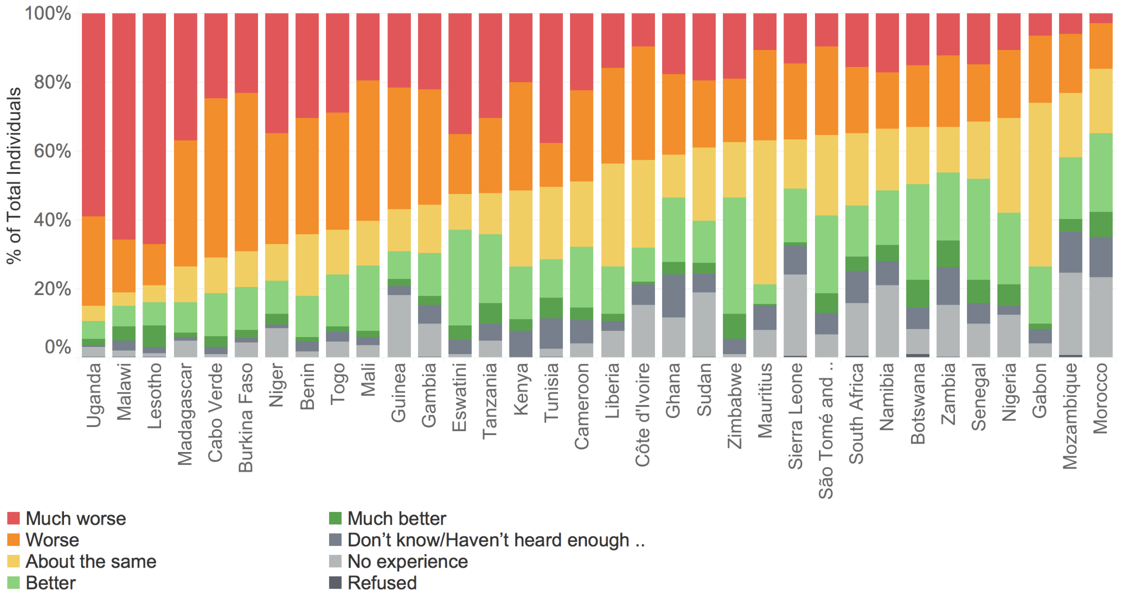
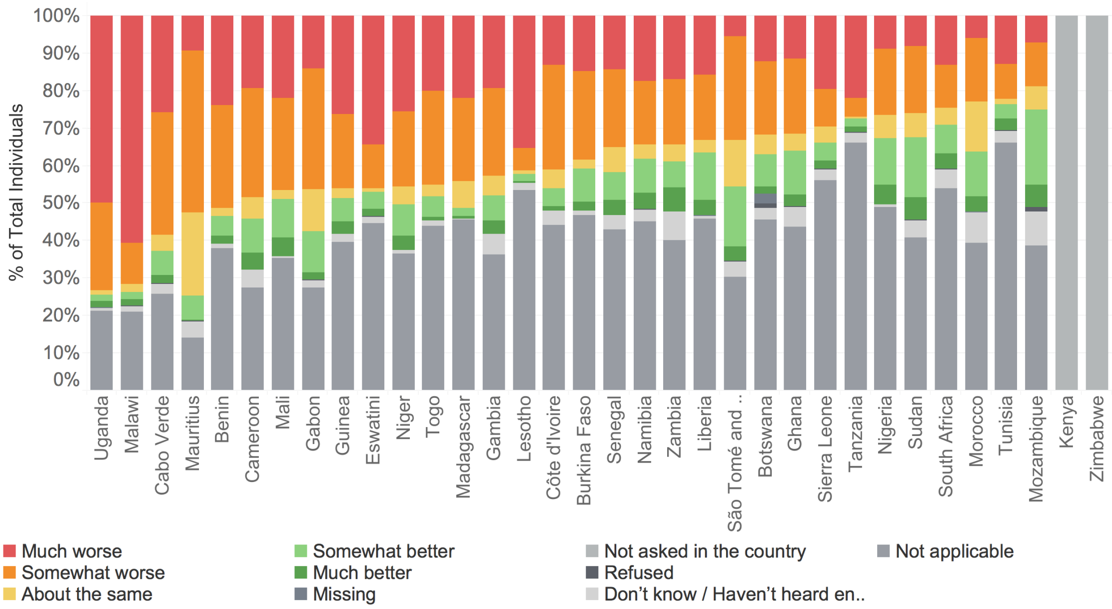


FIGURE 30. Climate change is making life in the country better or worse
Source: JRC elaboration of Afrobarometer survey data. *Note:* In Kenya and Zimbabwe this question was not asked.



MIGRATION ASPIRATIONS

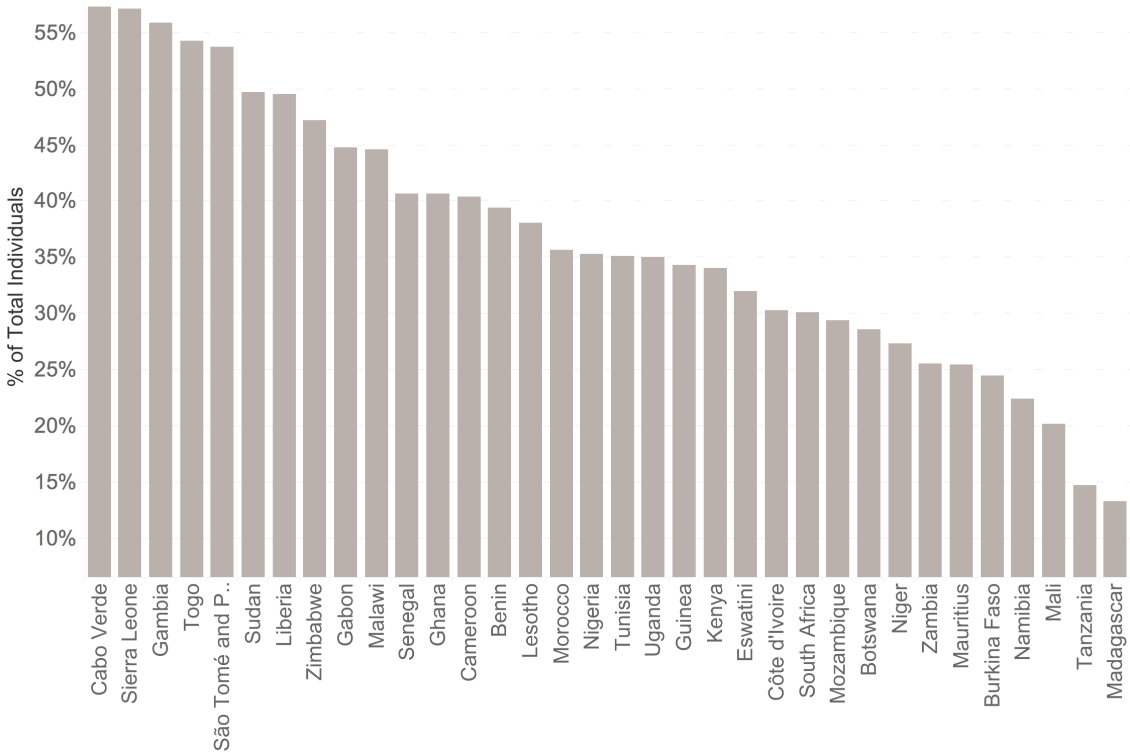
The relationship between migration aspirations – i.e., the desire to move to another country – and the actual move has been investigated for several decades (De Jong et al. 1985; De Groot et al. 2011; Carling and Schewel 2018; Migali and Scipioni 2018). The self-reported migration aspirations available through public opinion surveys (such as, for instance, the Gallup World Poll) are widely used by social scientists to identify the individual sociodemographic individual characteristics (e.g. age, sex, education, etc.) and local factors (e.g. economic, political, environmental) shaping migration aspirations (Cai at al. 2014; Docquier et al. 2014; De Jong, 2000). It is well documented that only a small fraction of those who express their willingness to migrate plan and prepare to do so indicating that only very few intentions result in a real move (Belmonte et al. 2020). The existing studies rely on the assumption that those who express a willingness to emigrate have the greatest incentive to leave the country and might do so in the future if such an opportunity arises. While the expectations of future conditions and opportunities shaping the intentions to migrate may not be realised, it is however these perceptions that are most critical at the time the migration decision is made (Adger et al. 2021).
For the whole sample of countries covered by Afrobarometer, more than one third of individuals (37%) considered emigrating (moving to another country to live)[68] (Figure 31). In four countries more than half of the adult population wishes to migrate. The highest figures are observed for Cabo Verde and Sierra Leone (57% each). The percentage of those who wish to migrate is the lowest in Madagascar (15%), followed by Tanzania (13%). However, these aspirations do not necessarily turn into an actual move. Indeed, only 14% of individuals prepare for the move. More than half (60%) of those who are willing to emigrate are not currently making any specific plans or preparations – less than one third (30%) are actually planning to move in the next year or two, though not yet making preparations, and only 9% are currently making preparations to move (e.g. like getting a visa).

'Finding work' (44%), 'Economic hardship' (22%) and 'Poverty' (7%) are the most popular answers given by respondents to indicate the most important reasons for considering leaving the country.[69] In fact, environmental factors are at the bottom of the list of the most important reasons to migrate. Indeed, only 0.16% of those who would like to emigrate report natural disasters (such as drought, disease outbreaks, flooding, etc.) as the most important reason for considering moving from the country. This finding is consistent with other studies looking at reasons making people migrate (Sakdapolrak et al. 2014; Etzold et al. 2014; Koubi et al. 2016). Little difference is observed between responses given by those living in rural and urban areas: 0.20% and 0.23%, respectively. The figures are slightly higher in Kenya (0.81%), Benin (0.71%), Nigeria (0.68%) and Burkina Faso (0.57%), yet always remaining below 1%.

68 Belmonte et al. (2020) look at the intentions to migrate of young people in Africa and Europe and claim that the large difference between intentions and preparations observed for Africa potentially reflect the unavailability of resources or other constraints limiting the mobility of the African youth.

69 The respondents were asked the following question: 'There are several reasons why people leave their home to live in another country for an extended period of time. What about you? What is the most important reason why you would consider moving from the country?'.

FIGURE 31. Percentage of population who consider emigrating.
Source: JRC elaboration of Afrobarometer survey data.



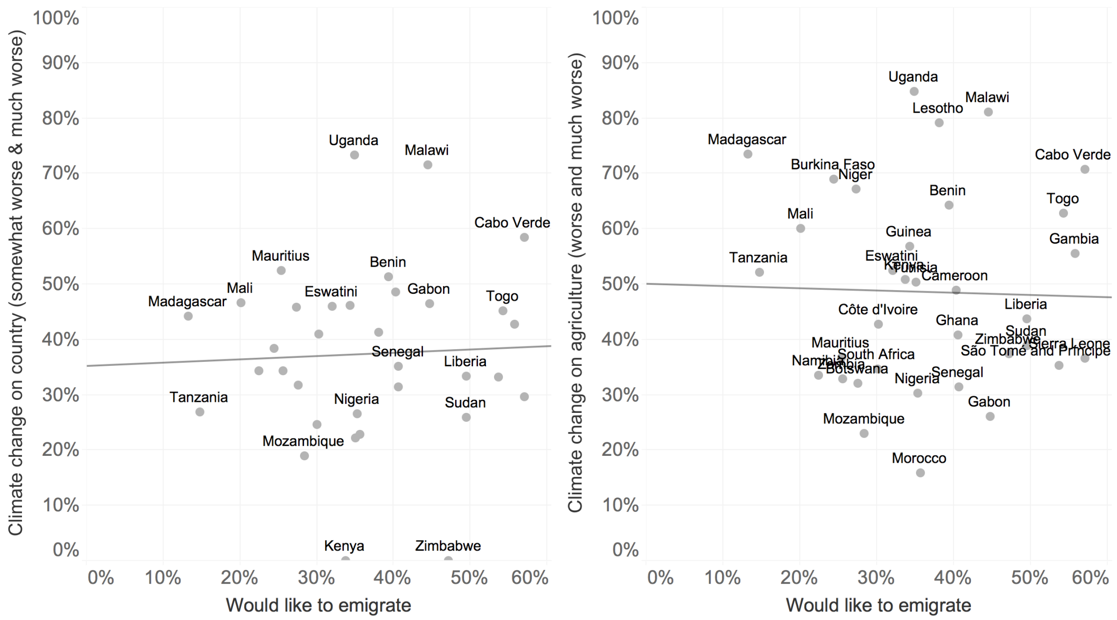
THE RELATIONSHIP BETWEEN CLIMATE CHANGE PERCEPTION AND MIGRATION ASPIRATIONS

The above figures reveal the existing disparities between African countries both in climate change perception and migration aspirations. This section examines these two sets of questions jointly. In other words, it seeks to understand whether having a negative perception of climate change tends to be associated with a higher desire to migrate (than having positive perceptions of the climate). The analysis is first carried out at country level (i.e., by considering figures aggregate by country), then at individual level.

The relationship between the negative perception of climate change and migration aspirations at country level plotted in Figure 32 does not reveal any clear pattern. There are countries like Morocco where both the aspirations to migrate and negative perceptions of climate change are relatively low. Instead, Uganda has a level of migration aspirations similar to Morocco but a very negative perception of climate change. In Cabo Verde both are high. In Burkina Faso, the percentage of those who wish to migrate is low but the perception of the climate is fairly negative.

The ambiguity of the relationship between climate change perceptions and migration aspirations at country level should not come as a surprise. Understandably, climate change is only one of many factors shaping an individual desire to migrate. Moreover, climate change is expected not to directly impact the decision to migrate. Climate change may influence living conditions, such as agricultural production and an increase in food prices, and these factors, in turn, would make people look for employment

FIGURE 32. Climate change perceptions and migration aspirations
Source: JRC elaboration of Afrobarometer survey data.



opportunities or better living conditions elsewhere. Unfolding this complexity requires a more sophisticated approach, such as a multivariate regression analysis which enables estimating the association between climate change perception and migration aspiration while controlling for variations attributable to the individual demographic and socio-economic characteristics of the respondents.

In particular, we estimate the association between having a negative perception of climate change and the desire to migrate.[70] We control for individual demographic characteristics of the survey respondents, (i.e., age and gender) and for a wide set of individual socio-economic conditions, such as labour market status (employed, unemployed, inactive) and the employment sector (agriculture versus others). As mentioned above, we consider dimensions of vulnerability similar to those included in the assessment of population vulnerability to climate change (see Chapter 2). More specifically, we consider the individual place of residence (urban or rural areas), the individual level of education (below and above secondary level), employment in the agricultural sector (vs. other sectors). The Afrobarometer has information on whether the respondents have experienced food or cash problems or have been deprived of basic necessities during the previous year (more than several times over the last year). Again, to mirror the analysis of population vulnerability, these questions are used as proxies – at individual level – of poverty and economic hardships.
The sample included in the analysis is gender-balanced with an average age equal to 37 (the descriptive statistics are reported in the Appendix). Slightly more than half (55%) of the respondents reside in rural areas. Half have an education level below secondary. When looking at the labour market characteristics, 36% of surveyed individuals are employed,

70 For perceptions on climate change, we consider the questions on: (a) 'climate country', i.e. whether climate change is making life in the country worse or much worse; (b) 'climate agriculture', i.e. whether climate conditions for agricultural production in the area have gotten worse over the last 10 years. The question on migration aspirations enquires as to whether the individual has considered moving to another country. The empirical model is presented in the Appendix.

27% unemployed and the rest are inactive. One third of the respondents (or the head of their households) are either employed in the agricultural sector or were employed before becoming unemployed, retired or disabled. Three quarters of the respondents have gone without basic necessities (food, water, medical care, cooking fuel or cash) several times over the past year. Two thirds (65%) of individuals have gone without a cash income and one third (32%) without food at least several times (more than twice) over the past year.

Figure 33 visualises the results[71] of regression analysis by reporting the point estimates (marginal effects) and the corresponding confidence intervals[72] for the entire sample and main African regions. The upper panel refers to the model specification, which includes perceptions of the effects of climate change in the country.[73] The lower panel refers to the model specification using the perceived impact of climate change on agriculture.[74] In both specifications and across all regions, the results suggest that individuals expressing the desire to migrate are more likely to be young, male (except in Middle Africa), reside in urban areas, to be active in the labour market (either employed or unemployed) and with at least secondary-level education. In all regions, considering that climate change is making life in the country worse is positively associated with expressing the desire to migrate. The magnitude is greatest for Northern African countries (0.101), Eastern and Southern Africa (0.083 each) and the smallest in Western Africa (0.039). The results on the perceived impact of climate change on agriculture confirm that those who consider that conditions for agricultural production in the area are worsening have a higher likelihood of expressing a desire to migrate. This result is significant for the entire sample covering all countries and for the sub-samples of Northern and Western African countries.

Following the concept of population vulnerability introduced in Chapter 2, we investigate whether, among those with negative perceptions on climate change, vulnerable individuals are more likely to desire to migrate (than those with no vulnerability). As mentioned above, in the analysis we include the following dimensions of vulnerability: residing in rural areas (vs urban); with above-secondary-level education (vs below), being employed in the agricultural sector (vs other sectors), facing food shortages, as well as being deprived of basic necessities.[75] Figure 34 presents the results[76] of the specification that looks at the impact of the negative perception of climate change, taking into account the potential differences in migratory response across various dimensions of vulnerability. For example, in the figure, 'Climate on country X Rural' indicates the group of individuals having negative perceptions of the impacts of climate change on the country and being vulnerable because of living in rural areas. Alternatively, 'Climate on country X Urban' refers to individuals with negative perceptions of climate change on the country and living in urban areas.

In the specification looking at the negative perception of climate change on the country (on the left), all interaction coefficients are positive and statistically significant. This means

71 The corresponding regression tables are shown in the Appendix – Table 15 and Table 16.

72 The full regression results are reported in the Appendix.

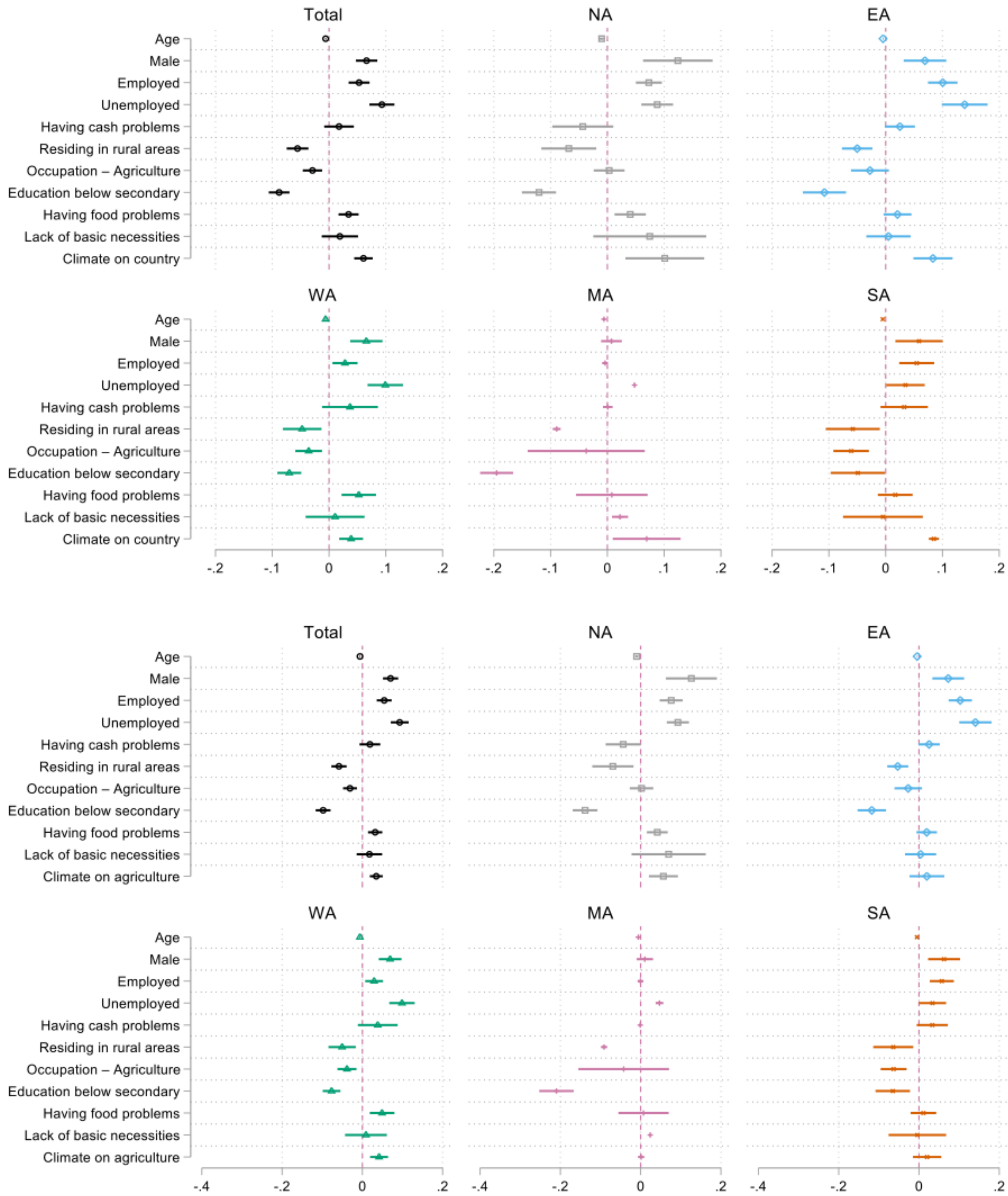
73 The climate on country variable refers to respondents declaring that climate change is making life in the country worse.

74 The climate on agriculture variable refers to respondents declaring that climate change is making life in the country worse.

75 To do so, we interact the variable of climate change perceptions with binary variables indicating, for example, whether an individual comes from a rural or urban area.

76 The corresponding regression tables are shown in the Appendix - Table 17 and Table 18.

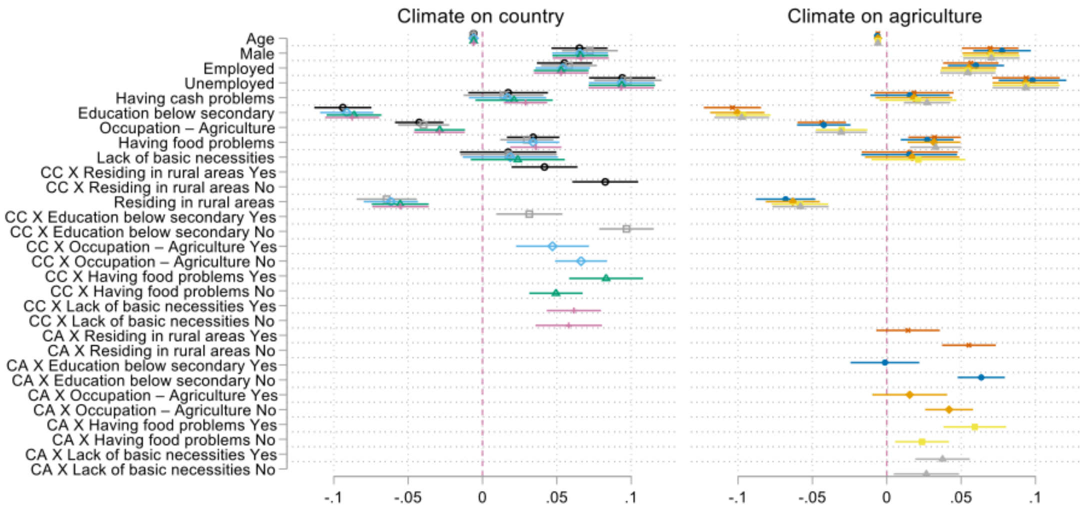
FIGURE 33. The relationship between climate change perception and migration aspirations – geographic perspective.
Note: Total refers to the whole sample of countries included in the Afrobarometer. NA = Northern Africa, WA = Western Africa, EA = Eastern Africa, MA = Middle Africa, SA = Southern Africa. Source: JRC elaboration of Afrobarometer survey data



that, regardless of the degree of vulnerability, those perceiving climate change negatively are more likely to express a willingness to migrate. Within this general pattern, those living in urban areas are twice as likely to express a desire to migrate than those living in rural areas.[77] Similarly, the likelihood of expressing a desire to migrate is three times

77 We statistically reject the hypothesis that coefficients are identical in magnitude at 1% statistical level (chi2(1) = 12.29, Prob > chi2 = 0.0005).

FIGURE 34. The relationship between climate change perception and migration aspirations – vulnerability perspective.
Source: JRC elaboration of Afrobarometer survey data.



higher among those with at least secondary-level education (0.033 vs 0.087). Those employed in the non-agricultural sector, with food shortages, are more likely to express a willingness to migrate. In relation to the overall deprivation of basic necessities, no statistically significant difference is detected between the two groups. This means that those with negative perceptions of the impacts of climate change are equally likely to express a desire to migrate, regardless of being deprived of basic necessities.

The results of the specification with Climate on agriculture (climate conditions for agricultural production in the area have gotten worse over the last decade) confirm the positive association between a negative perception of climate change and the desire to migrate, but only for those living in urban areas, with at least secondary-level education and employed in the non-agricultural sector (on the right). In relation to food shortages and the deprivation of basic necessities, the results suggest that individuals with a negative perception of climate change are more likely to express a willingness to migrate, regardless of having or not having food problems or lacking access to basic necessities. However, while the estimated association is greater for those facing food shortages (compare to those who do not), there is no statistically significant difference detected between those deprived and those not deprived of basic necessities in line with the results obtained for the first specification (i.e., climate on country).

CONCLUSION

In the effort to complement the macro perspective of this report with the individual one, this chapter has investigated the individual perceptions of climate change in Africa. The chapter has then examined whether and how perceptions on climate change are associated with the individual desire to move to another country. Furthermore, and most importantly, the analysis has focused on whether the dimensions of individual vulnerability – among those having negative perceptions on climate change – are associated with the desire to migrate.

Recent data from the Afrobarometer survey shows that more than half (58%) of the survey respondents have heard about climate change. Importantly, the awareness of climate change is higher in urban areas both at pan-African and country level, while there is no difference in the perception of climate change (negative or positive change in weather) between urban and rural areas at aggregate (pan-African) level. Overall, in Africa, around half (48%) of the respondents think that climate conditions for agricultural production in their area either got worse or much worse. This is much higher than the percentage of those who think that the change was positive (20%).

When considering migration aspirations, only 0.16% of those who would like to emigrate report natural disasters (such as drought, disease outbreaks, flooding, etc.) as the most important reason for considering moving from the country. However, after controlling for sociodemographic characteristics, the regression analysis shows that individuals considering that climate change is making life in the country worse tend to express a greater desire to migrate than those with positive perceptions of climate change impacts. The magnitude of the estimated effect is the greatest for North African countries, followed by East and South Africa, and is smallest in West Africa.

Lastly, the results suggest that perceiving climate change as a negative phenomenon is positively associated with migration intentions – regardless of the degree of vulnerability. However, among individuals perceiving climate change negatively: those living in urban areas; with at least secondary-level education; employed in the non-agricultural sector; with food shortages; and being deprived of basic necessities are more likely to express a willingness to migrate.

APPENDIX TO CHAPTER 2

SHARED SOCIOECONOMIC PATHWAYS

The five SSP scenarios describe the possible evolution of the economy and societies in form of narratives. These narratives are formulated having in mind mitigation and adaptation challenges to climate change.

- The first scenario 'SSP1: Sustainability—Taking the green road' describes a world along the path of sustainability where environmentally friendly development is accompanied by improvements in human well-being. This optimistic scenario results in low challenges both in terms of climate change adaptation and mitigation.

- The second scenarios 'SSP2: Middle of the road' is a baseline scenario characterised by a continuation of the historical trends which entail intermediate challenges for adaptation and mitigation.

- In the third scenario 'SSP3: Regional rivalry—A rocky road' the world would experience a rise in nationalism and weak global institutions with slow economic development and rising inequalities. These developments would strongly limit to the possibilities to mitigate and adapt to environmental degradation.

- The fourth scenario 'SSP4: Inequality—A road divided' describes diverging paths between and within countries. Environmental policies driven by a concentration of power with elites in middle- and high-income countries imply low challenges to mitigation. However, challenges to adaptations remain high for large part of the global population at low levels of development.

- In the last scenario 'SSP5: Fossil-fuelled development—Taking the highway' globalisation and economic success in industrialised and emerging countries will guarantee robust economic growth and the achievement of human development goals. However, there will be a trade-off between relatively low challenges for adaptation and high challenges to mitigation linked to the strong reliance on fossil fuels and the lack of global environmental concern.

TABLE 2. Detailed descriptions of the SSP scenarios (O'Neill et al. 2017)

SSP1: Sustainability—Taking the green road	The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries, the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.
SSP2: Middle of the road	The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including im- proved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education invest- ments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries.
SSP3: Regional rivalry—A rocky road	A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies high challenges to adaptation for many groups in all regions.

SSP4: Inequality—A road divided	Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low- tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle- and high-income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies low challenges to mitigation. Challenges to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.
SSP5: Fossil-fuelled development—Taking the highway	Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived trade-off with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labour markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.

METHODS AND DATA FOR CLIMATE CHANGE IMPACTS

CLIMATE CHANGE IMPACTS MODELS

Climate change projections used in this chapter rely on climate model results which are compared by the scientific community in international projects. Over the years, the various phases of the Coupled Model Inter-comparison Project (CMIP) have grown steadily both in terms of participants' number and scientific impacts. The fifth phase, CMIP5 (Taylor et al. 2012), has already provided major inputs to the latest IPCC fifth assessment report. In particular, impacts related to agriculture are covered by two major projects: the ISIMIP – Inter-Sectoral Impact Model Inter-comparison Project (Warszawski et al. 2014) and AgMIP – Agricultural Model Inter-comparison and Improvement Project (Rosenzweig et al., 2013). The objectives of the Inter-Sectoral Impact Model Inter-comparison Project (ISIMIP) are to provide a framework for the inter-comparison of global and regional-scale risk models within and across multiple sectors, and to enable coordinated multi-sectoral assessments of different risks and their aggregated effects (Warszawski et al. 2014). The overarching goal is to use the knowledge stemming from these models to support adaptation and mitigation policies that require both a regional and a global perspective.

The ISIMIP uses community-agreed sets of scenarios with standardised climate variables and socio-economic projections as inputs for projecting future risks and associated uncertainties, within and across sectors. The results are consistent multi-model assessments of sectoral risks and opportunities that enable studies that integrate across sectors, providing support for implementation of the Paris Agreement under the United Nations Framework Convention on Climate Change. Instead, the AgMIP (Agricultural Model Inter-comparison and Improvement Project) was initiated to improve agricultural modelling capacities by comparing models in simulation experiments using common protocols (Müller et al. 2019). Different modelling groups around the world can participate to AgMIP and contribute with data to the ensemble dataset. Protocols are developed to clearly describe important aspects in the configuration of the modelling experiments and all prescribed inputs are supplied to interested modellers. AgMIP analyses typically start out by describing the range of model results and then quantifying the uncertainty embedded in the choice of the crop model used and its parameterization. The agricultural components of ISIMIP have been coordinated under the umbrella of AgMIP, and ISIMIP (agricultural) components were included in the AgMIP agro-economic model inter-comparison. Each impact model was driven by a common daily, gridded climate dataset and delivered results in the form of a sector-specific set of common output variables at time resolutions ranging from sub-daily to monthly. Harmonisation across models was limited to the driving climate input data and, where applicable, socio-economic data (population and gross domestic product, GDP). Additional input data were selected according to the default settings of each model, to gain a representative picture of uncertainty across impact models using native settings and across various GCM (General Climate Model) output that drive impact models.

The analysis in this chapter is based on the results of both the ISIMIP and the AgMIP project. For each RCP scenario we constructed an ensemble of outputs from four General Circulation Models (GCMs) and two impact models (GEPIC and LPJmL) each with options for irrigation (full irrigation/no irrigation). By combining the outputs of these models, we obtained 8 different estimates of agricultural productivity for each of the four main crops of soybean, rice, maize and wheat. These estimates include historical simulations for the period 1975-2015 and projections for the period 2020-2100 for each cell of a global grid of 0.5 by 0.5 deg.
To derive anomalies in the future we calculated mean deviations from past trends over 5-year intervals for the period 2020-2070. Further details on the processing are described in Alessandrini et al. (2020) and Petroliagkis and Alessandrini (2021).

It should be noted that rencCo provide an evaluation of global crop models by comparing simulations driven with observations-based climate input (within the ISIMIP2a project) to reported crop yields. Six of these models contributed future simulations within the ISIMIP FastTrack. Among these, at the global level, one of the best-performing models (in terms of time-series correlation and mean bias in global yield) for both maize and wheat has been the LPJmL. For maize, GEPIC also performs very well; both models also have a reasonable performance for rice. Another advantage of this choice is that LPJmL is an ecosystem model, while GEPIC is a site-based model; thus, two of the major structural model types are covered.

SELECTION OF MODELS

Of the more than 30 global climate models (GCMs) that participated in the CMIP5 – Coupled Model Intercomparison Project phase 5, four models were used in the ISIMIP 2b (second phase of ISIMIP) to drive the crop models. These were already selected to cover a large fraction of the range of temperature and precipitation projections across the whole CMIP5 ensemble, although the entire range cannot be represented with only four models as it had been the case during the initial ISIMIP FT (Fast Track) phase (McSweeney and Jones 2018).

The simulation scenarios for ISIMIP 2b are divided into three groups, directed at addressing distinct scientific questions:

- Quantification of pure climate-change effects of the historical warming compared to pre-industrial reference levels;
- Future impact projections accounting for low (RCP2.6) and high (RCP6.0) greenhouse gas emissions assuming present day socio-economic conditions;
- Future impact projections accounting for low (RCP2.6) and high (RCP6.0) greenhouse gas emissions assuming dynamic future socio-economic conditions.

Input climate data are bias-corrected to the EWEMBI data set (especially compiled to support the bias correction of climate input data for ISIMIP2b and the ISIMIP2a protocol extension) at daily temporal and 0.5° horizontal resolution using updated versions of ISIMIP FastTrack (FT) methods utilising 0.5° horizontal resolution of a daily time step. Future (RCP2.6 and RCP6.0) conditions are provided by CMIP5 output of four GCMs: (1) GFDL-ESM2M, (2) HadGEM2-ES, (3) IPSL-CM5A-LR and (4) MIROC5.

For our study, the global climate model ensemble had to be further reduced to make its application in the population modelling framework feasible. From the four GCMs used in ISIMIP 2b, two (2) were chosen: the HadGEM2-ES and IPSL-CM5A-LR. The HadGEM2-ES is a family of climate models developed by the Met Office Hadley Centre for Climate Change in the United Kingdom (Collins et al. 2008), whereas the IPSL-CM5A-LR is a family of climate models developed by the Institute Pierre Simon Laplace Climate Modeming Center in France (Dufresne et al. 2013). The main practical reason for choosing these two models is that their precipitation forecast trends differ substantially in magnitude (and partly in sign) over our study area (Africa) as already denoted by (Schewe et al. 2014), so that at least for our area of interest a large range of possible future climate changes can be covered with only these two models. Further, both models had also been used in the past for producing impact simulations within the ISIMIP Fast Track (FT) project

(Frieler et al. 2017), so that the analysis presented in this report could easily be used for inter-comparison with past impact simulations (ISIMIP FT). Moreover, the HadGEM2-ES model has a particularly fine native resolution, potentially rendering it more realistic than other models at the regional scale.

It should be noted that, although it would be desirable to use climate impacts data at a higher spatial resolution, so far, no consistent set of impact model simulations is available that have been forced by regional climate models (RCMs). The use of global impact simulations in our study as in World Bank's Groundswell Report (Rigaud et al. 2018) provides an advance over using purely climate model-based indicators because they represent the actual resources (crops) relevant for human livelihoods. From the four impact models (CLM4.5 - GEPIC – LPJmL – PEPIC) utilised by ISIMIP 2b runs in the Agriculture Sector, only two were selected: GEPIC and LPJmL for the same constraint reasons to make their application in the population modelling framework feasible.

The full characteristics of the GEPIC (GIS-based Environmental Policy Integrated Climate) crop model can be found in Liu et al. (2007). In brief, the GEPIC is a crop growth model that possess the following characteristics: flexibility for the simulation of different crops under a variety of climatic conditions, ability to simulate ET and yield, availability of and easy access to the model, minimum data requirements, and technical feasibility for the integration with a GIS. The GEPIC model takes into account fertilizer applications and crop residual management. On the other hand, the LPJmL is a global water and crop model designed by Potsdam Institute for Climate Impact Research to simulate vegetation composition and distribution as well as stocks and land-atmosphere exchange flows of carbon and water, for both natural and agricultural ecosystems (Bondeau et al. 2007). The LPJmL impact model do not consider the effects of fertilizer applications and crop residual management.

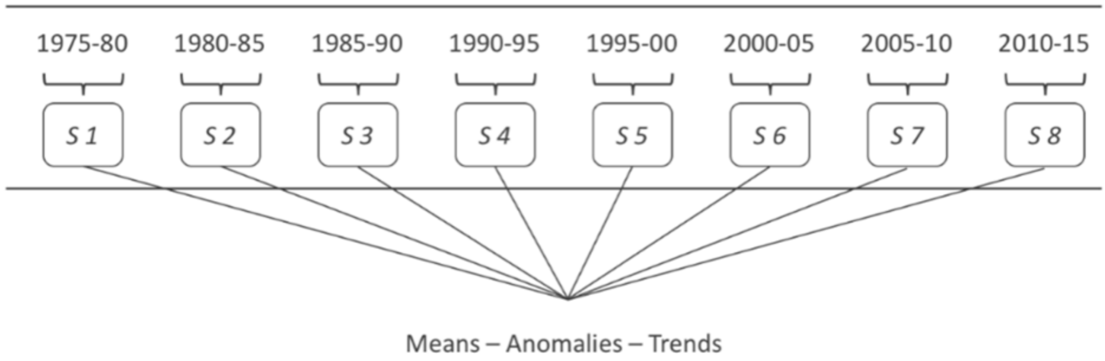
COMPILING A SET OF OPTIMAL ENSEMBLES

For the same constraint reasons mentioned above, we construct a set of optimal ensembles by considering for each RCP scenario (RCP2.6 and RCP6.0) two GCMs (HadGEM2-ES and IPSL-CM5A-LR). Each GCM output is then driving two impact models (GEPIC and LPJmL) with each of FIRR (full irrigation) and NOIRR (no irrigation) options. To account for the likelihood of having irrigation for a specific crop in a certain area, the models for FIRR and NOIRR have been weighted on the basis of the of the shares of irrigated and rainfed crop areas around the year 2000 reported in the MIRCA2000 data set (Portman et al. 2010). Following this approach, a set of 8-member ensembles are constructed. The mean value of each of these ensembles is taken under consideration for each of the main crops (soybean, rice, maize and wheat).

CALCULATION OF ANOMALIES

Anomalies in the future were estimated considering snapshots of historical data over 5-yearly time intervals as shown schematically in Figure 35.
Further details of the construction of such anomalies and trends can be found in (Alessandrini et al. 2020; Petroliagkis and Alessandrini 2021).

FIGURE 35. 5-year time interval snapshots of NMG (New Migration Grid) over 1975 to 2015 schematic setup for estimating 5-yearly means, anomalies and trends of potential climate drivers.

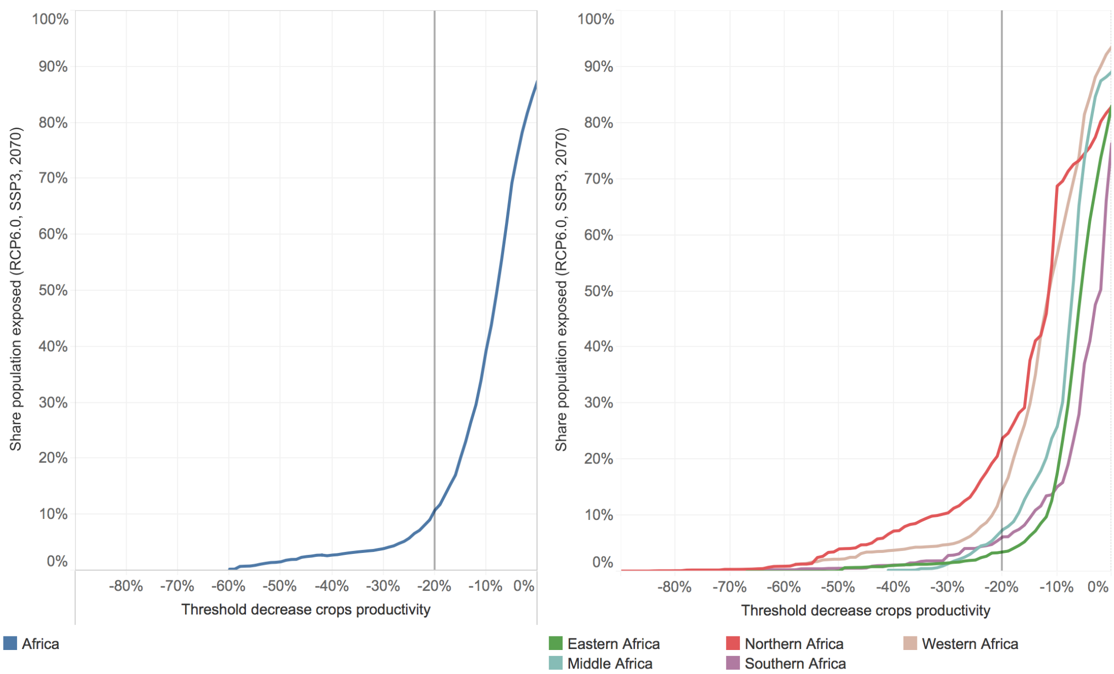


SENSITIVITY TO THE THRESHOLD FOR DECREASES IN AGRICULTURAL PRODUCTIVITY

To estimate population exposed to major collapse of agricultural productivity we considered a change of more than -20% in respect of the historical baseline. As robustness check in Figure 36 we show the effect of choosing different thresholds on the size of exposed population in African regions and compare these results to the chosen threshold represented by the vertical line.

By increasing the threshold from -20% to -10% the size of exposed population in Africa would increase from 11% to 39%. When considering regions within Africa, Western Africa has the largest exposed population for all thresholds and Northern Africa for thresholds below -6%.

FIGURE 36. Estimates of exposed population using different thresholds for the decrease of agricultural productivity. The estimates refer to the SSP3 and RCP6.0 scenario and the year 2070.



APPENDIX TO CHAPTER 3

REGRESSION MODEL

This section presents the regression models briefly explained in Chapter 3 (see section on Methodology: an overview). The regression model is inspired by the recent work of Peri and Sasahara (2019) who estimate a panel data model using decennial data on migration and climatic events at high spatial resolution (0.5 deg). In particular, the results of this chapter are based on the estimation of the following panel data model:

$$Net\ migration_{i,t:t+5,c} = \beta_0 + \beta_1\, Temp_{i,t} + \beta_2 Pop.density_{i,t} + \beta_3 (Temp_{i,t}\ X\ Pop.density_{i,t}) + \beta_4 Prec_{i,t} + \beta_5\, (Prec_{i,t}\ X\ Pop.density_{i,t}) + \alpha_i + \alpha_c{}^*\alpha_t + \varepsilon_{i,t}$$

The data consists of a panel dataset for the period 1975-2015, with 5-year frequency; i refers to territories (or grid cells) of 0.5 deg resolution. The dependent variable is the 5-year[78] net migration of territory *i*. Positive values of net migration indicate that the territory is gaining population (since immigration is higher than emigration). Negative values of the dependent values indicate that the territory is losing population (since immigration is lower than emigration). Details on the net migration variable and its estimation can be found in Alessandrini et al. (2020).
It should be noted that net migration refers to comparable territories – - i.e., areas of the same geographical size of 0.5 deg x 0.5 deg. Thus, we do not need to define a rate or standardise the net migration with respect to the geographical size of the territory. It could be argued that net migration should instead be standardised with respect to the population living in the territory, even in case of territories of comparable geographical size. However, we do not use the net migration rate – that is, net migration as a share of the population in the territory – for the following reason. Net migration is a balance between immigration and emigration – hence, in demographic terms, it is not strictly correct to use the population of the considered territory as the population at risk.

The main variables of interest are the climatic indicators of temperature, precipitation, extreme temperatures, extreme precipitation, extreme slow-onset events such as heat waves and drought. Apart from the main specification including both temperature and precipitation – as is common in the relevant literature – the other model specifications reported in the chapter do not include more than two indicators in the same model specification. The reason for this choice is to avoid possible multi-collinearity issues. The climatic indicators are used as 5-year averages; or as anomalies with respect to the 1980-2010 period; or as trends, as defined in Peri and Sasahara (2019). The definition of the 90 climatic indicators used, a discussion on the criteria for their selection, and the related data sources are provided in Petroliagkis and Alessandrini (2021). In any case, as a general criterion, we included climatic variables ensuring the widest data coverage both in terms of time and geography. In some model specifications, we also include an indicator of estimated crop yield production per harvested area (in tonnes per hectare)

78 In other words, the net migration refers to the time interval between period t and period t+5.

(Lizumi and Sakai 2020) for each grid cell. We use four major crops – maize, wheat, rice, soybean.[79]

The climatic indicators are used as five-year averages; or as anomalies with respect to the 1980-2010 period; or as trends, as defined in Peri and Sasahara (2019). The definition of the ninety climatic indicators used, a discussion on the criteria for their selection, and the related data sources are provided in Petroliagkis and Alessandrini (2021). In any case, as a general criterion, we included climatic variables ensuring the widest data coverage both in terms of time and geography. In some model specifications, we also include an indicator of estimated crop yield production per harvested area (in tonnes per hectare for each grid cell) (Iizumi and Sakai 2020) for each grid cell. We use only four major crops – maize, wheat, rice, soybean. The problem of this dataset is that there are many missing observations – probably because these are estimates of main crops per cells.

As discussed in the section, to take population dynamics into account in the model, we include the population density of the cell as a control variable. Population density of the cell is expressed as inhabitants for square kilometre, at the beginning of the 5-year time interval considered.[80] More precisely, an increase in population density captures an urbanisation process or simply an increase in population. The model also includes an interaction term between population density and the climatic indicator. This interaction term is crucial to understand whether the association between climate change and migration is mediated by population density or, more generally, whether demographic forces and changes climatic conditions are interrelated.
The model is estimated using grid cell fixed effects, as in (Peri and Sasahara 2019). This allows us to isolate the relationship between the climate change indicators and net migration by getting rid of all the unobserved components that vary over time within cells. This comes at the expense of not being able to estimate coefficients of variables that do not vary over time – for example, geographic variables such as distances. All the model specifications also include country per period dummies. This is essential to controlling for all country specific characteristics that do vary over time.
We use robust standard errors clustered at country level or at regional level, as it is commonly the case in similar studies (Peri and Sasahara 2019). Additionally, we run model specifications with standard errors clustered according to the agro-ecological group[81] of the cell, as classified by the FAO (2012). This constitutes an innovation with respect to the existing literature. This choice is motivated by the fact that we assume that data are grouped into climatic or agro-ecological clusters, with regression model errors independent across clusters but correlated within clusters. In the regression table below, we show results including standard errors clustered at agro-ecological level.[82] The results using the different types of clustering are mixed – generally, the results presented with agro-ecological groups clustered standard errors are even more significant when using country or regional standard errors (not reported here), however not in all the cases.

79 The problem with this dataset is that there are missing observations, hence not all territories within each macro-region can be covered.

80 We do not control for population size in the cell because the 5-year change in population size has been used to, indirectly, estimate the dependent variable. Hence, this could create a problem of endogeneity due to reverse causality. This issue is mitigated when using population density at the end of the 5-year period.

81 Agro-ecological zones are considered as geographical areas exhibiting similar climatic conditions that determine their ability to support rain-fed agriculture. At regional scale, such zones are influenced by latitude, elevation, and temperature, as well as seasonality and rainfall amounts and distribution during the growing season.

82 The other results are not included due to space constraints.

We first run the model including grid cells for all Africa (corresponding to around 65 000 observations). Then, we use different African-macro regions, as defined by the United Nation Statistics Division geographical classification.[83] We also split the sample according to the income level group of countries or according to the agro-ecological classification. The results are unclear in these cases, predominantly not significant. A discussion and justification for the use of different samples is provided in the Methodology section.

Lastly, the following caveats of the approach and models should be mentioned:

- unlike Peri and Sasahara (2019) who develop a theoretical framework to model the individual migration decision – incorporating the effect of temperature on rural/urban productivity – we do not provide any theoretical framework. Moreover, we do not have strong theoretical insights upon which of the climatic indicators should be associated with net migration and whether the use of 5-year averages should be preferred to the use of climate anomalies or climate trends;

- to capture possible non-linear relations between the climatic indicators and net migration in the regression model, squared terms of the climatic variable are used, as well as interaction terms between different climatic variables. However, these model specifications do not give clear results and are not reported in the regression tables;

- as a further possible step for research, the presence of spatial effects in the data could be tested and a spatial model could be implemented. Despite the fact that this could constitute a possible extension of the modelling approach, the interpretation of spatial models is complex, hence not commonly used within migration economics.

83 https://unstats.un.org/unsd/methodology/m49/.

REGRESSION RESULTS

TABLE 3A. All Africa
Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
					Africa			
	All	All	Tropical	Tropical	Tropical	Subtropical	Subtropical	Subtropical
Precipitation	4.857	14.213	-0.064	8.031	16.462	-9.041	-206.903	-540.819**
	(7.549)	(12.326)	(6.938)	(6.170)	(12.607)	(116.073)	(120.651)	(143.087)
Population density	-1.390	-0.254	-62.398***	-86.318	-86.395	-11.347	-2.209	-15.589
	(128.821)	(128.925)	(15.229)	(85.814)	(85.762)	(68.997)	(415.799)	(418.502)
Precipitation X Population density	-0.201	-0.204		-0.305**	-0.309**		2.185**	2.288**
	(0.154)	(0.154)		(0.101)	(0.102)		(0.500)	(0.478)
Temperature	211.961	94.565	207.438	140.614	-9.502	-1,233.579	-849.121	-1,552.011
	(322.726)	(474.483)	(323.738)	(347.719)	(511.987)	(1,328.702)	(2,394.009)	(3,203.217)
Temperature X Population density	-1.875	-1.919		1.778	1.784		-4.196	-3.634
	(5.367)	(5.371)		(3.717)	(3.713)		(20.785)	(20.887)
Precipitation X Middle Africa		-10.378			-11.768			
		(29.342)			(31.766)			
Precipitation X Northern Africa		-111.184*			-53.307			
		(50.112)			(28.851)			
Precipitation X Southern Africa		42.155			28.519			510.710*
		(44.760)			(40.370)			(177.660)
Precipitation X Western Africa		-25.370			-22.694			
		(22.701)			(26.015)			
Temperature X Middle Africa		-626.374			-584.449			
		(788.917)			(852.779)			
Temperature X Northern Africa		1,478.520**			1,722.100**			
		(575.604)			(483.329)			
Temperature X Southern Africa		556.067			860.560			1,058.845
		(769.428)			(883.777)			(2,884.829)
Temperature X Western Africa		-1,247.613			-1,257.249			
		(815.769)			(908.535)			
Observations	64,877	64,877	60,528	60,528	60,528	3,933	3,933	3,933
R-squared (within)	0.118	0.118	0.123	0.125	0.125	0.129	0.179	0.185
Number of grid cells	8,494	8,494	7,949	7,949	7,949	493	493	493
Grid cell fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES	YES	YES

TABLE 3B. All Africa – cont'd
Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(9)	(10)	(11)	(12)	(13)	(14)
				Africa		
	Low-income	Low-income	Lower-middle-income	Lower-middle-income	Upper-middle-income	Upper-middle-income
Precipitation	0.037	-6.894	-21.631	11.078	-11.301	-67.602
	(15.482)	(21.850)	(21.088)	(39.384)	(50.078)	(328.642)
Population density	-239.635	-240.630	-132.218	-134.240	86.365	87.957
	(207.503)	(206.767)	(143.153)	(142.700)	(536.820)	(538.138)
Precipitation X Population density	0.288	0.301	-0.367**	-0.377**	-0.187	-0.126
	(0.734)	(0.737)	(0.155)	(0.154)	(1.627)	(1.642)
Temperature	-640.940	-131.399	1,050.176	-165.638	334.001	-207.399
	(424.041)	(355.772)	(740.139)	(867.298)	(472.742)	(1,008.451)
Temperature X Population density	7.683	7.667	3.077	3.176	-2.843	-3.058
	(6.338)	(6.297)	(6.403)	(6.380)	(30.302)	(30.307)
Precipitation X Middle Africa		30.491		-92.633		20.528
		(30.626)		(56.672)		(308.055)
Precipitation X Northern Africa				19.575		-311.311
				(79.617)		(243.461)
Precipitation X Southern Africa				-13.723		145.524
				(43.950)		(275.387)
Precipitation X Western Africa		-29.731		-21.891		
		(20.752)		(64.335)		
Temperature X Middle Africa		-617.003		-554.718		498.971
		(606.912)		(1,219.058)		(2,069.941)
Temperature X Northern Africa				3,283.279*		
				(1,643.074)		
Temperature X Southern Africa				3,294.593		782.563
				(1,826.859)		(937.184)
Temperature X Western Africa		-1,763.143		-501.866		
		(1,364.194)		(438.315)		
Observations	31,378	31,378	17,416	17,416	15,389	15,389
R-squared (within)	0.140	0.140	0.159	0.160	0.026	0.029
Number of grid cells	4,084	4,084	2,240	2,240	2,082	2,082
Grid cell fixed effects	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES

TABLE 4. Northern Africa

Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					Northern Africa				
	All	All	All	All	All	Tropical	Subtropical	Upper-middle income	Lower-middle income
Precipitation	-467.015***								
	(98.408)								
Population density	-948.844***	-380.573***	-392.725***	-87.319***	-76.559**	-415.909***	-298.994**	-173.534***	-72.944**
	(155.784)	(27.845)	(45.932)	(17.521)	(21.058)	(0.015)	(40.385)	(13.150)	(19.215)
Precipitation density X Population density	2.815*								
	(1.052)								
Temperature	313.893								
	(861.607)								
Temperature X Population density	38.409***								
	(6.559)								
Heat wave amplitude		-525.287				-42.119***	-759.803**		
		(340.650)				(0.199)	(127.382)		
Heat wave amplitude X Population density		14.731***				16.606***	9.512**		
		(1.592)				(0.001)	(2.046)		
Heat wave magnitude			-626.858						
			(371.912)						
Heat wave magnitude X Population density			15.674***						
			(2.118)						
Heat wave frequency				-72.390*					
				(27.838)					
Heat wave frequency X Population density				2.160***					
				(0.204)					
Heat wave duration					-355.414**			37.280	-565.485***
					(104.362)			(29.691)	(42.477)
Heat wave duration X Population density					6.941***			-6.788***	7.427***
					(0.469)			(1.419)	(0.210)
Observations	8,385	6,073	6,073	8,377	6,073	4,206	1,867	3,307	2,214
R-squared (within)	0.197	0.418	0.407	0.184	0.250	0.464	0.425	0.188	0.302
Number of grid cells	1,182	1,119	1,119	1,181	1,119	801	318	668	363
Grid cells fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES

TABLE 5. Egypt

Note: Robust standard errors clustered at the regional level in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and period dummies not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Heat wave amplitude	-164.488								
	(664.380)								
Population density	-408.240***	-74.598***	-86.694***	-37.681*	-38.412***	-36.375**	-67.163***	-76.911***	-74.628***
	(29.927)	(16.325)	(14.679)	(20.215)	(12.502)	(13.974)	(21.582)	(17.181)	(17.781)
Heat wave amplitude X Population density	16.098***								
	(1.247)								
Heat wave duration		-882.626**					-3,980.933**	-3,194.300**	-3,404.293*
		(345.539)					(1,788.242)	(1,359.050)	(1,741.598)
Heat wave duration X Population density		7.567***					5.440***	7.039***	6.930***
		(0.700)					(0.785)	(0.691)	(0.873)
Heat wave frequency			-287.910*						
			(157.683)						
Heat wave frequency X Population density			2.082***						
			(0.294)						
Rice productivity				24,732.308**			24,793.617**		
				(11,314.460)			(10,099.393)		
Wheat productivity					4,420.011			3,209.345	
					(5,967.079)			(6,233.564)	
Maize productivity						9,137.898			10,188.201
						(8,869.310)			(9,040.560)
Observations	784	784	1,117	133	238	231	101	187	181
R-squared (within)	0.523	0.308	0.237	0.378	0.261	0.285	0.486	0.411	0.436
Number of grid cells	146	146	156	19	34	33	19	34	33
Grid cells fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Period fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES

TABLE 6. Western Africa
Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					Western Africa				
	All	All	All	Low income	Lower-middle income	All	All	All	All
Precipitation	44.385								
	(33.463)								
Population density	1,113.111**	-27.448	-36.825	58.066	-47.336*	10.768	11.807	10.249	11.504
	(334.133)	(26.606)	(31.863)	(46.865)	(20.729)	(28.935)	(26.473)	(29.838)	(27.719)
Precipitation X Population density	-1.242***								
	(0.287)								
Temperature	-185.937								
	(766.687)								
Temperature X Population density	-36.454**								
	(11.529)								
Daily temperature range (trend)		-706.837		-1,191.253***	-475.410		-658.309		-803.248
		(382.898)		(238.178)	(433.683)		(783.367)		(773.781)
Daily temperature range (trend) X Population density		-4.057		20.719	-8.749		-4.611		-3.338
		(10.358)		(16.100)	(6.228)		(14.007)		(14.855)
Precipitation (trend)		-25.960**		-44.463	-20.853**		-41.859		-43.168
		(7.947)		(22.307)	(7.593)		(26.150)		(24.957)
Precipitation trend X Population density		0.515**		1.291*	0.310**		0.599		0.593
		(0.200)		(0.583)	(0.084)		(0.302)		(0.297)
Extreme drought			640.726						
			(585.788)						
Severe drought			373.164						
			(870.929)						
Moderate drought			636.530						
			(476.684)						
Moderate wet conditions			-1,054.978						
			(735.876)						
Severe wet conditions			543.461						
			(1,075.343)						
Extreme wet conditions			1,008.260						
			(944.658)						
Extreme drought X Population density			-31.801*						
			(16.128)						
Severe drought X Population density			-12.610						
			(26.051)						
Moderate drought X Population density			-21.487						
			(12.110)						
Normal wet conditions X Population density			0.000						
			(0.000)						

Moderate wet conditions X Population density			4.916						
			(7.830)						
Severe wet conditions X Population density			8.691						
			(31.148)						
Extreme wet conditions X Population density			-2161557.755***						
			(183.698)						
Maize productivity						-1,233.200	-757.332		
						(2,088.209)	(1,776.763)		
Rice productivity								159.807	280.984
								(305.411)	(274.898)
Observations	14,343	14,335	14,343	7,918	6,417	6,774	6,774	6,893	6,893
R-squared (within)	0.203	0.164	0.164	0.167	0.190	0.160	0.166	0.161	0.167
Number of grid cells	1,852	1,851	1,852	1,047	804	971	971	990	990
Grid cells fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES

TABLE 7. Sahel regions

Note: Robust standard errors clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)
		Sahel		
Temperature	-6,180.319**			
	(1,490.932)			
Population density	1,544.077	888.071***	827.308***	141.760***
	(1,283.626)	(93.321)	(148.208)	(1.179)
Temperature X Population density	-50.654			
	(46.412)			
Precipitation		332.202***		
		(61.404)		
Precipitation X Population density		-7.660***		
		(0.963)		
Minimum temperature			-4,192.747***	
			(831.357)	
Minimum temperature X Population density			-31.752**	
			(7.043)	
Extreme drought				1,365.540
				(646.539)
Severe drought				-1,289.050*
				(587.901)
Moderate drought				-4,077.375**
				(1,030.870)
Extreme drought X Population density				-47.870***
				(0.880)
Severe drought X Population density				224.166**
				(53.766)
Moderate drought X Population density				346.171***
				(21.133)
Normal wet conditions X Population density				0.000
				(0.000)
Observations	1,147	1,147	1,147	1,147
R-squared	0.257	0.302	0.238	0.625
Number of id_pair	144	144	144	144
Cell FE	YES	YES	YES	YES
Country X Period FE	YES	YES	YES	YES

TABLE 8. Eastern Africa

Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Eastern Africa									
	All	All	Low-income	Lower-middle income	All	All	All	All	All	All
Precipitation	8.797									
	(18.679)									
Population density	-213.249	-86.929***	-68.041*	-123.000**	-68.491**	-60.950**	-75.254***	-54.467**	-94.673**	-90.034***
	(178.235)	(13.187)	(33.503)	(43.897)	(19.443)	(17.979)	(14.771)	(19.416)	(26.373)	(24.131)
Precipitation X Population density	-0.133									
	(0.601)									
Temperature	-22.328									
	(484.036)									
Temperature X Population density	6.456									
	(7.306)									
Temperature (trend)		-1,154.924*	-1,625.861*	-517.897		-1,608.443*		-2,662.192**		-1,773.595
		(532.499)	(713.854)	(489.992)		(741.344)		(986.837)		(966.917)
Temperature (trend) X Population density		38.418***	50.519***	15.345		39.335***		48.009***		35.634***
		(6.585)	(13.212)	(30.514)		(6.858)		(3.759)		(3.557)
Extreme precipitation (trend)		-16.016	-12.651	0.997		-28.733		-21.732		-63.490
		(8.823)	(13.388)	(23.277)		(18.229)		(13.038)		(33.403)
Extreme precipitation (trend) X Population density		0.331*	0.126	0.330*		0.426		0.321***		0.486
		(0.142)	(0.307)	(0.161)		(0.228)		(0.077)		(0.345)
Maize productivity					-302.232	-355.881				
					(725.774)	(680.814)				
Rice productivity							644.576*	801.010**		
							(299.862)	(269.823)		
Wheat productivity									146.041*	40.482
									(70.017)	(66.644)
Observations	17,686	17,542	14,191	3,343	12,758	12,709	3,378	3,343	4,850	4,850
R-squared (within)	0.163	0.170	0.168	0.223	0.167	0.178	0.362	0.419	0.140	0.147
Number of grid cells	2,263	2,245	1,816	428	1,851	1,844	486	481	701	701
Grid cells fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

TABLE 9. Middle Africa

Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)
			Middle Africa			
	All	All	All	Low income	Lower-middle income	Upper-middle Income
Precipitation	3.649	11.570		53.489***	-44.292	-6.410
	(21.240)	(21.444)		(11.485)	(79.129)	(68.231)
Population density	400.516	-236.571	-130.843**	85.186	-573.082***	-81.201
	(503.427)	(144.758)	(50.447)	(182.693)	(139.452)	(479.555)
Precipitation X Population density	0.542	0.359		-1.595	1.694**	-1.460
	(0.948)	(0.677)		(1.365)	(0.593)	(3.529)
Temperature	-53.050					
	(306.766)					
Temperature X Population density	-24.894					
	(24.223)					
Consecutive dry days		-37.571**		-31.264	-49.089**	-20.345
		(14.456)		(27.472)	(15.626)	(33.420)
Consecutive dry days X Population density		1.435**		1.317	1.809**	0.072
		(0.425)		(0.837)	(0.636)	(1.311)
Extreme drought			-369.835			
			(897.643)			
Severe drought			-110.908			
			(583.776)			
Moderate drought			-296.298			
			(229.441)			
Moderate wet			865.167***			
			(182.563)			
Severe wet			-8.086			
			(1,250.271)			
Extreme wet			-2,831.539			
			(1,575.416)			
Extreme drought X Population density			33.172			
			(27.487)			
Severe drought X Population density			32.551			
			(22.612)			
Moderate drought X Population density			25.753***			
			(6.937)			
Moderate wet X Population density			-11.388			
			(12.366)			
Severe wet X Population density			-87.903***			
			(9.978)			
Extreme wet X Population density			230.768			
			(266.265)			
Observations	14,566	14,566	14,566	9,125	1,988	3,453
R-squared (within)	0.102	0.104	0.117	0.067	0.402	0.055
Number of grid cells	1,905	1,905	1,905	1,203	253	449
Grid celll fixed effects	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES

TABLE 9A. Middle Africa – cont'd
Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(6)	(7)	(8)	(9)	(10)
			Middle Africa		
	Upper-middle Income	All	All	All	All
Precipitation	-6.410		38.708		43.567
	(68.231)		(32.554)		(37.890)
Population density	-81.201	-129.282*	-268.851	-273.949***	-311.011*
	(479.555)	(58.702)	(141.131)	(51.281)	(127.145)
Precipitation X Population density	-1.460		0.867		0.411
	(3.529)		(0.610)		(0.687)
Temperature					
Temperature X Population density					
Consecutive dry days	-20.345		-28.502		20.671
	(33.420)		(16.929)		(11.701)
Consecutive dry days X Population density	0.072		0.965**		-0.178
	(1.311)		(0.274)		(0.233)
Maize productivity		-73.933	-203.680		
		(653.465)	(421.524)		
Rice productivity				-155.369	-216.838
				(374.280)	(448.330)
Observations	3,453	9,721	9,721	4,387	4,387
R-squared (within)	0.055	0.085	0.101	0.434	0.438
Number of grid cells	449	1,413	1,413	630	630
Grid celll fixed effects	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES

TABLE 10. Southern Africa

Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)
			Southern Africa		
	All	All	Tropical	Subtropical	Lower-middle income
Precipitation	-64.654**	-63.802**	-15.020	-105.446*	97.530
	(25.828)	(18.391)	(17.122)	(35.242)	(73.731)
Population density	94.564	-55.847	277.698***	-90.070	27.070
	(202.090)	(100.197)	(24.582)	(118.135)	(21.040)
Precipitation X Population density	3.910***	3.949***	3.376***	3.949*	-0.385
	(0.916)	(0.847)	(0.233)	(1.321)	(0.120)
Temperature	311.491				
	(225.371)				
Temperature X Population density	-8.716				
	(12.961)				
	(1,312.718)	(769.381)	(928.963)	(214.972)	
Daily temperature range		-748.605**	-373.261	-752.813	-2,604.194
		(223.995)	(279.341)	(692.572)	(1,939.952)
Daily temperature range X Population density		0.030	-19.170***	2.051	4.010
		(8.540)	(1.293)	(10.774)	(1.641)
Maize productivity					
Wheat productivity					
Observations	7,224	7,224	5,832	1,392	136
R-squared (within)	0.490	0.486	0.493	0.508	0.232
Number of grid cells	930	930	756	174	17
Grid cells fixed effects	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES

TABLE 10A. Southern Africa – cont'd
Note: Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(6)	(7)	(8)	(9)	(10)
			Southern Africa		
	Upper-middle income	All	All	All	All
Precipitation	-65.561**		-91.391***		-73.827***
	(19.668)		(12.739)		(10.503)
Population density	-55.517	153.961***	10.590	172.735***	230.030**
	(100.599)	(17.541)	(65.691)	(13.029)	(88.791)
Precipitation X Population density	3.987***		4.159***		5.362***
	(0.877)		(1.087)		(0.234)
Temperature					
Temperature X Population density					
	(784.573)	(988.104)	(700.718)	(888.716)	(731.866)
Daily temperature range	-749.191**		-730.077**		-538.181**
	(223.565)		(256.180)		(147.968)
Daily temperature range X Population density	-0.091		-3.077		-20.287***
	(8.649)		(6.586)		(4.960)
Maize productivity		-687.733*	-570.948*		
		(285.727)	(243.752)		
Wheat productivity				-95.155*	-110.489*
				(40.234)	(54.496)
Observations	7,088	4,055	4,055	2,036	2,036
R-squared (within)	0.491	0.406	0.550	0.468	0.677
Number of grid cells	913	585	585	293	293
Grid cells fixed effects	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES

TABLE 11. Regression results on any conflict event and number of events
Note: Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country X period effects not reported.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Any Event	Any Event	Any				
Event	Any						
Event - Rural	Any						
Event							
- Middle & City	Any Event	Number Events					
Temperature (anomaly)	0.090***	0.100***	0.102***	0.027	0.194***	0.104***	0.802***
	(0.027)	(0.026)	(0.031)	(0.066)	(0.070)	(0.030)	(0.308)
Temp (anomaly squared)	0.107***	0.108***	0.090***	0.164*	0.118	0.084**	0.479
	(0.029)	(0.029)	(0.033)	(0.089)	(0.096)	(0.033)	(0.415)
Precipitation (anomaly)	0.002	0.002	0.003*	0.001	0.004	0.003**	0.020
	(0.001)	(0.001)	(0.002)	(0.005)	(0.005)	(0.002)	(0.017)
Precipitation (anomaly squared)	0.001***	0.001***	0.001***	0.003***	0.002***	0.001***	0.006***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.002)
Population Density		0.001***				0.001**	0.010**
		(0.000)				(0.000)	(0.004)
Net migration (lagged)			0.001***	-0.001	0.001***	0.001***	0.001***
			(0.000)	(0.004)	(0.000)	(0.000)	(0.000)
Any event (lagged)						0.061**	
						(0.030)	
Num. Events (lagged)							0.216***
							(0.063)
Observations	3,993	3,993	3,148	735	594	3,148	3,148
R-squared	0.172	0.178	0.157	0.165	0.294	0.163	0.101
Number of grid cells	547	547	500	332	246	500	500
Grid cells fixed effects	YES	YES	YES	YES	YES	YES	YES
Country X Period fixed effects	YES	YES	YES	YES	YES	YES	YES

APPENDIX TO CHAPTER 4

TABLE 12. Questions on perceptions on climate change included in Afrobarometer 2016-2018 wave
Source: Afrobarometer. *Notes:* Robust standard errors clustered by agro-ecological group in parenthesis. *** p<0.01, ** p<0.05, * p<0.1. Constant term and country*period effects not reported.

Question	Set of answers
Q71. In your experience, would you say climate conditions for agricultural production in your area have gotten better, gotten worse, or stayed about the same over the last 10 years, or haven't you heard enough to say?	0. No experience 1. Much worse 2. Worse 3. About the same 4. Better 5. Much better 8. Refused to answer 9. Don't know/Haven't heard enough to say
Q73a. Have you heard about climate change or haven't you had the chance to hear about this yet?	0. No, I haven't had the chance to hear about it 1. Yes 8. Refused to answer 9. Don't Know/Haven't heard enough to say
Q73b. What does the phrase 'climate change' mean to you?	1. Negative changes in the weather (like more droughts, floods, or extreme heat) 2. Positive changes in the weather (like better rainfall patterns or longer growing seasons) 3. Other changes in weather patterns 7. Not applicable [If the response to Q73a was 0=No] 8. Refused to answer 9. Don't know/ Haven't heard enough to say
Q75 Do you think climate change is making life in the country better or worse, or haven't you heard enough to say?	1. Much better 2. Somewhat better 3. Neither/ no change / about the same 4. Somewhat worse 5. Much worse 7. Not applicable [If the response to Q73a was 0=No] 8. Refused to answer 9. Don't know / Haven't heard enough to say 99. Not asked in the country (Kenya and Zimbabwe)
Q68a. How much, if at all, have you considered to moving to another country to live?	0. Not at all 1. A little bit 2. Somewhat 3. A lot 8. Refused to answer 9. Don't know/Haven't heard enough

TABLE 13. Countries by large geographic areas

Geographic areas	Countries
North Africa	Morocco, Tunisia, Sudan
Eastern Africa	Kenya, Madagascar, Malawi, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe
Western Africa	Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Liberia, Mali, Mauritius, Niger, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, Togo
Middle Africa	Cameroon, Gabon
South Africa	Botswana; eSwatini, Lesotho, Namibia, South Africa

TABLE 14. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Consider migrating	44,969	0.362	0.480	0	1
Age	44,969	37.1	14.9	18	106
Male	44,969	0.499	0.500	0	1
Employed	44,969	0.356	0.479	0	1
Unemployed	44,969	0.272	0.445	0	1
Having cash problems	44,969	0.649	0.477	0	1
Residing in rural areas	44,969	0.552	0.497	0	1
Education below secondary	44,969	0.480	0.500	0	1
Occupation – Agriculture	44,969	0.333	0.471	0	1
Having food problems	44,969	0.322	0.467	0	1
Lack of basic necessities	44,969	0.744	0.437	0	1
Climate on agriculture (climate conditions for agricultural production gotten worse or much worse)	44,969	0.479	0.500	0	1
Climate on country (climate change making life in the country somewhat worse or much worse)	44,969	0.363	0.481	0	1

REGRESSION MODEL AND RESULTS

The results presented in this chapter are based on the following model specifications.

Specification 1

$$\textbf{\textit{Consider Migrating}}_{ic} = \beta_0 + \beta_1 \textbf{\textit{Climate on country}}_{ic} + + \beta_2 SD\ Characteristics_{ic} + \gamma_c + \varepsilon_{ic}$$

Specification 2

$$\textbf{\textit{Consider Migrating}}_{ic} = \beta_0 + \beta_1 \textbf{\textit{Climate on agriculture}}_{ic} + + \beta_2 SD\ Characteristics_{ic} + \gamma_c + \varepsilon_{ic}$$

Consider Migrating$_{ic}$ is the dependent variable which takes a value equal to 1 if an individual considers emigrating (‘a little bit’, ‘somewhat’ and ‘a lot’ and 0 otherwise.

The main explanatory variables of interest are:
Climate on country$_{ic}$ takes a value equal to 1 if an individual thinks that climate change is affecting the country ‘somewhat worse’ or ‘much worse’ and 0 otherwise (in Equation 1).
Climate on agriculture$_{ic}$ takes a value equal to 1 if an individual thinks climate conditions for agricultural production in your area have gotten ‘worse’ or ‘much worse’ over the last 10 years and 0 otherwise. (in Equation 2).
SD Characteristics$_{ic}$ stands for the set of variables capturing individual sociodemographic characteristics of the respondents.
γ_{ic} - captures country-specific fixed effects
ε_{ic} stands for unobserved individual characteristics

The empirical models described in Specification 1 and 2 are estimated using logit model (Consider migration 1/0) for the whole sample and subsample corresponding to large geographic areas.

TABLE 15. The relationship between climate change (on country) and migration aspirations: geographic perspective.
Note: Average marginal effects reported. All models include country dummies and a constant term. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Total	North Africa	East Africa	West Africa	Middle Africa	South Africa
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Age	-0.006***	-0.010***	-0.005***	-0.006***	-0.006***	-0.005***
	(0.000)	(0.002)	(0.000)	(0.001)	(0.001)	(0.000)
Male	0.066***	0.124***	0.069***	0.066***	0.007	0.059***
	(0.010)	(0.031)	(0.019)	(0.015)	(0.009)	(0.021)
Employed	0.053***	0.073***	0.100***	0.028**	-0.004*	0.055***
	(0.009)	(0.012)	(0.013)	(0.011)	(0.002)	(0.016)
Unemployed	0.093***	0.088***	0.139***	0.099***	0.048***	0.035**
	(0.011)	(0.014)	(0.021)	(0.016)	(0.001)	(0.017)
Having cash problems	0.018	-0.043	0.025*	0.037	0.001	0.033
	(0.013)	(0.027)	(0.014)	(0.025)	(0.004)	(0.021)
Residing in rural areas	-0.055***	-0.068***	-0.050***	-0.047***	-0.089***	-0.058**
	(0.010)	(0.025)	(0.014)	(0.017)	(0.004)	(0.024)
Occupation - Agriculture	-0.029***	0.003	-0.028	-0.036***	-0.037	-0.061***
	(0.009)	(0.014)	(0.017)	(0.012)	(0.053)	(0.016)
Education below secondary	-0.088***	-0.120***	-0.108***	-0.070***	-0.195***	-0.049**
	(0.009)	(0.015)	(0.019)	(0.011)	(0.015)	(0.024)
Having food problems	0.034***	0.040***	0.021*	0.052***	0.008	0.017
	(0.009)	(0.014)	(0.013)	(0.016)	(0.032)	(0.016)
Lack of basic necessities	0.019	0.075	0.005	0.011	0.022***	-0.005
	(0.016)	(0.051)	(0.020)	(0.026)	(0.007)	(0.036)
Climate affect	**0.061*****	**0.101*****	**0.083*****	**0.039*****	**0.069****	**0.085*****
	(0.008)	**(0.035)**	**(0.018)**	**(0.011)**	**(0.030)**	**(0.005)**
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	44,969	3,539	12,058	20,563	2,349	6,460

TABLE 16. The relationship between climate change (on agriculture) and migration aspirations: geographic perspective

Note: Average marginal effects reported. All models include country dummies and a constant term. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Total	North Africa	East Africa	West Africa	Middle Africa	South Africa
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Age	-0.006***	-0.010***	-0.005***	-0.006***	-0.006***	-0.005***
	(0.000)	(0.002)	(0.000)	(0.001)	(0.001)	(0.000)
Male	0.070***	0.126***	0.073***	0.069***	0.010	0.063***
	(0.010)	(0.032)	(0.020)	(0.014)	(0.010)	(0.020)
Employed	0.054***	0.076***	0.103***	0.029***	-0.001	0.057***
	(0.009)	(0.015)	(0.015)	(0.011)	(0.004)	(0.015)
Unemployed	0.093***	0.093***	0.141***	0.099***	0.047***	0.034*
	(0.011)	(0.014)	(0.021)	(0.016)	(0.005)	(0.017)
Having cash problems	0.019	-0.044*	0.025*	0.038	-0.001	0.033*
	(0.013)	(0.022)	(0.013)	(0.025)	(0.001)	(0.020)
Residing in rural areas	-0.058***	-0.069***	-0.053***	-0.050***	-0.091***	-0.064**
	(0.010)	(0.026)	(0.013)	(0.017)	(0.004)	(0.025)
Occupation Agriculture	-0.031***	0.002	-0.027	-0.038***	-0.042	-0.063***
	(0.009)	(0.015)	(0.017)	(0.012)	(0.058)	(0.016)
Education below secondary	-0.098***	-0.139***	-0.117***	-0.077***	-0.210***	-0.065***
	(0.009)	(0.016)	(0.018)	(0.011)	(0.022)	(0.022)
Having food problems	0.032***	0.041***	0.019	0.049***	0.007	0.011
	(0.009)	(0.013)	(0.013)	(0.016)	(0.032)	(0.016)
Lack of basic necessities	0.018	0.070	0.004	0.009	0.024***	-0.004
	(0.016)	(0.047)	(0.020)	(0.027)	(0.001)	(0.037)
Climate on agriculture	**0.035*** **	**0.057*** **	**0.020**	**0.042*** **	**0.001**	**0.020**
	(0.008)	(0.018)	(0.022)	(0.011)	(0.004)	(0.018)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	44,969	3,539	12,058	20,563	2,349	6,460

TABLE 17. The relationship between climate change (on country) and migration aspirations: Vulnerability perspective
Note: Average marginal effects reported. All models include country dummies and a constant term. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

	Rural vs Urban	Education	Agriculture	Food problems	Basic necessities
Variables	(1)	(2)	(3)	(4)	(5)
Age	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Male	0.065***	0.072***	0.066***	0.066***	0.066***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Employed	0.055***	0.058***	0.054***	0.053***	0.053***
	(0.009)	(0.010)	(0.009)	(0.009)	(0.009)
Unemployed	0.094***	0.098***	0.094***	0.094***	0.093***
	(0.011)	(0.012)	(0.011)	(0.011)	(0.011)
Having cash problems	0.017	0.014	0.017	0.021	0.029***
	(0.014)	(0.014)	(0.013)	(0.013)	(0.007)
Residing in rural areas		-0.064***	-0.062***	-0.055***	-0.055***
		(0.010)	(0.009)	(0.010)	(0.010)
Education below secondary	-0.094***		-0.091***	-0.086***	-0.088***
	(0.010)		(0.009)	(0.009)	(0.009)
Occupation - Agriculture	-0.043***	-0.040***		-0.029***	-0.029***
	(0.008)	(0.009)		(0.009)	(0.009)
Having food problems	0.034***	0.030***	0.034***		0.036***
	(0.009)	(0.009)	(0.009)		(0.009)
Lack of basic necessities	0.017	0.017	0.019	0.024	
	(0.017)	(0.016)	(0.016)	(0.016)	
Climate on country					
X Residing in rural areas Yes	**0.042*****				
	(0.011)				
X Residing in rural areas No	**0.083*****				
	(0.011)				
X Education below secondary Yes		**0.032*****			
		(0.011)			
X Education below secondary No		**0.097*****			
		(0.009)			
X Occupation - Agriculture Yes			**0.047*****		
			(0.013)		
X Occupation - Agriculture No			**0.066*****		
			(0.009)		
X Having food problems Yes				**0.083*****	
				(0.013)	
X Having food problems No				**0.049*****	
				(0.009)	
X Lack of basic necessities Yes					**0.061*****
					(0.009)
X Lack of basic necessities No					**0.058*****
					(0.011)
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	44,969	44,969	44,969	44,969	44,969

TABLE 18. The relationship between climate change (on agriculture) and migration aspirations: Vulnerability perspective
Notes: Average marginal effects reported. All models include country dummies and a constant term. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

	Rural vs Urban	Education	Agriculture	Food problems	Basic necessities
Variables	(1)	(2)	(3)	(4)	(5)
Age	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Male	0.070***	0.078***	0.070***	0.070***	0.070***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Employed	0.056***	0.060***	0.055***	0.055***	0.055***
	(0.010)	(0.010)	(0.009)	(0.009)	(0.009)
Unemployed	0.094***	0.098***	0.093***	0.094***	0.093***
	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)
Having cash problems	0.018	0.016	0.018	0.021	0.027***
	(0.014)	(0.014)	(0.013)	(0.013)	(0.008)
Residing in rural areas		-0.068***	-0.063***	-0.058***	-0.058***
		(0.010)	(0.009)	(0.010)	(0.010)
Education below secondary	-0.104***		-0.100***	-0.097***	-0.098***
	(0.010)		(0.009)	(0.009)	(0.009)
Occupation - Agriculture	-0.044***	-0.042***		-0.030***	-0.031***
	(0.008)	(0.009)		(0.009)	(0.009)
Having food problems	0.032***	0.027***	0.032***		0.033***
	(0.009)	(0.009)	(0.009)		(0.009)
Lack of basic necessities	0.015	0.015	0.017	0.021	
	(0.016)	(0.016)	(0.016)	(0.016)	
Climate on agriculture					
X Residing in rural areas Yes	**0.014**				
	(0.011)				
X Residing in rural areas No	**0.055*** **				
	(0.009)				
X Education below secondary Yes		**-0.001**			
		(0.012)			
X Education below secondary No		**0.064*** **			
		(0.008)			
X Occupation - Agriculture Yes			**0.015**		
			(0.013)		
X Occupation - Agriculture No			**0.042*** **		
			(0.008)		
X Having food problems Yes				**0.059*** **	
				(0.011)	
X Having food problems No				**0.024** **	
				(0.009)	
X Lack of basic necessities Yes					**0.038*** **
					(0.009)
X Lack of basic necessities No					**0.027** **
					(0.011)
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	44,969	44,969	44,969	44,969	44,969

REFERENCES

Adger, W. N., de Campos, R. S., Codjoe, S. N. A., Siddiqui, T., Hazra, S., Das, S., ... & Abu, M. (2021). Perceived environmental risks and insecurity reduce future migration intentions in hazardous migration source areas. One Earth, 4(1), 146-157.

Adhikari, Umesh, A. Pouyan Nejadhashemi, and Sean A. Woznicki. (2015). Climate Change and Eastern Africa: A Review of Impact on Major Crops. Food and Energy Security 4(2): 110–32.

Alessandrini Alfredo, Daniela Ghio, and Silvia Migali. (2020). Estimating Net Migration at High Spatial Resolution. LU: Publications Office of the European Union. https://data.europa.eu/doi/10.2760/383386 (October 13, 2020).

Alessandrini Alfredo, Daniela Ghio, and Silvia Migali. (2020). Estimating Net Migration at High Spatial Resolution. LU: Publications Office of the European Union. https://data.europa.eu/doi/10.2760/383386.

AQUASTAT, FAO. (2016). Country Profile-Egypt. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Araujo, Julio, John Marsham, Dave Rowell, Zinyengere Nkulumo, Andrew Ainslie, Andrew Clenaghan, Rosalind Cornforth, Giovanna De Giusti, Barbara Evans, and Declan Finney. (2016). Africa's Climate Helping Decision-Makers Make Sense of Climate Information: Burning Questions-East African Climate Variability and Change.

Assal, Munzoul A M. (2006). Sudan: Identity and Conflict over Natural Resources. Development 49 (3): 101–5. https://doi.org/10.1057/palgrave.development.1100284.

Baalen, Sebastian van, and Malin Mobjörk. (2018). Climate Change and Violent Conflict in East Africa: Integrating Qualitative and Quantitative Research to Probe the Mechanisms. International Studies Review 20 (4): 547–75. https://doi.org/10.1093/isr/vix043.

Belmonte, M., Conte, A., Ghio, D., Kalantaryan, S., & McMahon, S. (2020). Youth and migration: an overview. Publications Office of the European Union.

Black, R., Adger, W.N., Arnell, N.W., Dercon, S., Geddes, A., and Thomas, D. (2011). The effect of environmental change on human migration. Glob. Environ. Change 21, S3–S11.

Black, Richard, Stephen R. G. Bennett, Sandy M. Thomas, and John R. Beddington. (2011). Migration as Adaptation. Nature 478 (7370): 447–49. https://doi.org/10.1038/478477a.

Bondeau, Alberte et al. (2007). Modelling the Role of Agriculture for the 20th Century Global Terrestrial Carbon Balance. Global Change Biology 13(3): 679–706.

Borderon, Marion, Patrick Sakdapolrak, Raya Muttarak, Endale Kebede, Raffaella Pagogna, and Eva Sporer. (2019). Migration Influenced by Environmental Change in Africa: A Systematic Review of Empirical Evidence. Demographic Research 41 (August): 491–544. https://doi.org/10.4054/DemRes.2019.41.18.

Brown, H. Carolyn Peach, Johnson Ndi Nkem, Denis J. Sonwa, and Youssoufa Bele. (2010). Institutional Adaptive Capacity and Climate Change Response in the Congo Basin Forests of Cameroon. Mitigation and Adaptation Strategies for Global Change 15 (3): 263–82. https://doi.org/10.1007/s11027-010-9216-3.

Brown, Oli. (2008). Migration and climate change (Geneva: International Organization for Migration)

Bruckner, T, I A Bashmakov, and Y Mulugetta. (2014). Energy Systems. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge, United Kingdom.

Burke, Marshall, Solomon M. Hsiang, and Edward Miguel. (2015). Global Non-Linear Effect of Temperature on Economic Production. Nature 527(7577): 235–39.

Cai, R., Esipova, N., Oppenheimer, M., & Feng, S. (2014). International migration desires related to subjective well-being. IZA Journal of Migration, 3(1), 1-20.

Cai, Ruohong, Shuaizhang Feng, Michael Oppenheimer, and Mariola Pytlikova. (2016). Climate Variability and International Migration: The Importance of the Agricultural Linkage. Journal of Environmental Economics and Management 79: 135–51.

Carling, J., & Schewel, K. (2018). Revisiting aspiration and ability in international migration. Journal of Ethnic and Migration Studies, 44(6), 945-963.

Cattaneo, Cristina, Michel Beine, Christiane J. Fröhlich, Dominic Kniveton, Inmaculada Martinez-Zarzoso, Marina Mastrorillo, Katrin Millock, Etienne Piguet, and Benjamin Schraven. (2019). Human Migration in the Era of Climate Change. Review of Environmental Economics and Policy 13 (2): 189–206.

Cattaneo, Cristina, and Valentina Bosetti. (2017). Climate-Induced International Migration and Conflicts. CESifo Economic Studies 63 (4): 500–528.

Cattaneo, Cristina, and Giovanni Peri. (2016). The Migration Response to Increasing Temperatures. Journal of Development Economics 122: 127–46. https://doi.org/10.1016/j.jdeveco.2016.05.004.

Ceccherini, Guido, Simone Russo, Iban Ameztoy, Andrea Francesco Marchese, and Cesar Carmona-Moreno. (2017). Heat Waves in Africa 1981-2015, Observations and Reanalysis. Natural Hazards and Earth System Sciences 17 (1): 115–25. https://doi.org/10.5194/nhess-17-115-2017.

Chavunduka, Charles, and Daniel W. Bromley. (2011). Climate, Carbon, Civil War and Flexible Boundaries: Sudan's Contested Landscape. Land Use Policy 28 (4): 907–16. https://doi.org/10.1016/j.landusepol.2011.03.007.

Collier, P. (2004). Greed and Grievance in Civil War. Oxford Economic Papers 56 (4): 563–95. https://doi.org/10.1093/oep/gpf064.

Collier, P., G. Conway, and T. Venables. (2008). Climate Change and Africa. Oxford Review of Economic Policy 24(2): 337–53.

Corbane, Christina, Daniele Ehrlich, Aneta Jadwiga Florczyk, Sergio Freire, Thomas Kemper, Michele

Melchiorri, Martino Pesaresi, and Marcello Schiavina. (2018). Atlas of the Human Planet 2018 – A World of Cities. European Commission, Luxembourg.

Cuaresma, Jesus Crespo. (2018). World Population and Human Capital in the 21st Century. http://www.iiasa.ac.at/web/home/research/researchPrograms/WorldPopulation/PublicationsMediaCoverage/POPNETNewsletter/Popnet46-web.pdf (June 15, 2016).

Czaika, Mathias, and Hein de Haas. (2014). The Globalization of Migration: Has the World Become More Migratory? International Migration Review 48(2): 283–323.

Damette, Olivier, and Mélanie Gittard. (2017). Changement climatique et migrations : les transferts de fonds des migrants comme amortisseurs ? Mondes en développement n° 179 (3): 85. https://doi.org/10.3917/med.179.0085.

Defrance, Dimitri et al. (2020). Impact of Climate Change in West Africa on Cereal Production Per Capita in 2050. Sustainability 12(18): 7585.

De Groot, C., Mulder, C. H., Das, M., & Manting, D. (2011). Life events and the gap between intention to move and actual mobility. Environment and planning A, 43(1), 48-66.

De Jong, G. F. (2000). Expectations, gender, and norms in migration decision-making. Population studies, 54(3), 307-319.

De Jong, G. F., Root, B. D., Gardner, R. W., Fawcett, J. T., & Abad, R. G. (1985). Migration intentions and behavior: Decision making in a rural Philippine province. Population and Environment, 8(1-2), 41-62.

De Juan, Alexander. (2015). Long-Term Environmental Change and Geographical Patterns of Violence in Darfur, 2003–2005. Political Geography 45 (March): 22–33. https://doi.org/10.1016/j.polgeo.2014.09.001.

Dellink, Rob, Jean Chateau, Elisa Lanzi, and Bertrand Magné. (2017). Long-Term Economic Growth Projections in the Shared Socioeconomic Pathways. Global Environmental Change 42: 200–214.

Department of Agriculture, Forestry and Fisheries. (2017). Trends in TheAgricultural Sector 2016. Department of Agriculture, Forestry and Fisheries. https://www.dalrrd.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/.Trends%20in%20the%20Agricultural%20Sector%202016.pdf.

De Sherbinin, A. (2015). Global Estimated Net Migration Grids By Decade: 1970-2000. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4319SVC.

De Sherbinin, A., VanWey, L.K., McSweeney, K., Aggarwal, R., Barbieri, A., Henry, S., Hunter, L.M., Twine, W., and Walker, R. (2008). Rural household demographics, livelihoods and the environment. Glob. Environ. Change 18, 38–53.

Desmet, Klaus, and Esteban Rossi-Hansberg. (2015). On the Spatial Economic Impact of Global Warming. Journal of Urban Economics 88: 16–37.

Docquier, F., Peri, G., & Ruyssen, I. (2014). The cross-country determinants of potential and actual migration. International Migration Review, 48(1_suppl), 37-99.

Dosio Alessandro. (2017). Projection of Temperature and Heat Waves for Africa with an Ensemble of CORDEX Regional Climate Models. Climate Dynamics 49 (1): 493–519.

Dufresne, J.-L. et al. (2013). Climate Change Projections Using the IPSL-CM5 Earth System Model: From CMIP3 to CMIP5. Climate Dynamics 40(9): 2123–65.

Dyson, Tim. (2011). The Role of the Demographic Transition in the Process of Urbanization. Population and Development Review 37: 34–54.

Etzold, B., Ahmed, A. U., Hassan, S. R., & Neelormi, S. (2014). Clouds gather in the sky, but no rain falls. Vulnerability to rainfall variability and food insecurity in Northern Bangladesh and its effects on migration. Climate and Development, 6(1), 18-27.

European Commission. Joint Research Centre. (2021). Population Dynamics, Climate Change and Variability in Western Africa: The Case of Sahel Regions. LU: Publications Office. https://data.europa.eu/doi/10.2760/797541.

European Commission (2021) Statement by Executive Vice-President Timmermans on delivering the European Green Deal (available online at https://ec.europa.eu/commission/presscorner/detail/en/speech_21_3722, accessed 20th October 2021)

FAO. (1997). Plant Nematode Problems and Their Control in the Near East Region: Proceedings of the Expert Consultation on Plant Nematode Problems and Their Control in the Near East Region, Karachi, Pakistan 22 - 26 November 1992. FAO Plant Production and Protection Paper 144. Rome: FAO.
———. 2012. 'Global Ecological Zones for FAO Forest Reporting: 2010 Update'. Forest Resources Assessment Working Paper 179.

FAO/GIEWS. (2020a). GIEWS Country Brief Mali. FAO. http://www.fao.org/giews/countrybrief/country/MLI/pdf/MLI.pdf.
———. (2020b). GIEWS Country Brief Senegal. FAO. http://www.fao.org/giews/countrybrief/country/SEN/pdf/SEN.pdf.

FAO. (2012). Global Ecological Zones for FAO Forest Reporting: 2010 Update. Forest Resources Assessment Working Paper 179.

Feinstein, N. W., and K. J. Mach. (2020). Three Roles for Education in Climate Change Adaptation. Climate Policy 20(3): 317–22.

Fontaine, Bernard, Serge Janicot, and Paul-Arthur Monerie. (2013). Recent Changes in Air Temperature, Heat Waves Occurrences, and Atmospheric Circulation in Northern Africa: HEAT WAVES AND ATMOSPHERIC CIRCULATION. Journal of Geophysical Research: Atmospheres 118 (15): 8536–52. https://doi.org/10.1002/jgrd.50667.

Foresight. (2011). Migration and Global Environmental Change: Future Challenges and Opportunities. London, UK. https://sustainabledevelopment.un.org/content/documents/867migrationscience.pdf.

Frieler, Katja et al. (2017). Assessing the Impacts of 1.5 °C Global Warming – Simulation Protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b). Geoscientific Model Development 10(12): 4321–45.

Gersfelt, Birgitte. (2007). Allocating Irrigation Water in Egypt. In: Per Pinstrup-Andersen and Fuzhi Cheng (Editors), "Food Policy for Developing Countries: Case Studies."'14 Pp.' Per Pinstrup-Andersen and Fuzhi Cheng.

Gonin, Patrick, and Véronique Lassailly-Jacob. (2002). Les réfugiés de l'environnement: Une nouvelle catégorie de migrants forcés? Revue européenne des migrations internationales 18 (2): 139–60. https://doi.org/10.4000/remi.1654.

Graff Zivin J, Neidell M. (2013). Temperature and the allocation of time: implications for climate change. J Labor Econ (in press)

Henderson, J. Vernon, Adam Storeygard, and Uwe Deichmann. (2017). Has Climate Change Driven Urbanization in Africa? Journal of Development Economics 124 (January): 60–82. https://doi.org/10.1016/j.jdeveco.2016.09.001.

Hey, Christian. (2005). EU Environmental Policies: A Short History of the Policy Strategies. Pp. 17–30 in EU environmental policy handbook: a critical analysis of EU environmental legislation: making it accessible to environmentalists and decision makers, EEB publication, edited by S. Scheuer and European Environmental Bureau. Brussels: European Environmental Bureau.

Hoffmann, Roman, Anna Dimitrova, Raya Muttarak, Jesus Crespo Cuaresma, and Jonas Peisker. (2020). A Meta-Analysis of Country-Level Studies on Environmental Change and Migration. Nature Climate Change 10 (10): 904–12. https://doi.org/10.1038/s41558-020-0898-6.

Hoffmann, Roman et al. (2020). A Meta-Analysis of Country-Level Studies on Environmental Change and Migration. Nature Climate Change 10(10): 904–12.

Högbladh, Stina. (2021). UCDP GED Codebook version 21.1, Department of Peace and Conflict Research, Uppsala University

Hsiang SM. (2010). Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. PNAS 107(35):15367–15372

Hultman, Lisa. (2012). Attacks on Civilians in Civil War: Targeting the Achilles Heel of Democratic Governments. International Interactions 38 (2): 164–81. https://doi.org/10.1080/03050629.2012.657602.

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. . Special Report of IPCC. https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/.

Ida, Tetsuji. (2021). Climate refugees – the world's forgotten victims, World Economic Forum (available online at https://www.weforum.org/agenda/2021/06/climate-refugees-the-world-s-forgotten-victims/, accessed 22nd October 2021)

Jiang, Leiwen, and Brian C. O'Neill. (2017). Global Urbanization Projections for the Shared Socioeconomic Pathways. Global Environmental Change 42: 193–99.

Jones, B. (2016). Spatially Explicit Global Population Scenarios Consistent with the Shared Socioeconomic Pathways. Environ. Res. Lett.: 11.

Jones, B, and B C O'Neill. (2016). Spatially Explicit Global Population Scenarios Consistent with the Shared Socioeconomic Pathways. Environmental Research Letters 11 (8): 084003. https://doi.org/10.1088/1748-9326/11/8/084003.

Jones, Bryan, and Brian C O'Neill. (2013). Historically Grounded Spatial Population Projections for the Continental United States. Environmental Research Letters 8 (4): 044021. https://doi.org/10.1088/1748-9326/8/4/044021.

Kaczan, David J, and Jennifer Orgill-Meyer. (2020). The Impact of Climate Change on Migration: A Synthesis of Recent Empirical Insights. Climatic Change 158 (3): 281–300.

Kamal, Bahar. (2017). Climate Migrants Might Reach One Billion by 2050, International Organization for Migration (available online at https://reliefweb.int/report/world/climate-migrants-might-reach-one-billion-2050, accessed 22nd October 2021)

Kc, Samir, and Wolfgang Lutz. (2017). The Human Core of the Shared Socioeconomic Pathways: Population Scenarios by Age, Sex and Level of Education for All Countries to 2100. Global Environmental Change 42: 181–92.

Kelman, Ilan. (2019). Imaginary Numbers of Climate Change Migrants? Social Sciences 8(5): 131.

Kraler, Albert. (2020). Climate Change and Migration. Legal and Policy Challenges and Responses to Environmentally Induced Migration. : 114.

Koubi, V., Spilker, G., Schaffer, L., & Bernauer, T. (2016). Environmental stressors and migration: Evidence from Vietnam. World Development, 79, 197-210.

Leff, Jonah. (2009). Pastoralists at War: Violence and Security in the Kenya-Sudan-Uganda Border Region. International Journal of Conflict and Violence (IJCV), December, 188-203 Pages. https://doi.org/10.4119/IJCV-2785.

Li, Binquan, Wei Zhou, Yaoyang Zhao, Qin Ju, Zhongbo Yu, Zhongmin Liang, and Kumud Acharya. (2015). Using the SPEI to Assess Recent Climate Change in the Yarlung Zangbo River Basin, South Tibet. Water 7 (10): 5474–86. https://doi.org/10.3390/w7105474.

Liu, Junguo, Jimmy R. Williams, Alexander J.B. Zehnder, and Hong Yang. (2007). GEPIC – Modelling Wheat Yield and Crop Water Productivity with High Resolution on a Global Scale. Agricultural Systems 94(2): 478–93.

Lizumi, Toshichika, and Toru Sakai. (2020). The Global Dataset of Historical Yields for Major Crops 1981–2016. Scientific Data 7 (1): 1–7.

Lobell, D.B. and Burke, M. eds., (2009). Climate change and food security: adapting agriculture to a warmer world (Vol. 37). Springer Science & Business Media.

Lobell, David B, and Christopher B Field. (2007). Global Scale Climate–Crop Yield Relationships and the Impacts of Recent Warming. Environmental Research Letters 2 (1): 014002. https://doi.org/10.1088/1748-9326/2/1/014002.

Lustgarten, Abrahm. (2020). The Great Climate Migration (New York: New York Times Magazine, available online at https://www.nytimes.com/interactive/2020/07/23/magazine/climate-migration.html)

Maggio, Giuseppe, Nicholas J Sitko, and Ada Ignaciuk. (2018). Cropping System Diversification in Eastern and Southern Africa: Identifying Policy Options to Enhance Productivity and Build Resilience.

Marchiori, Luca, Jean-François Maystadt, and Ingmar Schumacher. (2012). The Impact of Weather Anomalies on Migration in Sub-Saharan Africa. Journal of Environmental Economics and Management 63 (3): 355–74. https://doi.org/10.1016/j.jeem.2012.02.001.
———. (2017). Is Environmentally Induced Income Variability a Driver of Human Migration? Migration and Development 6 (1): 33–59. https://doi.org/10.1080/21632324.2015.1020106.

Marcus, Harold G., and Anthony D. Low. n.d. Eastern Africa. Encyclopedia Britannica. https://www.britannica.com/place/eastern-Africa.

Massey, Douglas S. et al. (1993). Theories of International Migration: A Review and Appraisal. Population and Development Review 19(3): 431–66.

Mastrorillo, Marina, Rachel Licker, Pratikshya Bohra-Mishra, Giorgio Fagiolo, Lyndon D. Estes, and Michael Oppenheimer. (2016). The Influence of Climate Variability on Internal Migration Flows in South Africa. Global Environmental Change 39: 155–69. https://doi.org/10.1016/j.gloenvcha.2016.04.014.

Maystadt, J.-F., M. Calderone, and L. You. (2015). Local Warming and Violent Conflict in North and South Sudan. Journal of Economic Geography 15 (3): 649–71. https://doi.org/10.1093/jeg/lbu033.

Menashe-Oren, Ashira, and Philippe Bocquier. (2021). The Role of Internal Migration in Urbanisation in Contemporary Low- and Middle-Income Countries. Document de travail.

Menashe - Oren, Ashira, and Philippe Bocquier. (2021). Urbanization Is No Longer Driven by Migration in Low and Middle-Income Countries (1985–2015). Population and Development Review, July, padr.12407. https://doi.org/10.1111/padr.12407.

McMahon, Simon and Sigona, Nando. (2018). Navigating the Central Mediterranean in a time of 'crisis' : Disentangling migration governance and migrant journeys Sociology, 52:3, 497-514

Migali, S. and Scipioni, M. (2018). A global analysis of intentions to migrate, European Commission, 2018, JRC111207

Migali, Silvia, Fabrizio Natale, and Guido Tintori, eds. (2018). International Migration Drivers: A Quantitative Assessment of the Structural Factors Shaping Migration. Luxembourg: European Commission Publication Office.

Migali, Silvia, Fabrizio Natale, Guido Tintori, Sona Kalantaryan, Sara Grubanov-Boskovic, Marco Scipioni, Fabio Farinosi, et al. (2018). International Migration Drivers. EUR - Scientific and Technical Research Reports. Publications Office of the European Union. JRC112622. https://doi.org/10.2760/63833 (main report online),10.2760/56068 (exec summary online),10.2760/565135 (main report print),10.2760/933233 (exec summary print).

Mistry, Malcolm Noshir. (2019). A High-Resolution (0.25 Degree) Historical Global Gridded Dataset of Climate Extreme Indices (1970-2016) Using GLDAS Data, Supplement to: Mistry, Malcolm Noshir (2019): A High Resolution Global Gridded Historical Dataset of Climate Extreme Indices. Data, 4(1). Text/tab-separated-values. PANGAEA - Data Publisher for Earth & Environmental Science. https://doi.org/10.1594/PANGAEA.898014.

Morton, J. F. (2007). The Impact of Climate Change on Smallholder and Subsistence Agriculture. Proceedings of the National Academy of Sciences 104(50): 19680–85.

Mpandeli, Sylvester, Luxon Nhamo, Sithabile Hlahla, Dhesigen Naidoo, Stanley Liphadzi, Albert Thembinkosi Modi, and Tafadzwanashe Mabhaudhi. (2020). Migration under Climate Change in Southern Africa: A Nexus Planning Perspective. Sustainability 12 (11): 4722. https://doi.org/10.3390/su12114722.

Müller, Christoph et al. (2017). Global Gridded Crop Model Evaluation: Benchmarking, Skills, Deficiencies and Implications. Geoscientific Model Development 10(4): 1403–22.
———. (2019). The Global Gridded Crop Model Intercomparison Phase 1 Simulation Dataset. Scientific Data 6(1): 50.

Muttarak, Raya, and Wolfgang Lutz. (2014). Is Education a Key to Reducing Vulnerability to Natural Disasters and Hence Unavoidable Climate Change? Ecology and Society 19(1): art42.

Myers, N., “Environmental Refugees: An emergent security issue”, 13th Economic Forum, Prague, May 2005

Natale, Fabrizio, Silvia Migali, and Rainer Münz. (2018). Many More to Come? Migration from and within Africa. https://doi.org/10.2760/1702.

Naude, W. (2010). The Determinants of Migration from Sub-Saharan African Countries. Journal of African Economies 19 (3): 330–56. https://doi.org/10.1093/jae/ejq004.

Niang, Isabelle, Oliver C. Ruppel (Namibia) Lead Authors Mohamed Abdrabo (Egypt, Ama Essel (Ghana, Christopher Lennard (South Africa, Jonathan Padgham (USA, Penny Urquhart (South Africa) Contributing Authors Ibidun Adelekan (Nigeria, Sally Archibald (South Africa, et al. 2014. ‘IPCC WGII AR5 Chapter 22. Africa’. https://doi.org/10.13140/RG.2.2.22673.84329.

Nordhaus, William. (2013). The Climate Casino. Yale University Press. http://www.jstor.org/stable/j.ctt5vkrpp (May 7, 2021).

O’Neill, Brian C. et al. (2017). The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century. Global Environmental Change 42: 169–80.
———. (2020). Achievements and Needs for the Climate Change Scenario Framework. Nature Climate Change 10(12): 1074–84.

Olsson, Ola, and Eyerusalem Siba. (2013). Ethnic Cleansing or Resource Struggle in Darfur? An Empirical Analysis. Journal of Development Economics 103 (July): 299–312. https://doi.org/10.1016/j.jdeveco.2013.02.004.

Parkes, Ben et al. (2018). Projected Changes in Crop Yield Mean and Variability over West Africa in a World 1.5 K Warmer than the Pre-Industrial Era. Earth System Dynamics 9(1): 119–34.

Peri, Giovanni, and Akira Sasahara. (2019). The Impact of Global Warming on Rural-Urban Migrations: Evidence from Global Big Data. Cambridge, MA: National Bureau of Economic Research. http://www.nber.org/papers/w25728.pdf (August 19, 2019).

Peri, Giovanni, and Akira Sasahara. (2019). The Impact of Global Warming on Rural-Urban Migrations: Evidence from Global Big Data'. w25728. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w25728.

Pesaresi, Martino, Aneta Florczyk, Marcello Schiavina, Michele Melchiorri, and Luca Maffenini. (2019). GHS Settlement Grid, Updated and Refined REGIO Model 2014 in Application to GHS-BUILT R2018A and GHS-POP R2019A, Multitemporal (1975-1990-2000-2015), R2019A. European Commission, Joint Research Centre (JRC). https://doi.org/10.2905/42E8BE89-54FF-464E-BE7B-BF9E64DA5218.

Petroliagkis, Thomas, and Alfredo Alessandrini. (2021). Screening and Selecting Climate Change Impact Parameters as Potential Drivers of Migration. LU: Publications Office of the European Union.

Pham-Duc, Binh, Florence Sylvestre, Fabrice Papa, Frédéric Frappart, Camille Bouchez, and Jean-Francois Crétaux. (2020). The Lake Chad Hydrology under Current Climate Change. Scientific Reports 10 (1): 5498. https://doi.org/10.1038/s41598-020-62417-w.

Potts, Deborah. (2009). The Slowing of Sub-Saharan Africa's Urbanization: Evidence and Implications for Urban Livelihoods. Environment and Urbanization 21(1): 253–59.
———. (2016). Debates about African Urbanisation, Migration and Economic Growth: What Can We Learn from Zimbabwe and Zambia?: Debates about African Urbanisation, Migration and Economic Growth. The Geographical Journal 182(3): 251–64.

Potts, Deborah. (2009). The Slowing of Sub-Saharan Africa's Urbanization: Evidence and Implications for Urban Livelihoods. Environment and Urbanization 21 (1): 253–59. https://doi.org/10.1177/0956247809103026.

Raleigh, Clionadh, and Håvard Hegre. (2009). Population Size, Concentration, and Civil War. A Geographically Disaggregated Analysis. Political Geography 28 (4): 224–38. https://doi.org/10.1016/j.polgeo.2009.05.007.

Rao, Narasimha D., Petra Sauer, Matthew Gidden, and Keywan Riahi. (2019). Income Inequality Projections for the Shared Socioeconomic Pathways (SSPs). Futures 105: 27–39.

Riede, Jens O, Rafael Posada, Andreas H Fink, and Frank Kaspar. (2016). What's on the 5th IPCC Report for West Africa? In Adaptation to Climate Change and Variability in Rural West Africa, 7–23. Springer.

Rigaud, Kanta Kumari, Alex de Sherbinin, Bryan Jones, Jonas Bergmann, Viviane Clement, Kayly Ober, Jacob Schewe, et al. (2018). Groundswell: Preparing for Internal Climate Migration. World Bank. https://doi.org/10.1596/29461.

Rogers, Andrei. (2008). Demographic Modeling of the Geography of Migration and Population: A Multiregional Perspective. Geographical Analysis 40 (3): 276–96.

Rosenzweig, C. et al. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and Pilot Studies. Agricultural and Forest Meteorology 170: 166–82.

Roudier, Philippe, Benjamin Sultan, Philippe Quirion, and Alexis Berg. (2011). The Impact of Future Climate Change on West African Crop Yields: What Does the Recent Literature Say? Global Environmental Change 21(3): 1073–83.

Rowhani, Pedram, Olivier Degomme, Debarati Guha-Sapir, and Eric F Lambin. (2012). Malnutrition and Conflict in Eastern Africa: Impacts of Resource Variability on Human Security. In Climate Change, Human Security and Violent Conflict, 559–71. Springer.

Russo, Simone, Jana Sillmann, Sebastian Sippel, Monika J. Barcikowska, Claudia Ghisetti, Marek Smid, and Brian O'Neill. (2019). Half a Degree and Rapid Socioeconomic Development Matter for Heatwave Risk. Nature Communications 10 (1): 136. https://doi.org/10.1038/s41467-018-08070-4.

Ruyssen, Ilse, and Glenn Rayp. (2014). Determinants of Intraregional Migration in Sub-Saharan Africa 1980-2000. The Journal of Development Studies 50 (3): 426–43. https://doi.org/10.1080/00220388.2013.866218.

Sakdapolrak, P., Promburom, P., & Reif, A. (2014). Why successful in situ adaptation with environmental stress does not prevent people from migrating? Empirical evidence from Northern Thailand. Climate and Development, 6(1), 38-45.

Schewe, Jacob et al. (2014). Multimodel Assessment of Water Scarcity under Climate Change. Proceedings of the National Academy of Sciences 111(9): 3245–50.

Schlenker, Wolfram, and David B Lobell. (2010). Robust Negative Impacts of Climate Change on African Agriculture. Environmental Research Letters 5(1): 014010.

Schlenker W, Roberts M. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. PNAS 106(37):391–398

Sherbinin, Alex de. (2014). Climate Change Hotspots Mapping: What Have We Learned? Climatic Change 123 (1): 23–37. https://doi.org/10.1007/s10584-013-0900-7.

Sonwa, Denis J., Olufunso A. Somorin, Cyprian Jum, Mekou Y. Bele, and Johnson N. Nkem. (2012). Vulnerability, Forest-Related Sectors and Climate Change Adaptation: The Case of Cameroon. Forest Policy and Economics 23 (October): 1–9. https://doi.org/10.1016/j.forpol.2012.06.009.

Sosnowski, Amelia, Eman Ghoneim, Jeri J. Burke, Elizabeth Hines, and Joanne Halls. (2016). Remote Regions, Remote Data: A Spatial Investigation of Precipitation, Dynamic Land Covers, and Conflict in the Sudd Wetland of South Sudan. Applied Geography 69 (April): 51–64. https://doi.org/10.1016/j.apgeog.2016.02.007.

Striessnig, Erich, and Wolfgang Lutz. (2016). Demographic Strengthening of European Identity. Population and Development Review 42(2): 305–11.

Stuch, Benjamin, Joseph Alcamo, and Rüdiger Schaldach. (2021). Projected Climate Change Impacts on Mean and Year-to-Year Variability of Yield of Key Smallholder Crops in Sub-Saharan Africa. Climate and Development 13(3): 268–82.

Sundberg, Ralph, and Erik Melander. (2013). Introducing the UCDP Georeferenced Event Dataset. Journal of Peace Research 50 (4): 523–32. https://doi.org/10.1177/0022343313484347.

Taylor, Karl E., Ronald J. Stouffer, and Gerald A. Meehl. (2012). An Overview of CMIP5 and the Experiment Design. Bulletin of the American Meteorological Society 93(4): 485–98.

Termote, Marc. (1993). Causes et Conséquences Économiques de La Migration Internationale. Revue Études Internationales 24 (1): 51.

Turner, B L et al. (2003). A Framework for Vulnerability Analysis in Sustainability Science. Proceedings of the National Academy of Sciences of the United States of America 100(14): 8074–79.

UNEP. (2018). South Sudan: First State of Environment and Outlook Report 2018.

van Vuuren, Detlef P. et al. (2011). The Representative Concentration Pathways: An Overview. Climatic Change 109(1–2): 5–31.

United Nations, Department of Economic and Social Affairs, Population Division. (2019). World Population Prospects 2019. Online Edition. Rev. 1.

Vesco, Paola, Matija Kovacic, Malcolm Mistry, and Mihai Croicu. (2021). Climate Variability, Crop and Conflict: Exploring the Impacts of Spatial Concentration in Agricultural Production. Journal of Peace Research 58 (1): 98–113. https://doi.org/10.1177/0022343320971020.

Vicente-Serrano, S. M., S. Beguería, J. I. López-Moreno, M. Angulo, and A. El Kenawy. (2010). A New Global 0.5° Gridded Dataset (1901–2006) of a Multiscalar Drought Index: Comparison with Current Drought Index Datasets Based on the Palmer Drought Severity Index. Journal of Hydrometeorology 11 (4): 1033–43. https://doi.org/10.1175/2010JHM1224.1.

Warszawski, Lila et al. (2014). The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project Framework. Proceedings of the National Academy of Sciences 111(9): 3228–32.
'Wittgenstein Centre Human Capital Data Explorer'. http://dataexplorer.wittgensteincentre.org/wcde-v2/ (August 30, 2021).

World Bank. (2020). World Development Indicators. URL: http://data.worldbank.org/data-catalog/world-development-indicators

Yousry, Mahmoud, and Tarek A Aboul Atta. (1997). The Challenge of Urban Growth in Cairo. The Urban Challenge in Africa: Growth and Management of Its Large Cities, London, Tokyo and Paris: The United Nations University Press. Available from Www. Unu. Edu/Unupress/Unupbooks/Uu26ue/Uu26ue0e. Htm.

Zhao, Chuang et al. (2017). Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates. Proceedings of the National Academy of Sciences 114(35): 9326–31.

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