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Understanding the climate change-migration nexus through the lens of household surveys: An empirical review to assess data gaps

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Abstract

Over the last two decades, the causal relationship between climate change and migration has gained increasing prominence in international research and policy. Despite recent advances in conceptual frameworks and applied techniques, the empirical evidence does not provide clear-cut conclusions, mainly due to the intrinsic complexity of the phenomenon of interest, the irreducible heterogeneity of the transmission mechanisms, some common misconceptions, and, in particular, the paucity of adequate data. In this work, we present the first data-oriented review of the nexus between climate change and migration. Then, we discuss open issues and assess the main data gaps that currently prevent more robust quantifications. Finally, using a prominent survey collection produced by the World Bank as a case study, we highlight opportunities for exploiting and enhancing the potential of existing multi-topic and multi-purpose household survey datasets.

KEYWORDS

climate change, data gaps, household surveys, microdata, migration

JEL CLASSIFICATION
C80, O12, O15, Q54

1 | INTRODUCTION

Over the last couple of decades, the causal relationship between climate change and migration has emerged as a central issue for both scholars and policymakers, receiving growing attention in the media and public debate, and gaining an important place among policy priorities of the global agenda. Environment and climate change have been formally recognized as key drivers of migration in the UN Global Compact for Safe, Orderly, and Regular Migration (GCM) endorsed by the UN General Assembly in 2018. The Sustainable Development Goals (SDGs) explicitly include a specific target (10.7) to "facilitate orderly, safe, and responsible migration and mobility of people, including through implementation of planned and well-managed migration policies."

As a consequence of this increased prominence at the international level, climate-induced human migration has become a main channel of interest for the quantification of the socio-economic impacts of future climate change. The common expectation is that an increase in average global temperature of 2°C or more above pre-industrial levels would result in substantially higher migration flows in the coming decades (Biermann & Boas, 2010; Myers, 2002), a view which is endorsed by the recent Groundswell reports from the World Bank (Clement et al., 2021; Rigaud et al., 2018). However, this view is not supported by solid research and sound empirical evidence (Boas et al., 2019), which, as our survey will demonstrate, is in part due to severe data gaps. Actually, there is mixed and inconclusive evidence about not just the magnitude, but even the sign of the climate-migration relationship, and widespread heterogeneity of findings rule out possible generalizations of the effects of climate change on mobility.

Despite the lack of substantive evidence, concerns about potentially dramatic increases in migratory flows triggered by large-scale climate-induced environmental phenomena have spurred the birth of an empirical research field dedicated to shedding light on the consequences of climate-related hazards on human mobility. As a result, a growing body of research has started to investigate the causal link between the two phenomena to satisfy the need for reliable projections and provide robust empirical evidence on the issue. The empirical results differ depending on the environmental factors considered, the data and scale of the analysis, the methodology employed, and the geographical contexts covered. However, scholars agree that lack of data are the most severe constraint. Notwithstanding the increasing availability of panel micro datasets, coupled with refinements of conceptual frameworks and advances in econometric techniques, there are still many key questions to tackle and technical hurdles to overcome: given the need to differentiate types of migration (displacements, rural-urban flows, international migrations), what are the information needs? And how to prioritize them? What are the opportunities offered by the household survey data collection? What could be possibly achieved with slight modifications to current data-collection instruments used by popular, long-established micro (household) survey programs, such as the World Bank's Living Standards Measurement Study (LSMS)?

This critical review aims to shed light on the above issues. Given the vastness of the topic and the huge body of work available, a few preliminary clarifications on the scope of this review are in order: first, this review has an explicit orientation toward *empirical* and *data* perspectives on climate change-migration links. Hence, we assume as given the state of the art of the theoretical

underpinnings of current empirical investigation, and we do not consider studies on projections or predictions of future migratory flows; second, since it is now widely recognized that developing countries, which are both hotter and poorer, will be disproportionately affected by climate change (Auffhammer, 2018; Dell et al., 2014; Nordhaus & Moffat, 2017; Tol, 2018), the focus of this work will be on migration originating within and/or from these countries, and specifically from Sub-Saharan African (SSA) countries, that are among the world's least developed and most vulnerable to climate change (World Bank, 2022); third, we will focus on the more *recent* empirical advances—this means we limit our exploration to studies and works published in the last decade;[1] fourth, in our assessment of data gaps in household survey data, we use, as a case study, the Living Standards Measurement Study (LSMS) collection by the World Bank, a set of multi-purpose household surveys with a geographical focus on SSA.

The LSMS has been the World Bank's flagship household survey program since 1980 and it is a global leader in the methodological development of rich and extensive multi-topic questionnaires designed to study various aspects of household welfare. Within the broader LSMS program, we restrict our attention to the LSMS-ISA household survey program because of its explicit focus on agriculture, one of the leading channels through which climate-change impacts materialize in developing settings and shape migratory responses. Nonetheless, most reflections and recommendations we propose throughout this paper are relevant to multi-topic and multi-purpose household surveys in general.

This paper is organized as follows. Section 2 reviews the most recent empirical literature on the causal relationship between climate change and migration. This section also clarifies important conceptual distinctions, summarizes key open research questions, and takes a closer look at Sub-Saharan Africa, the area where the LSMS-ISA survey program currently operates. Section 3 presents the empirical and methodological challenges and highlights related data gaps. Section 4 focuses on LSMS-ISA data and discusses their main limitations and opportunities in leveraging its key advantages. Section 5 sets up an agenda for future work and concludes this paper.

2 | REVIEW AND CURRENT STATE OF THE LITERATURE

2.1 | A synthesis of recent empirical findings

In this subsection, we carry out an updated review of the literature by focusing on the period from 2010 to 2022.[2] Heterogeneity—depending on several context-specific features including, *inter alia*, the type and frequency of climatic shocks, peoples' resources, and adaptation strategies—seems to be an irreducible aspect of the climate-migration relationship. Such complexity calls for caution when issuing predictions that climate change will force tens of millions of people to move within and/or out of their own country (Boas et al., 2019; Clement et al., 2021; Rigaud et al., 2018) and instead pay more attention to the potential of climate change to trap more vulnerable and poorer populations in immobility, with large consequences on global welfare.

By analyzing this flourishing strand of the literature, we flesh out some thematic issues that we see as pivotal to the subsequent analysis of the empirical issues and data gaps. Specifically, we look at recent insights into five key facets of the climate-migration relationship as they have emerged in the literature: slow versus fast-onset events (Bohra-Mishra et al., 2014; United Nations Framework Convention on Climate Change, 2012); direct and indirect links (Bardsley & Hugo, 2010); internal versus international migrants; liquidity constraints; and migration as adaptation.[3] Besides the discussion carried out below, the reader can consult Table A.1 in the Appendix where

we summarize, for each relevant empirical work on climate migration we identified, the main outcome of interest, the level of analysis (micro/meso/macro), the migration and climate data used, the area and time period under scrutiny, the model and identification strategy, and the key findings.

2.1.1 | Fast-onset events versus slow-onset changes

The impacts on migration from fast-onset extreme weather events (such as hurricanes, heavy rains, floods, and landslides) related to climate change are usually sudden and direct, resulting mainly in temporary movements over short distances (McLeman & Gemenne, 2018). A specific strand of the literature investigated the role of floods on migration, with mixed results: while Gray and Mueller (2012a) and Bohra-Mishra et al. (2014) document a lack of significant effects of floods on migration in, respectively, Ethiopia and the Philippines, Mueller et al. (2014) find that floods reduce the probability of migrating in Pakistan. Koubi et al. (2016) show that in Vietnam fast-onset shocks are more likely to trigger migration, whereas long-term environmental changes (such as salinization) *reduce* the likelihood of migration. All these studies, which report similar findings of the absence of large migratory flows caused by weather shocks, employ *direct* measures of migration—taken from household survey microdata—to study internal migration, except for Mueller et al. (2014), who also use household survey data but capture any type of migration.[4] In contrast, Robalino et al. (2015) carry out a meso-level analysis using an indirect proxy of migration—census data—and provide evidence that flooding and other hydro-environmental emergencies increase migratory flows in Costa Rica, but also find that more severe emergencies decrease migration. Kaczan and Orgill-Meyer (2020) argue that this may happen as floods and other fast-onset shocks rapidly deplete household assets and resources, leaving households unable to migrate.

Using a global dataset that combines climatic, census, and night-light data to build indirect measures of rural-urban migration, Castells-Quintana et al. (2021) study the macro-level relationship between changes in weather patterns and the spatial distribution of population and economic activity, and find that worse climatic conditions are associated with higher urbanization. Their results suggest that while slow-onset changes in climate may lead to more permanent, and more long-distance, movements, sudden-onset events are primarily associated with temporary displacements and short-term migration to nearby urban areas. Koubi et al. (2022) use cross-country survey data from Cambodia, Nicaragua, Peru, Uganda, and Vietnam and document that there is substantial heterogeneity in the migration response: less educated and lower-income people are less likely to migrate after exposure to fast-onset shocks, compared to people with higher education and more economic resources. Finally, in poor countries, even in the absence of sudden resource depletion, the populations affected may not have enough monetary resources for long-distance migration (Zickgraf & Perrin, 2016).

In addition to the above studies that are based on traditional measures of migration, there are also recent works leveraging non-conventional data sources to investigate migration responses triggered by fast-onset events: for example, twin works by Lu et al. (2016a, 2016b) used anonymized Call Detail Records (CDR) from a mobile network provider (Grameenphone) to retrieve geographical positions and movements of users, so as to be able to examine behavioral and human mobility effects of the 2013 Mahasen cyclone in Bangladesh. Overall, while the expectation was to detect mass evacuations and displacement from coastal areas in the aftermath of the cyclone, the authors found little evidence of permanent changes in the distribution of population across areas.[5]

Overall, Cattaneo et al. (2019) emphasize that the main insight from this strand of the literature is that the potential for fast-onset events to cause long-term, long-distance migrations appears limited, especially in the case of costlier international migration. From a data perspective, it is remarkable that this insight is consistent across studies despite wide differences in terms of the type of analysis—ranging from micro to meso and macro—as well as data sources employed to build migration outcomes—ranging from direct measures based on traditional and nonconventional data to indirect proxies retrieved from census and urbanization data.

In contrast, slow-onset changes are more likely to induce migration than rapid-onset ones, but the literature has paid less attention to the migration outcomes of slow-onset changes compared to sudden disasters (Kaczan & Orgill-Meyer, 2020). Part of the reason is that slow-onset changes are not regarded as sufficiently extreme to trigger migration, since they have less of an immediate impact on people (Koubi et al., 2022). The effect of events such as drought, desertification, and warming on migration is less sudden than floods, landslides, hurricanes, and similar events, because they tend to emerge gradually, and attribution is intrinsically more difficult for departures in response to gradual changes. Moreover, migratory flows can be staggered, more difficult to capture, and more susceptible to measurement error.

There are bodies of work documenting that slow-onset changes and rising temperatures increase migration (Bohra-Mishra et al., 2017; Cai et al., 2016; Dallmann & Millock, 2017; Dillon et al., 2011; Feng et al., 2010; Gray & Mueller, 2012a, 2012b; Hunter et al., 2013; Jessoe et al., 2018; Mastrorillo et al., 2016; Mueller et al., 2014). Many of these studies are discussed in other sections of this paper. From a data perspective, most of these studies use household surveys and study internal migration, but the results are also confirmed by macro and meso-level analyses on international migration (Cai et al., 2016; Hunter et al., 2013). However, there are some notable exceptions in this literature showing that slow-onset changes may also have the opposite effect, resulting in a reduction in migration. For example, the macroeconomic analysis by Cattaneo and Peri (2016) finds that, consistent with the presence of severe liquidity constraints, higher temperatures reduce the probability of migration from poor countries. The data include bilateral migration stocks and macro-level data on urbanization rates. The findings of Cottier and Salehyan (2021)—who use direct information on unauthorized migration—and Martinez Flores et al. (2021)—who use cell-level data from the IMO on the number of international migrants—on the role of droughts in influencing international migration support this conclusion. From a within-country internal-migration perspective, Hirvonen (2016) uses household survey data and shows that temperature anomalies decrease (male) migration in rural Tanzania because of tightened liquidity constraints. The meso-level study by Liu et al. (2022) leverages census data to explore responses to slow-onset temperature changes in Indian districts, and concludes that progressive warming and rising temperatures inhibit structural transformation and limit rural-urban migration in households living in isolated areas.

Other authors emphasize that, in most cases, migration depends much more on political and economic factors and is only minimally associated with slow-onset changes. For example, Selby et al. (2017) find that environmental variables have a marginal role in explaining migration flows to Syria in the period before the civil war. Similarly, Niva et al. (2021) performed a geospatial analysis of a gridded global net migration dataset for the decade 1990–2000, and found that slow-onset changes, such as droughts and water scarcity, were the dominant environmental events in explaining net-migration. Yet, they also emphasize that income levels and adaptive capacity crucially mediate environmental variables in determining migration outcomes.

In short, while there seems to be a prevailing consensus that slow-onset shocks do increase migratory flows, there are cases in which the opposite happens, and affected populations are instead trapped in immobility because of the negative consequences of such shocks on their liquidity. This should come as no surprise: since the determinants of migration, and especially climate-related migration, are complex (IPCC, 2014), it is expected that the sign of the relationship cannot be known a priori, as the direction will depend on local circumstances and is ultimately an empirical question.

In terms of data gaps, there is scarce micro evidence coming from studies using direct measures of migration—primarily individual panels and household survey data, on the immobility effects of slow-onset changes such as droughts, soil erosion, and desertification, and scant within-country research on the quantification of the specific channels driving heterogeneous responses—especially in terms of the sign of the relationship, other than its magnitude—to both slow and fast-onset shocks in poor countries.

Lastly, weather data employed typically come from "objective" data sources, but there are exceptions using self-reported measures of weather shocks (e.g., Gray & Mueller, 2012a). However, the functional form in which weather variables enter in the regression (e.g., linear vs. non-linear), the type of weather variable (e.g., temperature and rainfall vs. SPEI), and the specific measure of weather shocks employed (levels, anomalies with respect to long-run averages, annual vs. growing-season measures, etc.) vary substantially across the empirical literature. Since there is recent evidence (Michler et al., 2021) that the relationship between agricultural outcomes—one of the key transmission channels in the climate-migration relationship—and weather variability is very sensitive to these key choices, the lack of systematic approaches and thorough prescriptions appears as an important data gap in the literature, which could partly be responsible for the heterogeneous findings.

2.1.2 | Direct versus indirect effects

Climate change could exert both direct and indirect effects on migration. In the latter case, one must understand how climatic events affect other drivers of migration via demographic, socioeconomic, and political channels. Among the main channels of the indirect effects of weather and climate-related hazards on migration, the two most important ones are the economic and sociopolitical drivers. To date, however, there is only limited and partial evidence about these links. Feng et al. (2010) carry out a meso-level analysis on international movements with census data and provide empirical support to the links between extreme temperatures, crop yields, farmers' incomes, and migration from Mexico to the United States. In an important macroeconomic study, Marchiori et al. (2012) leverage annual panel data from 1960 to 2010 and find that weather shocks in sub-Saharan Africa not only boost rural-urban migration through a decrease in rural wages, but also affect international migration both directly and indirectly. Similarly, Dallmann and Millock (2017) find that drought effects on inter-state migration in India are stronger in agricultural states.

Developing countries are particularly vulnerable to climate-related hazards because they have a large share of their incomes from agriculture (the most weather-dependent sector), tend to be hotter and closer to biophysical limits, and lack adaptive capacity to cope with the negative impacts of climate change. For example, using bilateral migration data from 1980 to 2010, Cai et al. (2016) demonstrate that temperature shocks induce international migration only from agriculture-dependent countries and increase migration to OECD countries. Using a panel of

bilateral migration flows, to investigate the role of climatic factors in international migration, the macro study by Beine and Parsons (2015) finds evidence of an indirect channel operating through wages. Niva et al. (2021) couple cell-level net-migration data with a machine learning predictive approach based on a random forest model, and find that income is a key determinant in explaining both net-negative and net-positive migration. Based on this result they conclude that it is the difference between income-levels of the origin and destination areas that matters, rather than income level *per s*e.

Other than affluence, the main socio-political factor investigated in the specialized literature is the well-known (and often prominent in the media) conflict channel. For example, Kelley et al. (2015) suggest that a prolonged and unprecedented drought in parts of Syria exacerbated the (pre-existing) vulnerability of the affected population, prompting them to migrate. According to their view, migration, in turn, increased tensions and contributed to the outbreak of the civil war. Note, however, that there are sharp disagreements about the possible causal role of climate change via migration in the Syrian civil war (Fröhlich, 2016; Selby et al., 2017) and that, more generally, the relationship between migration, climate change, and conflict is particularly complex and context-specific.

Regarding data gaps, we notice that there is a paucity of microeconomic studies exploring the differences and linkages between direct and indirect effects, especially with survey data containing direct information on migrants' histories. Multi-topic and multi-purpose household surveys, especially those with agricultural modules such as the LSMS-ISA, particularly show promise for shedding light on these different mechanisms and the way in which they operate at the microeconomic level, but, until now, their potential remains underutilized.

2.1.3 | International versus internal migration

Previous research paid more attention to weather and climate-related international migration due to the paucity of internal migration data in developing contexts (Laczko & Aghazarm, 2009). However, the picture has changed in the last decade and we are witnessing an increasing number of studies focusing on the relationship between weather shocks and short or long-distance within-country movements, sometimes even comparing migration outcomes across multiple types of destinations. Gray and Mueller (2012b) use longitudinal household survey data to study the effects of natural disasters in Bangladesh and find that these are stronger and more significant for local movements than long-distance outmigration. Jessoe et al. (2018) couple an individual retrospective panel with daily weather data from ground stations to show that extreme heat events in Mexico boost rural-urban internal migration as well as cross-border migration to the United States. Hirvonen (2016) finds that, in rural Tanzania, temperature increases reduce internal migration via increased liquidity constraints implied from the estimated negative consumption shock, but detects this effect only for men. Peri and Sasahara (2019) study internal rural-urban movements and, using a gridded global dataset covering the period 1970–2000, find that progressive warming reduces rural-urban migration in poorer countries but increases it in middle-income countries. Gray and Bilsborrow (2013) find that adverse rainfall conditions reduce local, short-distance migration (i.e., movement within the same canton)[6] and international migration in Ecuador, but increase internal long-distance (between-cantons) migration, pointing to highly heterogeneous impacts concerning the type of migration. Nawrotzki et al. (2013) employ individual retrospective migration data taken from censuses and find a positive and statistically significant relationship between weather anomalies and international migration from Mexico to the United

States. Liu et al. (2022), working with Indian census data, also show that increasing temperature can reduce internal rural-urban migration.

Cottier and Salehyan (2021) use temporally disaggregated data on the detection of unauthorized migrants at the EU's external borders and report that droughts in origin countries do not increase international migration towards the European Union but, if anything, reduce it, in particular for countries dependent on agriculture, whereas more rainfall increases migration. Their interpretation of the results is that international migration is cost-prohibitive and that adverse weather shocks amplify liquidity constraints. Similarly, the study by Schutte et al. (2021) on the association between climatic conditions and asylum migration reveals that temperature anomalies are weak predictors of bilateral asylum migration to the European Union, and concludes that future asylum migration will mainly be driven by political changes rather than by climate change. This is in line with the findings of the meso-level analysis by Martinez Flores et al. (2021) for West and Central Africa, which estimates that a standard deviation decrease in soil moisture leads to a 25-percent reduction in the number of international migrants, likely due to liquidity constraints. Bekaert et al. (2021) leverage individual-level cross-sectional data from Gallup World Polls conducted in 90 countries to show that exposure to environmental stressors increases the probability of intention to migrate, both domestically and internationally (but more so intra-regionally), especially in rural and less developed regions.

In short, there seems to be wide heterogeneity in the type and destination of migratory flows triggered by climatic shocks, depending on a variety of factors including, among others, the severity and frequency of the shock, the gender and resources of the affected individuals, and the context of the case study. Despite such heterogeneity, however, meta-analyses of the existing studies have found evidence that the case for weather-related migration is much more compelling for internal, within-country movements than for international cross-border flows (Hoffmann et al., 2020), a finding which contradicts the "conventional wisdom" about large-scale international migration triggered by climate change. Lastly, an important missing piece, indeed also due to data gaps, is the paucity of studies reconstructing a potential "climate migration chain" that might be triggered, directly or indirectly, by climatic changes in the originally affected areas. New research shows, that in Sub-Saharan Africa, previous internal migration is significantly associated with intentions to migrate internationally (Cirillo et al., 2022). Thinking about climate migration, it is not implausible to imagine a scenario in which a future increase in the frequency or intensity of weather shocks in a rural context will determine rural-urban internal migration, which, in turn, gives rise to international, cross-border movements of urban workers due to changes in local labor markets. If and how much this kind of climate migration chain will become more relevant as climate change intensifies, for the moment, remains speculative.

From a data perspective, the more robust linkage between climatic factors and internal migration, compared to the lack of evidence of large-scale effects of weather shocks on international movements, provides an argument in favor of data sources such as household surveys. These sources, on the one hand, often allow direct measures of migration, which reconstruct people's movements; but, on the other, are inherently disadvantaged when it comes to studying international migration. However, with some exceptions, surveys are often not long enough to allow studying the dynamics of the climate-internal migration relationship. With cross-sectional and two-wave surveys, causation cannot be rigorously established due to identification threats, which only allow to shed light on statistical associations. Boosting data collection to enhance the availability of household surveys covering at least a medium-run horizon should therefore be a key priority in the migration research agenda. Finally, to investigate the existence of potential migra-

tion chains, interoperability between different data sources—micro and macro, conventional and non-conventional—emerges as the most promising and innovative solution.

2.1.4 | Heterogeneous responses and the role of liquidity constraints

A crucial insight from the most recent literature is that climate-related hazards can cause or worsen liquidity constraints (Cattaneo & Peri, 2016; Cottier & Salehyan, 2021; Hirvonen, 2016). It is precisely for this reason that the capacity for migration in response to climatic shocks is much more limited than commonly assumed: poor people, who are disproportionately affected by climate change, have more incentives to migrate but often cannot leave because they lack the necessary resources (Cattaneo et al., 2019). From this perspective, migration is a costly investment in risk diversification that only richer households can undertake, while poorer households are "forced to stay" rather than "forced to move" (Kaczan & Orgill-Meyer, 2020). Depending on the interaction between the severity of the climatic event and household-specific characteristics such as wealth, number of income sources, assets and resources, we should expect a wide heterogeneity of outcomes depending on whether liquidity constraints or migratory responses ultimately prevail.

Indeed, the empirical evidence is mixed, with some studies showing that the poorest households are more prone to migrate in response to weather shocks (Gray & Mueller, 2012b; Mastrorillo et al., 2016; Mueller et al., 2014), while others find that liquidity constraints trap poor people in immobility (Bazzi, 2017; Cattaneo & Peri, 2016; Hirvonen, 2016). Cattaneo et al. (2019) argue that this contradictory evidence can be explained by the different types of migration involved: poor families respond to negative shocks through low-return or even "survival" migration, taking the form of temporary movements across short distances, whereas wealthier families engage in risk-management migration, which is typically costlier, semi-permanent, and over a longer distance. Koubi et al. (2022) suggest that (im)mobility depends on both the type of the climate shock that individuals experience and their adaptive capacity in terms of endowments and resources. Simulations by Choquette-Levy et al. (2021), who parameterize an agent-based model on household survey data from Nepal, support this perspective, but also highlight that cash transfers and risk-transfer mechanisms may prevent climate-induced immobility of farmers.

In short, the final outcome is ultimately household- and context-specific. In such a complex picture, migration and immobility are only two of the possible outcomes and the decision to leave can be interpreted as one of many potential adaptation strategies that an individual or household can adopt. If the outcome is household- and context-specific, there is a need to go as granular as possible to retrieve the roots of the heterogeneity of results. As such, a microeconomic perspective, rather than a macroeconomic one, should be preferred regarding this specific aspect of climate migration. Macro-level analyses can find that the sign of the relationship is the opposite between rich and poor countries (e.g., Cattaneo and Peri (2016)), but cannot shed light on why and how liquidity constraints arise and if they are pre-existent to weather shocks or caused by them. Furthermore, there is a need to improve our understanding of the causes and consequences of the immobility of populations "trapped" by environmental disasters, because too often the policy focus is on "those who leave" rather than on "those who cannot" (Findlay, 2012). We are of the opinion that, in order to shrink these data gaps, researchers should pay more attention to the potential offered by longitudinal, multi-purpose, and multi-topic household surveys.

2.1.5 | Migration as adaptation

One of the most interesting advances in the scientific literature is the progressive integration of the issues of migration and adaptation into a single, unified conceptual framework. In such a framework, the decision to migrate constitutes *one* of the possible strategies to adapt to climate change. There is some empirical support for the notion that migration is a subset of decision options within the broader issue of adaptation and coping strategies in response to shocks (Alam et al., 2016; Black et al., 2011; Kattumuri et al., 2017; McNamara et al., 2018). On the other hand, migration could be a last-resort solution for households, because it is perceived as costlier than other *in-situ* adaptation strategies (Wodon et al., 2014). While some studies suggest that migration and on-farm adaptation can indeed be substitutes, there is a dearth of sequential analyses assessing whether the migration decision happens before or after the implementation of alternative adaptation options (Cattaneo et al., 2019). The available evidence comes from cross-sectional studies (e.g., Alam et al. (2016), for Bangladesh) and is thus inconclusive. Here, again, the use of longitudinal micro-level surveys, especially those featuring extensive information on agricultural practices, inputs, and technologies, can boost research on the interrelation and dynamics between *in-situ* adaptation and migration.

The issues of immobility and trapped populations can also be viewed as inability to adapt, and should be examined through an adaptation lens within an integrated framework, but research to date remains scarce and fragmented. Among the few exceptions, Martinez Flores et al. (2021)—whose outcome variable is the cell-level number of international migrants taken from the IOM and who find that only people living in middle-income areas are less likely to migrate abroad after a drought (but not people living in wealthy or poor areas)—argue that this is evidence that people, who under normal climatic conditions would be able to migrate, are not able to invest in adaptation mechanisms such as migration, thus sinking into poverty. Migration is just one of the many options among potential coping strategies farmers can employ to mitigate the effects of climate change. The literature has thus ignored for too long that migration is only one of many potential responses to environmental stress and, consequently, has to be analyzed against the background of other adaptive options, which can either complement or substitute migration (Hoffman et al., 2020). Therefore, understanding how migration fits into this larger pool of coping strategies, and the temporal and causal dynamics of the migration-adaptation nexus, should be considered as research priorities. A microeconomic perspective, based on direct—rather than indirect—sources of migration information that allow reconstructing and tracking individual and household migration histories and intentions, offers a way to integrate the analysis of the migration decision with households' coping strategies and adaptation options (or lack thereof) before and after shocks.

A key take-home message that emerges from this overview is that, despite a growing body of research, there are still substantial gaps in our understanding of the complex and multifaceted relationship between climate change and migration, and thus are areas where further research is needed. Nevertheless, the nuances and differentiations revealed by this body of recent research question the conventional and simplified narrative that climate change will bring about permanent mass migration (Findlay, 2012). Slow-onset changes, immobility, internal migration, heterogeneous responses based on context-specific factors and liquidity constrains, and the relationship between *in-situ* adaptation and migration, are the driving factors that seem to matter more to understand the future of climate migration. At the same time, these aspects have often been underexplored in the literature, in part due to the widespread, but misleading, narrative of climate change as a driver of massive and sudden large-scale international migration flows, in

part due to the existence of data gaps. Our view is that many of these key aspects can nowadays be investigated with comprehensive and longitudinal household surveys which, in turn, can be amended and designed so to shrink existing data gaps.

2.2 | A closer look at Sub-Saharan Africa

When talking about climate change impacts, low- and lower-middle-income countries are those bearing the heaviest burden. These countries are also greatly dependent on the agricultural sector to employ and provide livelihoods to a large share of their population and therefore particularly vulnerable to climate variability. Sub-Saharan Africa (SSA) is one of the parts of the world indisputably more vulnerable and exposed to climate change (IPCC, 2014). Some of these countries, especially those on the coasts and surrounding large water basins, are projected to experience among the highest rates of internal migration due to climate hazards within the next 30 years in the absence of any concrete climate and development actions (Rigaud et al., 2021b, 2021c). Like other low and middle-income economies, SSA countries are also seriously limited in the availability of good quality migration data, hindering the production of a solid evidence base on the real dimension of the climate-migration phenomenon. Nonetheless, this is the geographical focus of the LSMS-ISA program, here considered as the natural candidate to exploit the potential of the existing multi-purpose household surveys. Bearing in mind the major insights from the main review, therefore, in this subsection we take a closer look at recent studies with exclusive focus on SSA.

A few studies also looked at Ethiopia to find evidence of climate-induced movements, which are frequently driven by agriculture-related factors. Di Falco et al. (2011) carry out a study based on a survey conducted on 1000 farm households located within the Nile Basin of Ethiopia in 2005. They find that about 58 percent and 42 percent of farm households had used no adaptation strategies in response to long-term changes in temperature and rainfall, respectively, and that migration is one among many adaptation strategies, adopted by less than 5 percent of those surveyed. This finding is partly in contrast with the results of Gray and Mueller (2012a), who, through a longitudinal household survey, study the consequences of drought on population mobility in Ethiopia's rural highlands, providing evidence that drought increases long-distance and work-related relocation of men, especially in land-poor households. However, severe droughts reduce women's short-distance and predominantly marriage-related mobility, pointing to gender-differentiated effects. Mueller et al. (2020) combined NASA's high-resolution climate data with longitudinal microdata on migration, labor participation, and LSMS-ISA data (see also Section 4), to test whether climate variability affects temporary migration to rural and urban East Africa and whether climate-induced migration coincides with a lack of local job opportunities. The data included surveys conducted in Ethiopia, Malawi, Tanzania, and Uganda over 6 years (2009–2014). They found that climate variability significantly affects temporary migration decisions in eastern Africa, specifically that temperature and rainfall shocks cause a reduction in temporary urban out-migration. Findings by Mueller et al. (2020) are consistent with the results of Hirvonen (2016) for rural Tanzania and challenge the narrative that temporary migration acts as a safety valve in response to climatic push factors. Yet, still focusing on (Northern) Tanzania, Beegle et al. (2011) document that precipitation anomalies increased both the probability of people leaving the village and the distance moved.

The negative effects of weather shocks on mobility, however, are also confirmed in some prominent studies on international migration: for instance, in a study already mentioned above,

Martinez Flores et al. (2021), leverage high-frequency (daily) migration data on the place of origin of migrants and the time of migration, collected from the International Organization for Migration in 17 West and Central African countries over the period from 2018 to 2019, and estimate that droughts, as measured by soil moisture anomalies during the growing season, strongly reduce the number of international migrants. As they detect these effects only in middle-income areas, but neither in rich nor poor ones, they conclude that climate-induced liquidity constraints and income losses are the key mediating channels.

Complementary micro-evidence, which is consistent with the findings of Martinez Flores et al. (2021) is provided by Karanja Ng'ang'a et al. (2016), who focus on the role played by the interrelationship between remittances, agricultural innovations, and climate change in shaping the livelihoods of shepherds in arid and semi-arid lands in Kenya. By analyzing data from a survey of 500 rural households in northern Kenya that relates adaptive family behavior to family migration, their analysis suggests that migration and local innovation are complementary mechanisms that ensure resilience to adverse shocks. In addition, families with at least one migrant member can employ high-cost agricultural innovations through remittances, thus improving their self-protection against weather shocks. In short, the migration of household members softens liquidity constraints, favors agricultural innovation, and fosters local adaptation via remittances.

Despite the lack of abundant panel data for many sub-Saharan African countries, a number of works have emerged in recent years that attempt to estimate these relationships over longer timespans, using data sources such as census or multi-decadal household surveys. Specifically, some of these longer-run studies have already been mentioned in the main review above: Dillon et al. (2011) combine data on temperature degree days with a household survey from northern Nigeria, which collected information on migrant individuals from villages originally sampled in 1988. They report empirical evidence that households respond to ex ante risk through male outmigration.

Similarly, in a recent working paper, Di Falco et al. (2022) exploit LSMS-ISA panel data from Ethiopia, Malawi, Niger, Nigeria, and Uganda (see also Section 4) combined with high-resolution precipitation data to study the effects of cumulative climate shocks on long-term migratory flows in Sub-Saharan Africa. Overall, they find evidence of a persistent impact of droughts on the probability of migrating in these countries. The authors also detect a relationship between rainfall shortage and accelerating urbanization trends in four of the five countries in their analysis. At the country level, their findings contrast with previous studies that use similar multi-country micro-level datasets to examine the effect of climate shocks on rural out-migration, which found no significant or consistent migration-inducing effect of droughts in the short and long-run. Conversely, the authors notice that their results are in line with those of macro-level cross-country studies that corroborate the contribution of rainfall deficits to faster urban development.

Mastrorillo et al. (2016) argue that agriculture acts as a primary channel through which weather anomalies influence migration. They combine South African census data with climate data on spatiotemporal weather variability to examine South African bilateral inter-district migration flow patterns and determinants during the periods from 1997 to 2001 and 2007 to 2011. The results reveal that precipitation scarcity and higher temperatures act as push effects for migration. However, the importance of the effect of climate on migration varies greatly depending on migrant characteristics, including ethnicity. In particular, the flows of black and low-income migrants in South Africa are strongly influenced by climate variables, while white and high-income migrants are weakly or not affected.[7]

Other findings from longer-run studies, however, fail to detect the same push effects of weather and climate: Grace et al. (2018) find that rainfall did not affect temporary migration rates in two Malian villages. The authors combine unique data from highly detailed stories of migration

collected over 25 years in two rural communities in Mali, and document that a poor rainy season is not correlated with extreme or even above-average emigration rates. Even accounting for some known sources of variability (age, gender, etc.), a decrease in rainfall does not directly lead to higher emigration rates. Instead, the results suggest that during low-rainfall years outmigration is lower. Henderson et al. (2017) estimate the effects of climate variability and change on African urbanization patterns over two different temporal and spatial scales: (i) local, within-district urbanization for an unbalanced 50-year panel of census data from 359 districts in 29 countries; (ii) urbanization patterns from 1992 to 2008 in 1158 cities. Their estimates show that climatic conditions do affect urbanization rates, with better conditions delaying urbanization and adverse conditions leading to faster urban population growth, but that these effects are confined to a subset of about 20–25 percent of Sub-Saharan African districts.

The cross-country study by Mueller et al. (2020) is somewhere in-between, and points to the context dependency of the migration response. The authors use census data on the migrations of four million individuals over 22 years to estimate the climate effects on migration in Botswana, Kenya, and Zambia. Their results for Kenya show that temperature has limited effects on migration, whereas a one standard deviation increase in precipitation causes a 10 percent reduction in migration. In Botswana, mobility decreases by 19 percent with a one standard deviation increase in temperature, and an equivalent change in rainfall causes an 11 percent decrease in migration. The effects of temperature appear more severe among poorly educated individuals. Rainfall shocks increase mobility in Zambia, while an increase in temperature does not affect mobility in the region. Decreases in inactivity and unemployment coincide with increases in migration, which suggests that the perspective of new job opportunities may act as a driver of climate-induced migration.

Overall, this sub-review confirms that agreement on the relationship between migration and climate change in Sub-Saharan Africa is far from univocal, with some studies considering migration as a direct consequence of weather shocks and climatic changes and others not finding that these factors exert a clear or significant impact on people's mobility. The majority of the SSA literature focuses on slow-onset rainfall and temperature events, whereas only a few studies specify the type of migration. As an aside, we notice that there is unequal country coverage in this literature, with repercussions in terms of external validity. For instance, the Sahel region is particularly underrepresented, despite being one of the areas identified among the worldwide hotspots of climate change (IPCC, 2014). As already indicated, this might be partly due to a paucity of adequate data in the area, especially concerning migratory flows. With this in mind, we argue that leveraging ongoing national data collection efforts such as the LSMS-ISA is a way to improve availability of migration data in the SSA region and a strategic choice that is urgent and needed.

3 | OPEN EMPIRICAL ISSUES AND DATA GAPS

3.1 | Open empirical issues

A number of key open empirical issues emerge from the conceptual discussion above. First, how to disentangle, from an empirical point of view, short-run elasticities of weather shocks on migration from the compounding effects of slow-onset, long-run, eventually permanent changes in climate and progressive warming? Most current works only investigate short-run weather effects of migration and then extrapolate with respect to climate change. But this poses the problem of the already-mentioned external validity gap between weather shocks and climatic change. To

empirically investigate the latter, one needs to look either at longer time series in a longitudinal setting, using several lags of the weather parameters or long-run (e.g., 30-year, which corresponds to the agreed definition of "climate") averages, or the cumulative effect of repeated weather events driven by an increase in frequency linked to climate change.

There are some promising approaches in the literature in this respect. For example, Cattaneo and Peri (2016) employ a technique that is now quite common in new weather-economy literature (Burke & Emerick, 2016; Dell et al., 2014; Liu et al., 2022) called "long-differences". This approach consists of replacing annual averages of both the dependent and independent (climatic) variables of interest with decadal or multi-decadal averages. This allows one to test whether the short-run relationships retrieved using annual measures also hold in the medium and long-run, thus directly testing the external validity of the empirical findings from a climate change perspective. Cattaneo and Peri (2016) cleverly use long-differences to confirm their short-run result that warming in poor countries reduces migration (consistently with the presence of severe liquidity constraints) and find evidence to support persistence of this type of effect.

Second, as explained in the previous subsection, it is now well established that the causal link between the two phenomena is not as simple and straightforward as it once seemed to be, and there are many intervening factors (liquidity constraints, assets, *in-situ* adaptation strategies such as irrigation or other on-farm investments, etc.) that have the power to alter not just the magnitude, but even the sign of the relationship. Once the analyst retrieves a statistically significant relationship between a climate shock and the decision to migrate, how can the effect be explained in light of the above-mentioned mechanisms?

Recent advances in empirical micro-econometrics, such as, in particular, mediation analysis to investigate the mediating role of a variable of interest (the so-called "mediator") in explaining a causal relationship of interest appear promising, although not yet picked up by scholars in the migration field.[8] In this context, mediation analysis could allow one to decompose aggregate impacts of climate on migration between "direct" effects of climatic shocks on migration decisions and "indirect" effects, which materialize through one or more specific channels of interest (e.g., liquid assets), as well as to quantify the share of the total impact mediated by such a channel.

Sticking to the liquid assets example, mediation analysis allows testing whether a climatic shock leads to enhanced migration (direct effect) in the absence of a counterbalancing negative effect stemming from tightened liquidity constraints (indirect effect, that is, a climate-induced reduction in liquid assets) that might overweigh direct climate impacts. Empirically, this scenario would materialize in a positive and statistically significant direct effect and a negative and statistically significant indirect—that is, asset-mediated—effect. Conceptually, such findings would point to heterogeneity depending on pre-shock asset conditions, and to a relevant indirect channel that could be leveraged for policy purposes.

The analysis of migration-as-adaptation, that is, how the decision (not) to migrate fits within a broader analytical framework of the full pool of adaptation options available to farmers in response to climate change, is also still underexplored. Such an issue is partly linked to the above discussion on the potential of mediation analysis, because shedding more light on the transmission channels and contextual factors acting as key mediators would also improve our understanding of adaptation responses and coping strategies implemented by households, including migration, and their causal and chronological interlinkages.

Third, migration is a statistically rare event because it is not the only possible outcome of adverse weather events—since lack of adaptation and liquidity constraints could make migration impossible; that is, forced immobility. From an empirical perspective, identifying people trapped in immobility from people that are not exposed and/or not vulnerable in the aftermath of a shock

is challenging. As highlighted recently by McKenzie and Yang (2022), liquidity constraints will likely determine both the pattern of self-selection of migrants, as well as the range of job opportunities and consumption-smoothing opportunities that individuals will have at home. A possible complementary identification strategy is to investigate the welfare effects of weather shocks and indirectly argue that a reduction in consumption or assets, or an increase in liquidity constraints induced by the shocks may have prevented migration (see Hirvonen (2016) for an example of this approach).[9] In any case, the thorough investigation of potential immobility traps remains an open issue for empirical migration literature. In this respect, this literature could greatly benefit from the theoretical insights and models of well-established literature on geographical and asset-based poverty traps (Barrett & Carter, 2013; Carter & Barrett, 2006; Carter et al., 2008; Jalan & Ravallion, 2002). This integration would, in turn, embed the analysis of mobility patterns within the broader framework of adaptation or lack thereof, and open the ground to the implementation of new and comprehensive survey modules devoted to adaptation and migration aspirations that could provide data on these surrogate outcomes and make up for the "rare event" issue.

Fourth, while the shift from older cross-sectional studies—which were vulnerable to a wide range of potential confounders and sources of omitted variable bias—to more robust panel methods exploiting longitudinal information on household and individual movements, indeed represents an important empirical step forward, ì the use of panel settings is not in itself a panacea. In fact, the issues highlighted above of self-selection, endogeneity, transmission channels, longer-run effects and persistence, reverse causality, and other key empirical concerns still need to be addressed through clever research design (De Brauw & Carletto, 2012). For instance, the climate-migration literature generally assumes that short-term variation in weather is exogenous. However, as weather data are often derived from stations located in specific locations, the quality and continuity of coverage is heterogenous and actually depends on the characteristics of those specific locations. For instance, Schultz and Mankin (2019) show that civil conflicts in SSA are negatively correlated with the number and density of weather stations, both from a cross-sectional (countries with higher average conflict risk have poorer coverage) and cross-temporal (civil conflicts determine a loss of weather stations) point of view. Auffhammer et al. (2013) and Dell et al. (2014) also argue that the entry and exit of stations (quite common, especially in poorer countries) can be endogenous and represents an additional source of measurement error of the true weather conditions experienced on the ground.[10] As it stands, these issues have not yet been properly acknowledged and addressed by the specialized literature.

3.2 | Data gaps and needs

Given the conceptual and empirical limitations of existing studies and the research priorities set out above, we have identified the main data gaps that currently prevent carrying out the proposed research agenda and possible solutions to address these data needs that can come from improvements to longitudinal, multi-topic household surveys such as the LSMS-ISA. We here start by outlining the main data gaps and needs separately for migration and weather data.

3.2.1 | Migration data

Until recently, there was a widespread lack of basic migration data, especially in developing countries, which are more vulnerable to climate change (Laczko & Aghazarm, 2009). While

the situation has improved, and macro-level and international migration data are now available for a wide range of countries, accurate estimates on internal migration remain unavailable or incomplete for most developing countries. This is a problem because we know from the literature discussed above that the migration effects of climate change will primarily concern poor people living in developing countries. This paradox can only be solved by using direct sources able to track internal migration such as household surveys, and by scaling up migration data collection efforts in low and middle-income origin countries. Despite some recent progress, there is a specific scarcity of longitudinal and long-term data from migration surveys in developing contexts, which currently do not exist at all for many poor countries. Identification issues due to the lack of panel data have long hampered empirical progress, so data collection efforts should primarily be focused on tracking individuals over time, either using self-reported data or information from proxy respondents, also to address non-response issues.

From the discussions on the tight nexus between migration and adaptation in the previous section, there is a strong case for integration, in multi-topic household surveys, between questions on migration and those on risk management, and mitigation and coping strategies adopted in response to shock, such as an explicit distinction between voluntary versus involuntary migration, survival versus risk-management migration, immobility due to *in-situ* adaptation versus immobility due to liquidity constraints and inability to move.[11] These nuances and amendments to the existing surveys and modules would greatly enhance the scope for empirical applications in this active area of research, while being relatively low cost and easy to implement and collect.

As far as short-term, temporary and seasonal migratory flows are concerned, not only should data be longitudinal, but they should also be high-frequency, that is, they should be collected annually. As apparent from the meta-analysis of Beine and Jeusette (2021), frequency of collection of data plays a significant role in determining the findings of econometric analyses: data sampled at higher frequencies tend to support the case of an effect on mobility more, since migration measures spread over several years or longer periods are less able to capture short-term migratory flows driven by climatic shocks.

The use of direct measures of mobility, rather than indirect proxies, has often also been stressed as important but remains the exception rather than the rule. Importantly, econometric analyses using measures of mobility that are computed or derived from proxies tend to find less empirical evidence in favor of a causal effect of environmental shocks on migration (Beine & Jeusette, 2021). The use of migration flows as the dependent variable in the regressions increases the probability of finding an impact, and data on direct measures of migration should be collected accordingly.

Ex-post counterfactual policy evaluations of development and social policy interventions aimed at either favoring or reducing weather-induced migration flows are also scant. More research is needed on the role played by institutions and policies in "interfering" with the decisions to migrate in response to climatic stress. Development policies can affect migration outcomes in a way that is difficult to know a priori, as they could either facilitate or inhibit migration depending on the type of intervention and the related welfare outcome. For instance, while local investments in climate-resilient infrastructures or in the development of early-warning systems may reduce the need to migrate and improve *in-situ* adaptation, social protection interventions or emergency responses alleviating weather-induced liquidity constraints may make voluntary migration possible. This is especially important in order to provide evidence-based recommendations on national and international climate migration policies. There is a need for empirical evidence on the ex-post impacts of such programs to improve our understanding about the role of policy in mediating the causal relationship between climatic shocks and human mobility. As a complement to that, the

collection of detailed community-level data to supplement household survey data on the rollout and implementation of such programs is also a key element to be considered.

Last but not least, the growing availability of big data and citizen-generated information has spurred a debate on their potential integration or complementarity with more traditional data-collection methods, such as census and surveys, to fill migration data gaps. In principle, these new data sources could massively improve the quantity of data available to study climate change and migration. Entities such as the European Commission and the International Organization for Migration (IOM) have already started to assess the potential of sources of big data. Among the most prominent examples of these non-traditional data sources: mobile phone Call Detail Records (CDR); Internet activity such as Google searches; online media content; geo-referenced social media activity, which can be obtained via advertising platforms offered by social media (IOM, 2018).

There are by now many recent scientific works based directly on migration metrics derived from non-traditional data sources. Lai et al. (2019) used a massive dataset of 72 billion anonymized CDRs in Namibia, from October 2010 to April 2014, to explore how internal migration estimates can be derived and modelled from CDRs at subnational and annual scales. Blumenstock (2012) computed a metric of "inferred mobility" from the phone records of 1.5 million people in Rwanda to study internal migration patterns, finding low permanent migration but high levels of temporary and circular migration. Wesolowski et al. (2013) and Kirchberger (2021) offer an interesting comparison between mobile phone data and census data and discuss the potential for research on internal migration of the first source relative to the latter. As for social networks, Spyratos et al. (2019) used anonymized and publicly available data provided by Facebook's advertising platform to estimate the number of Facebook Network (FN) "migrants" in 119 countries of residence and concluded that these estimates could be used for trend analysis and early-warning purposes. Specifically concerning climate change, some have highlighted that, especially in combination with field-level data derived from household surveys and key-informant networks, big data could be used to detect how sudden-onset natural disasters and progressive environmental change impact migration patterns (Franklinos et al., 2020)

While the use of non-conventional data sources to investigate the mobility responses to climate hazards is still very limited in climate migration literature (with some exceptions—see Lu et al. (2016a, 2016b) —this is now a well-established practice to examine migration patterns following other types of shocks and push factors. Several works have leveraged big data—specifically, mobile phone data—to assess and track mobility levels and features during epidemics (see, for instance, Bengtsson et al. (2011) and Bengtsson et al. (2015): for the 2010 Haiti cholera outbreak, Peak et al. (2018), for the Ebola epidemic in Sierra Leone, and, more recently, Beria and Lunkar (2021) and Hu et al. (2021) for the COVID-19 pandemic, as well as sudden-onset natural disasters such as earthquakes—among the most important works, Bengtsson et al. (2011) and Lu et al. (2012) on population displacement caused by the 2010 Haiti earthquake, and Wilson et al. (2016) for displacement in the aftermath of the 2015 Nepal earthquake. In line with Franklinos et al. (2020), we see no practical reason similar approaches could not be replicated for the study of the mobility effects of fast-onset climate shocks such as hurricanes, storms, and floods.

More generally, given their increasing availability and huge potential, there is a clear need to invest more in research aimed at developing methods to improve integration and interoperability of household surveys with these new data sources. This is conditional on finding adequate solutions to the privacy, ethical, and legal challenges associated with the use of non-traditional data that are generally collected by private companies for internal commercial purposes rather than for statistical, public use. In this respect, the recent COVID-19 pandemic represented an important

turning point in that, for the first time, big tech corporations (e.g., Meta, Google, Apple, among others) and mobile network companies started sharing their data with governments and the scientific community for public global good. This has been accompanied by developments in analytical techniques for big data contributing to advancing applied research in many important domains such health care, public policy, and social change, including human mobility (see Riswantini et al. (2021) for a comprehensive review of big data research for COVID-19).

3.2.2 | Weather data

Accurate and georeferenced weather information is needed to investigate climate-related migration outcomes. However, most household surveys include, at best, self-reported measures of weather shocks based on individuals' recalls, which is hardly reliable or comparable, given their subjective nature. For this reason, household data from multi-topic surveys are almost always autonomously integrated with external weather information. The main public domain sources of weather data include NASA's *Modern-Era Retrospective Analysis for Research and Applications* (MERRA-2), the *Terrestrial Air Temperature and Precipitation* database from the Center for Climatic Research at the University of Delaware, and the *High-Resolution Gridded Datasets* from the Climatic Research Unit of the University of East Anglia. Remote sensing weather datasets, which can take the form of gridded, satellite, or reanalysis data, have been used in many studies leveraging LSMS-ISA data to address weather and climate-related research questions in Sub-Saharan African contexts (see, among many, d'Errico et al., 2019; Di Falco et al., 2022; Letta et al., 2018; Mueller et al., 2020).

While this integration is typically carried out directly by the research team, this practice can be suboptimal for several reasons. First, the intrinsic diversity of weather data products. For instance, satellite data provide less accurate data than ground stations in most locations and do not extend as far back in time. Gridded data, on the other hand, aggregate data from ground stations via interpolation and across a given space. This works well in developed countries, where there is wide and uniform coverage of weather stations across the entire territory, but not so much in developing contexts, where often gridded data aggregate weather information from a few old stations spread across the country. Sparse coverage is a serious issue, given the interpolation method adopted by gridded products. Finally, entry and exit of stations (quite common, especially in poorer countries) can be endogenous and represents an additional source of measurement error of true weather conditions experienced by people.[12]

Such diversity in weather data products can affect econometric estimates of the relationship between climatic events and a given socio-economic outcome of interest. In addition, the need for spatial anonymization for privacy protection in household surveys, usually implemented through a random offset of true household geocoordinates, can introduce mismeasurement when integrating them with remote sensing weather data.

On top of these issues related to the type of product and matching with household data, different indicators capture different weather and climatic phenomena: for instance, the Standardized Evapotranspiration Index (SPEI), a composite indicator measuring "potential evapotranspiration," which in turn depends on temperature, latitude, sunshine exposure, and wind speed, has been found to outperform other weather variables in accurately predicting crop yields and, more generally, agricultural outcomes (Vicente-Serrano et al., 2012). Even different indicators generated from the same source of raw weather data can lead to considerable heterogeneity in the type of climatic event that is being measured. As an example, using the increase in anomalies over

time is different from using the increase in temperature levels, and may matter more for migration even in places in which overall warming is limited. Similarly, growing-season variables may lead to retrieving stronger impacts if the agricultural channel is the main one driving the climate-migration nexus, whereas annual measures may "wash away" a lot of relevant weather variation. Overall, there is a real possibility that such heterogeneity in products—degrees of spatial and temporal resolution, variables, and indicators—partly accounts for the contrasting results detected in the empirical literature.

In a new study based on a pre-analysis plan, Michler et al. (2022) use 90 linked weather-household datasets that vary by spatial anonymization method and show that, as the spatial resolution of most weather data produce is too coarse, spatial anonymization techniques have an overall small effect on estimates of the weather-agricultural productivity relationship and do not introduce substantial mismeasurement. Depending on the specific type of weather data, however, measurement error can become significant, especially for higher-resolution data products. Importantly, Michler et al. (2022) also find that estimates of weather impacts on agricultural productivity vary substantially in sign, significance, and magnitude across different weather datasets for the same spatial anonymization technique. For these reasons, caution is in order when integrating household surveys such as the LSMS-ISA with external weather data, and the first best would be to have high-resolution weather data already embedded in the survey dataset.

4 | LSMS-ISA DATA: LIMITATIONS AND OPPORTUNITIES

To start drawing concrete operational implications from the review above, we start by outlining what the implications would be for the LSMS-ISA program, which is one of the international survey programs that has been at the forefront of the methodological debate on data collection in low and middle-income countries for the past 15 years or so. It was launched in 2009 with funding from the Bill and Melinda Gates Foundation with the explicit aim is to improve the availability, quality, and relevance of agricultural data in multi-topic, multi-purpose household surveys through close collaboration with the national statistical offices (NSOs) of partner countries. As such, LSMS-ISA has a distinct advantage over standard LSMS surveys when it comes to studying issues specifically related to climate change. This is because its strong focus on agriculture allows study of impacts of weather and climate-related events on several household welfare outcomes that might either trigger or prevent migratory flows, and at the same time explore farmers' adaptation responses, especially *in-situ* ones, which can complement or constitute an alternative to migration as coping strategies in the face of climatic shocks such as, for instance, the switch to drought-tolerant or improved seeds, the use of irrigation on the main plots, investments in modern agricultural inputs, and diversification of livelihoods through non-farm enterprises. Furthermore, the richness and granularity of information collected in LSMS-ISA that can be linked to data on households' and individual movements is something that cannot be found in other types of existing household surveys used to study migration.[13] This is a crucial aspect if one wants to unravel the dynamics underpinning the climate-migration nexus and assess their effects on (or the responses of) different groups of people (e.g., women, youth, marginalized groups, etc.). Moreover, LSMS data fulfill the most important criteria necessary, in terms of data requirements, for the investigation of the climate-migration nexus: (i) it is longitudinal, unlike most of the widely available harmonized household survey data sources (e.g., the Demographic and Health Surveys, DHS); its survey panels are administered approximately every 1–3 years, currently covering a time span of about 10 years for most of the countries involved—this allows rigorous establishing of causality

and isolate the effect of climatic factors; (ii) it is harmonized and standardized across countries, unlike most ad hoc surveys used by the literature, and this makes cross-country comparisons possible and enhances external validity; (iii) its surveys are multi-topic and multi-purpose in nature, paving the way for a thorough investigation of mediating channels and contextual factors and have a specific focus on agriculture, the most important transmission channel in the climate-migration relationship; and (iv) lastly, to date, the LSMS-ISA project has been carried out in eight SSA countries, namely, Burkina Faso, Ethiopia, Malawi, Mali, Niger, Nigeria, Tanzania, and Uganda. Some of these countries are among the least developed and most vulnerable to climate change in the world (World Bank, 2022) and, as previously indicated, also characterized by a paucity of adequate data to study migration-related issues.

More broadly, our focus on the World Bank's LSMS program is justified by the ongoing discussion on the possibility of leveraging and upgrading existing household surveys to fulfil new increasing demand for migration data worldwide[14] and the fact that LSMS surveys are routinely referred to as vested candidates to contribute to this task (Bilsborrow, 2016). In addition, considering the LSMS focus on methodological development and innovation in survey methods, as one of the lead products stemming from this wider survey program, LSMS-ISA is a powerful vehicle for introducing, testing, and validating innovative solutions with potential to be scaled up in other similar types of surveys to address key data and empirical gaps in the climate-migration microeconomic domain. In the LSMS-ISA, original households are revisited during each wave, even if they relocate within the country and individual household members who split off from previously selected households are also tracked and included in subsequent waves in some surveys. This intertemporal aspect of LSMS-ISA unlocks the potential for the analysis of internal and rural–urban migration patterns, among other things (Carletto & Gourlay, 2019).

The next subsection starts by highlighting the main limitations of LSMS-ISA in filling the data and empirical gaps as they emerge from the literature review presented in Section 2. We then emphasize that, in the past years, these limitations led to very modest application of LSMS-ISA data in the empirical study of the climate-migration nexus and illustrate the main migration-related elements covered by the survey. Finally, recognizing the potential of the LSMS-ISA survey instruments for the various reasons specified above, we identify priority areas where these can be improved, and the use of LSMS-ISA data enhanced in the climate-migration research field. As already pointed out in the introduction, it is worth reiterating that while we concentrate on the LSMS-ISA program in the following subsections, our reflections and recommendations apply to multi-topic and multi-purpose household surveys in general.

4.1 | Key limitations of the LSMS-ISA datasets

Given the current features of the LSMS-ISA program, and based on our previous critical overview, we identify the following as the main limitation of LSMS-ISA data collection to empirically break down the climate-migration nexus: questionnaire design; sample size and statistical challenges; and respondents' issues. In the rest of this section, we focus on each of these areas in turn.

4.1.1 | Questionnaire design

Although the LSMS-ISA questionnaires are usually standardized across surveys and countries, the information is sparse, and there are inconsistencies, not just across countries, but also across

different surveys within the same country. The lack of consistency, in terms of the set of questions included to detect migration and/or define migrants, is certainly the first element to be considered for revision of the LSMS-ISA to improve data collection on migration. The only cross-country investigations on the climate-migration links that uses LSMS-ISA were forced to rely on proxies to define different types of migrations. Mueller et al. (2020) exploit questions regarding the absence of individuals during follow-up surveys to define temporary migration—whether individuals present at baseline reported migrating for at least 1 month over the previous 12 months. Without knowing, in most cases, either the destination or the reasons for migrating, they had to make strong assumptions on the equivalence between temporary absence from the household and outmigration. See below (Section 4.2) for further discussion on this point. Di Falco et al. (2022) made even stronger assumptions to assess long-term migration, proxying individuals as migrants if households report them to have left between two visits or waves of the survey and who had not returned to their households during the time of analysis (including individuals who left after they married).

4.1.2 | Sample and statistical issues

Migration is, statistically speaking, a rare event and, in a normal clustered sample design typical of multi-topic surveys, the expected number of households associated with emigration may be very low (Carletto et al., 2014). To better identify rare events, two potential approaches can be exploited: disproportionate sampling and two-phase sampling. However, both sample designs require some prior knowledge of migration in the population and are not easy to implement as part of a household survey such as those of the LSMS-ISA collection, which are meant to be, by their very nature, multi-topic and nationally representative, and not exclusively targeted toward the study of migration. In this respect, the relatively small sample size of most LSMS-ISA surveys often makes them unsuitable for migration studies as the standard LSMS-ISA multi-stage cluster design is unlikely to sample a sufficiently large number of households with migrants (De Brauw & Carletto, 2012).

4.1.3 | Respondents' issues

More broadly related to data collection, Lucas (2021) notes that collecting migration data are essentially limited to two approaches: asking individuals about their migration experiences or asking remaining household members about those who left, and both present limitations. The former, in fact, provides little information about the household that the migrant left; the latter assumes that the respondent knows the current whereabouts and activities of the migrated household members, and memory of the list of those who left may prove selective. In addition, as noted by Kirchberger (2022) in her recent review, even when panel household surveys aim to track respondents, household surveys can still suffer from high levels of attrition. Other general shortcomings are: (i) questions about migrants need to be answered by a proxy, generally a family member, which may introduce many imperfections and substantial bias (Carletto et al., 2014); (ii) the double-counting of migrants, especially those who can be claimed as members in other household rosters; and (iii) the difficulty in classifying the type of migration: temporary (short-term) migration and (long-term) permanent migration are usually distinguished by an arbitrary threshold or time criterion set by the analyst. Return migration, seasonal migration, and circu-

lar migration can also be difficult to distinguish from one another (De Brauw & Carletto, 2012).[15] Finally, specifically concerning climate-related hazards, it is unlikely that migration caused by a fast-onset climatic disaster would be captured in an LSMS-ISA survey, given the localized nature of these types of events and unless the survey takes place soon after the shock (De Brauw & Carletto, 2012).

4.2 | Limited empirical research uses LSMS-ISA datasets to explore the climate-migration nexus

As a result of the above limitations, it is not surprising that our literature search on the number of works on migration and climate change that used LSMS-ISA data returned only five papers, four of which were published in peer-reviewed journals: Becerra-Valbuena and Millock (2021), Kubik and Morel (2016), Mueller at al. (2020), Ocello et al. (2015), and a recent working paper by Di Falco et al. (2022).[16]

Ocello et al. (2015) and Kubik and Maurel (2016) both focus on Tanzania, and employ the LSMS-ISA National Panel Surveys. While the first looks at both the 2008–2009 and the 2010–2011 waves (although the latter is used only to identify migrants), Ocello et al. (2015) only use the first. Both also share similar identification strategies (a two-stage setting with an IV probit model for the former, logit regression for the latter) based on a cross-sectional setting that is vulnerable to identification threats. Despite the similarities, they arrive at somewhat contrasting results: Kubik and Morel (2016) find that a reduction in agricultural income caused by a weather shock *increases* the probability of internal migration. However, this effect is significant only for middle-income households, whereas it is insignificant for the poorest and the richest households, confirming that the decision to migrate as an adaptation strategy depends on liquidity constraints and initial endowments, with the poorest households that cannot afford migration costs, while the richest ones can afford *in-situ* adaptation strategies, such as irrigation or drought-resistant crops. Ocello et al. (2015) document that being exposed to droughts or floods or crop diseases is associated with an overall decrease in the likelihood of inter-district mobility, with the exception of low-educated individuals.

Mueller et al. (2020) use the LSMS-ISA data from four countries, namely, Ethiopia, Malawi, Tanzania, and Uganda. They combine these household panel data with climatic data from NASA's MERRA to investigate temporary migration responses to weather anomalies in the East African context. Using a linear probability model, they find that climate impacts tend to *decrease* out-migration and, perhaps surprisingly, are most pronounced in urban areas. Becerra-Valbuena and Millock (2021) combine LSMS-ISA Malawi surveys with satellite weather data covering the period of 2000–2016 to estimate the probability of migration for reasons related to work and marriage separately for men and women. They find that, overall, droughts inhibit marriage-related migration for women, but increase migration of children for work, especially boys. To carry out their analysis, they use the migration-related questions on where the individual lived before moving to the current area of residence, when he/she moved, and the stated motive for doing so. Although this allows one to retrieve the districts of origin and destination as well as the time of migration of individuals interviewed, they notice that the lack of information at origin before moving is a limitation for their study.

Di Falco et al. (2022) use LSMS-ISA data to construct a multi-country panel dataset covering Ethiopia, Malawi, Niger, Nigeria, and Uganda, that is, merged with high-resolution gridded precipitation historical records from the Climate Research Unit to analyze the effects of cumulative

drought shocks on the decision to migrate in rural households. While confirming the existence of an immediate, although small, impact on migration decisions in the aftermath (i.e., the subsequent year) of a severe and extreme drought shock, they interestingly show that this impact is long-lasting, increasing migration for at least 5 years after the shock occurs, and not even fading or diminishing over time. Furthermore, they find that the effect of multiple recently experienced droughts (previous 5 years) accumulates over time, which results in a much higher number of migrants than one would expect based on the immediate effect of the shock only. The authors emphasize that this has relevant implications for the study of climate-induced migration and make a plea for advancing research on the cumulative impacts of climate change in determining migratory flows in the long-run while at the same time improving the availability of detailed data on migration.

The relative scarcity of studies employing LSMS-ISA data (and even with conflicting findings), is a clear indicator of the limited capacity of the LSMS-ISA datasets to provide a basis for meaningful analysis on climate change and migration. As indicated in the previous subsection, an often-small migrant sample size is one of the main limitations hindering the use of LSMS-ISA data for the study of migration-related phenomena. Interested readers, who are considering the potential use of survey tools such as the LSMS-ISA to study climate migration, could first explore the feasibility of their study by following the back-of-the-envelope test suggested by Bilsborrow (2016). He suggests performing a simple calculation, which involves looking at the size of the existing sample and the prevalence of migrants (or households with migrants of interest) in a given country. The larger the sample size, and the higher the prevalence, the less severe the "rare event" problem is. While this certainly affects the ability to use household survey data to study international migration, the issue is substantially less severe for internal migration which, in any case, constitutes the bulk of climate-induced movements as evidenced by this literature review.

Sampling considerations apart, let us focus, as a benchmark (see below for a comparative analysis of all LSMS-ISA surveys), on the Tanzanian National Panel survey, which was used by three of the five studies above. All the available migration information in the questionnaires is essentially limited to a few questions in two sections in the Household Questionnaire, Modules B and G.[17] Module G, named "Children Living Elsewhere—Migration" contains some information on households responding affirmatively to the question: "*Do you have any children 15 and older who live elsewhere (outside this household)*?", such as information on the most recent job, education level, and money sent by the absent individual (who is not necessarily a migrant). No questions are asked about the reasons that prompted her/him to move in the first place. Figure 1 below provides an idea of the type of migration tracking that is possible using the LSMS-ISA data.

In addition to this module, some basic questions are also asked in Module B of the household questionnaire, namely:

- B.9: For how many cumulative months during the last 12 months has [NAME] been away from this household?
- B.10: What was [NAME]'s main occupation for the past 12 months?
- B.24: For how many years have you lived in this community?
- B.25: From which districts did you move?
- B.26: Why did you move here?
- B.27: In which district where you born?

This is why both Ocello et al. (2015) and Kubik and Maurel (2016) had to rely on some assumptions to identify migrants. In Ocello et al. (2015), a migrant was defined as a person aged 15 or older

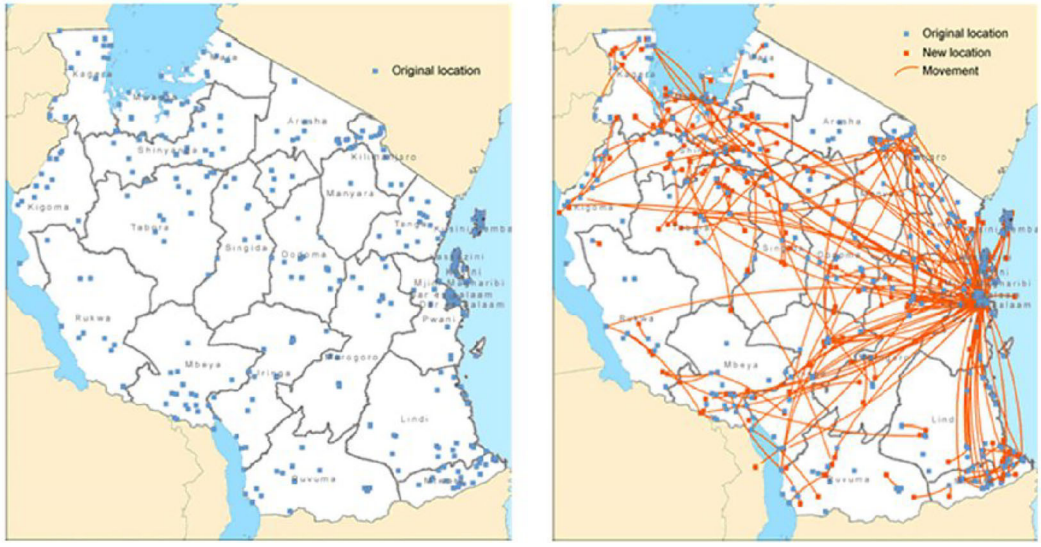

FIGURE 1 Household between-wave mobility—Tanzania National Panel Survey.
Source: Carletto and Gourlay (2019).
[Colour figure can be viewed at wileyonlinelibrary.com]

who had moved from one to another district in the 5 years before the interview, while migrants who moved into or out of the country were excluded from the analysis, given the focus of the study on internal migration. Specifically, the authors identified origin and destination districts using questions B.24 and B.25 reported above, and considered respondents living in the community for less than 5 years as migrants. After this selection process, their sample included 2883 individuals aged 15 or above, only 6 percent of whom migrated from one Tanzanian district to another in the period between 2004 and 2008.

Kubik and Maurel (2016), instead, in the absence of an explicit question on permanent migration in the dataset, exploited the second wave of the survey collection (2010–2011) to identify migrants, by directly comparing the place of residence of all household members in the first and the second waves of the survey and identifying residential moves based on the GPS coordinates of the place of origin and destination. Following this strategy, they defined their outcome variable of interest as a migration dummy equal to one for households with at least one member who permanently moved out of the original village between 2008–2009 and 2010–2011, and found that 14 per cent of households had at least one migrant between the two waves. Note also that Kubik and Maurel (2016), by design, observe internal migration only. In the subsequent waves of the Tanzanian NPS collection, some changes were implemented. From Wave 2 (NPS 2010–11) on, Module G on children living outside the household was dropped. In Wave 3, NPS 2012–13, an amendment was added among the roster of possible replies to the following question in the *Shocks* Section R:

> R.6: "What did your household do in response to this [SHOCK] to try to regain your former welfare level?"

Among the possible replies, there is the following choice: "*Household member migrated*". This option, however, was not present in the subsequent, and currently final, wave of the collection, NPS 2014–15. The Tanzania example, chosen as its surveys were used by the studies reviewed

above, is emblematic of the limitations and internal inconsistencies involving migration data in most surveys of the LSMS-ISA collection.

Prompted by the reply featuring migration as a coping strategy in the Tanzania surveys, we carried out a screening of all the questions and answers potentially related to the climate-migration nexus that are currently available in the entire LSMS-ISA collection. The detailed outcome of this screening is reported in Table A.2 in the Appendix. The migration-as-coping-strategy option is actually present in the shock questionnaires of many LSMS-ISA surveys in other countries. Interestingly, across the whole LSMS-ISA project, the most explicit questionnaire reference to the climate-migration nexus can be found in the Uganda collection, in rounds 2008–2009, 2009–2010, 2010–2011, 2013–2014, and 2015–2016 of the panel, where the following question appears:

Q.3.18: "What was the main reason for moving to the current place of residence?"

Among the options, there is the following possible reply: "*Drought, flood, or other weather-related condition*". Although this is the type of question that would enable more research on the climate-migration relationship, it is likely that respondents will fail to report weather-related events as the primary reason for moving especially if they were not forced to relocate but rather pushed into voluntary migration, for example, to look for job opportunities or diversify income.[18] This suggests that greater emphasis should be put on upgrading LSMS-ISA tools and methods to collect climate-migration information more accurately and consistently across and within all LSMS-ISA countries.[19] Our general conclusion, therefore, is that given the current limitations of the LSMS-ISA datasets, there is limited scope for these data to help shed light on some aspects of the climate-migration relationship. Nonetheless, the LSMS program is currently undergoing a broader effort to improve the collection of migration-related information in LSMS surveys to which this paper also aims to contribute by providing literature-based data-oriented recommendations in the specific domain of climate induced migration. In this spirit, we believe that relatively straightforward amendments to the questionnaires and a change of perspective on some key issues could greatly enhance the potential of this multi-topic household survey collection in the climate-migration research field. This is the focus of the next section.

4.3 | Adapting LSMS-ISA surveys to collect literature-based migration data

In this section, we identify promising areas in which, with minor improvements, household survey collections *à la* LSMS-ISA could greatly contribute to the understanding of the climate change-migration nexus, with specific reference to the issues of migration as adaptation, climate-induced immobility, and the role of mediating channels and contextual factors. We also provide a preliminary assessment of the potential integration of LSMS-ISA surveys with other non-traditional data sources. Clearly, given the reliance on longitudinal migration information tracking individuals and households over time (and across space), all these data-related opportunities crucially depend on the continuation of existing panels, including the collection of individual disaggregated data over time[20] and, ideally, the launch of new ones to increase the geographic coverage of LSMS-ISA,[21] which should go in parallel with efforts towards improving questionnaire design and interoperability with other data sources.

4.3.1 | Look at (im)mobility in the broader framework of adaptation to climate stress

While the issue of small sample sizes of households with migrants, stemming from the "rare event" nature of migration, is an intrinsic shortcoming of general-purpose multi-topic representative surveys, a change of perspective on the issue can help in thinking about new research directions. In particular, our review has emphasized that the potential immobility traps of climate-related hazards are at least as important as the mobility effects triggered by such events. In this respect, household surveys could be used not only to look at migratory flows causally linked to weather anomalies and climatic disasters but also, and perhaps especially so, to the relationship between such events and the presence of potential immobility traps associated with adaptation failures.

Collecting additional data on "migration-as-adaptation", with particular emphasis on questions investigating the reasons (e.g., the role of liquidity constraints) that hampered the implementation of household or individual-level coping strategies, including those that are migration-related, is highly recommended. In such a perspective, migration is seen as one among a pool of household adaptation strategies in the face of environmental change. The study of *in-situ* adaptation strategies, therefore, should be considered complementary to the adaptive decision to migrate. Ideally, therefore, new microdata on migration-as-adaptation should ultimately be collected through an ad hoc section embedded within a broader and comprehensive *Adaptation Module*. McCarthy provided a set of key indicators and modules to supplement LSMS and LSMS-ISA survey instruments based on a taxonomy of household agricultural practices and investments that can contribute to adapting to climate change (the so-called sustainable land management or SLM). These include agroforestry investments, reduced or zero tillage, use of cover crops, and various soil and water conservation structures. There are often long-term benefits for households from adopting such activities in terms of increasing yields and reducing the variability of yields, making the system more resilient to changes in climate.

The implementation of a comprehensive *adaptation module* capturing these aspects as well as other insights from resilience and vulnerability studies (D'Errico et al., 2019; Magrini et al., 2018) would represent a clear added value for household surveys. It would allow one to distinguish between migration as adaptation mainly implemented as a strategic risk-diversification strategy by richer and better-endowed households versus survival migration adopted as a last-resort option by the poorer households, and hence enhance our understanding of the nature of migration as voluntary or involuntary. It would also have important implications for studying adaptation policies to climate change in rural developing contexts in Sub-Saharan Africa. For example, the systematic inclusion, in the roster of potential answers to the question on coping strategies, of a follow-up question, after the one asking the main reason for the migration of the individual, asking whether the reason selected (e.g., "to find work elsewhere") was exacerbated by weather anomalies or a general and progressive deterioration in climatic conditions, would be a straightforward way to collect more information on climatic push factors. Even if a module should not be seen as a viable solution, the collection of additional questions and to make up for the current lack of an integrated framework on adaptation in household surveys such as the LSMS-ISA should be in any case strongly encouraged.

4.3.2 | Investigate the socio-economic channels and contextual factors driving climate-related (im)mobility

A complementary and parallel solution to collecting data on migration-as-adaptation is the study of "potential migrants" through the investigation of people's climate risk perception and the so-called "intention to migrate" (Helbling et al., 2021; Koubi et al., 2016; Zander et al., 2019). This framing should be inspired by the theoretical insights of the sound literature on asset-based and geographic or shock-driven poverty traps (Barrett & Carter, 2013; Carter & Barrett, 2006; Carter et al., 2008; Jalan & Ravallion, 2002; Letta et al., 2018). With information on the "intention to migrate", it would be possible to fully unleash the potential of one of the main advantages household surveys hold over other data sources on migration, the possibility of assessing the role of transmission mechanisms and contextual factors that affect the magnitude, or even the direction, of the climate-migration link. The LSMS-ISA collection, given its multi-topic nature, can be particularly informative on these issues, because the analyst can fully exploit the wealth of information available about household demographic, economic, and geographic characteristics to investigate a broader range of issues involving the causal links between poverty, agriculture, climate, and the (in)ability to migrate.

4.3.3 | Other possible data improvements in longitudinal surveys

Migration data

The proposed amendments above imply a change of perspective to investigate immobility and transmission mechanisms. There are, however, a series of other data improvements in longitudinal household surveys à la LSMS-ISA that can be implemented. These surveys, in fact, exhibit a clear potential given their intertemporal nature (Carletto & Gourlay, 2019), which also allows them to track over time, and include in the subsequent waves households that relocate within the country, as well as individual members who split from previously selected households. First and foremost, household surveys should be equipped with questions and modules able to clearly distinguish the different types of migration to avoid overlapping and mismatch in definitions. Most importantly, in order to distinguish the type of migration response triggered by weather shocks and climatic push factors, surveys should be able to precisely separate short-term migrants from long-term ones.[22] Next, in order to avoid misattribution, they should also be able to incorporate information about temporary, circular, and return migrants.[23] To study potential climate-induced immobility traps and migration-as-adaptation, surveys should also be able to clearly distinguish between trapped populations—that is, those who are "forced to stay" from non-affected and non-vulnerable people, who choose to stay and, if needed, invest to adapt in situ. For this, additional modules on migration aspirations, intentions-to-migrate, and adaptation practices, coping strategies, and risk management and aversion, are the most obvious solutions. Possible additional ways to enhance people's traceability are: (i) to keep track of people who are not members of the surveyed households but are somehow associated with them (e.g., close relatives); (ii) to collect migration histories and retrospective data in panel waves covering years between surveys. In any case, the data gaps on migration require one to track people over time and across space, either directly or indirectly. More extended coverage, questions better targeted to capture precise definitions and different types of migrations, and new modules on previously neglected phenomena and interrelationships represent solutions to greatly expand the scope and usability of

household survey tools. A last route could consist of establishing a functional link with proximate data collection on national and local patterns of local labor mobility. Enhancing the interoperability with labor mobility and big data is key to explore climate-induced rural-urban movements and their consequences on urban labor markets, as well as to provide insights on the so-called *migration chains*—subsequent international migratory flows from urban areas triggered by initial weather-induced internal movements towards cities. At the moment, the LSMS-ISA has a strong comparative advantage for the investigation of the agricultural channel and rural-urban internal movements, but limited capability to track urban migration patterns, and almost none when it comes to international flows and potential rural-urban-international mobility chains. However, this integration is neither straightforward nor readily available. To facilitate and make this integration possible, efforts should be made to improve accessibility of data sources for integration, foster data interoperability by design, establish total quality frameworks for data integration, and maintain ethical standards and data confidentiality (Carletto et al., 2022).

Weather and climate data, short and long-term impacts

Thanks to their panel nature, LSMS-ISA surveys can capture, in principle, repeated weather shocks, cumulative weather risk, and their potential impact on migration outcomes. However, there are some key actions that could be undertaken to maximize this potential impact. First and foremost, it is fundamental to ensure that the horizon of LSMS-ISA panels could be extended as much as possible to enhance their capacity to capture longer climate-related impacts and their underlying dynamics. At the same time, it has to be acknowledged that these surveys suffer from an inherent attrition rate due to the typical household splitting dynamics. This makes them unsuited to study the long-term effects of climate change, meaning that, as it stands, these data—like virtually all the other available microdata surveys—can be used at most to estimate medium-run effects.[24] A viable solution to this issue is, as highlighted above, the collection of individual disaggregated data over time, but it comes at the cost of changing the identification strategy.

Using LSMS-ISA data from six Sub-Saharan African countries, Michler et al. (2021) tested many different weather metrics used to quantify precipitation and temperature impact estimates of agricultural production (crop yields and harvest quantities). Of the 22 metrics they assess, they find that the simpler metrics (i.e., total seasonal rainfall, mean daily temperature) performed relatively better in predicting agricultural outcomes across different models and countries. Based on these findings, they conclude that more care is needed to justify their choice of weather metrics. Additionally, there is also evidence that defining the growing season matters in terms of potential measurement error while using remote sensing data: ideally, daily or monthly weather indicators should be selected on the basis of growing seasons defined at the highest possible level of spatial resolution or of self-reported planting dates (Viswanathan & Kumar, 2015; Michler et al., 2021; Letta et al., 2022). Extrapolating from the weather-agriculture relationship to mobility outcomes, under the assumption that agricultural acts as one of the most important channels in mediating the climate-migration nexus, a more systematic and ambitious approach is needed, both regarding the merging of household survey data with external remote sensing products, and in enriching survey collections with harmonized and comparable measures of weather variables. This common effort would pose a limit on the plethora of choices regarding weather variables and indicators currently adopted in the literature, whose heterogeneity might at least partially account for the heterogeneity of findings and inconclusive evidence regarding climate migration.

We therefore deem it necessary to incorporate, within LSMS-ISA in particular and multi-topic surveys in general, a built-in and comprehensive set of (spatially and temporally) high-resolution

weather data, which should: (i) not be limited to temperature and precipitation, but also incorporate other key weather variables such as humidity, windspeed, etc.; (ii) include ad hoc, agriculturally-relevant weather information, such as weather indicators constructed on the basis of crop-specific and local growing season calendars; iii) also include, in addition to weather data, all the equivalent climate variables, based on the long-run averages (e.g., 30-year) of the weather time series. The provision of a set of built-in weather data would prevent risks arising from independent user integration with external remote sensing weather data, that is, measurement error due to spatial anonymization and sensitivity of econometric estimates to the specific weather data product chosen by the researcher (Michler et al., 2022), as well as the use of self-reported weather shocks—such as in Ocello et al. (2015)—based on the perceptions of individuals interviewed, whose accuracy remains questionable.

The inclusion of longer-run climatic measures and time series would also allow the implementation of more recent and sophisticated techniques tailored to bridge the external validity gap between weather and climate, such as long differences or the inclusion of several weather lags in the regression models. Moreover, as this information typically comes from publicly available remote sensing data products which can be subject to different sources of measurement error (Michler et al., 2021), it would be also important, in terms of methodological research, to conduct validation studies on the accuracy of remote sensing estimates *vis-à-vis* ground-based measurements of weather events characterized by a high degree of spatial variability and to understand the direct implications on the prediction of agricultural outcomes and the analysis of other key socio-economic indicators computed from georeferenced survey data.[25] Should this type of methodological research be unfeasible due to timing or budget constraints, efforts could be made to integrate existing surveys with crowdsourced weather data (Minet et al., 2017; Muller et al., 2015; Overeem et al., 2013), to obtain maximum possible spatial and temporal granularity of climate information.

Lastly, standard nationally-representative household surveys, such as the LSMS-ISA, are clearly disadvantaged with respect to the possibility of investigating migratory outcomes of localized sudden-onset weather shocks, which require ad hoc post-disaster surveys. Thus, the use of "mixed-mode" data collections solutions, such as the alternation of standard face-to-face surveys with higher-frequency phone-survey interviews, would allow one to obtain more timely and frequent longitudinal information in general and also, if a sudden shock occurs, basic migration data in the aftermath of the shock itself, in an easier and less expensive way compared to the complexity associated with the implementation of a swift ad hoc survey in the area exposed to the disaster.

4.3.4 | Integration with non-traditional data sources

Big data, digital-trace data, and citizen-generated information are emerging as new sources of migration data and their increasing availability is leading to the development of innovative ways to measure migration (Kirchberger, 2021; Tjaden, 2021). Their potential to measure and track human mobility and other behavioral patterns, and the challenges associated with their use, suddenly became evident in the context of the non-pharmaceutical interventions and public health policies adopted in response to the COVID-19 pandemic (Milusheva et al., 2021; Oliver et al., 2020; World Bank, 2021). Despite their potential, these data remain mostly untested and only sporadically adopted in official statistics; applications, including those that try to combine some of these new data sources among themselves, are still in a very early stage and there are important challenges connected to their use that are not yet resolved. In terms of opportunities offered by the

TABLE 1 Summary of the literature-based assessment of data gaps.

Conceptual issues	Empirical issues	Data issues	LSMS-ISA issues	Proposals
Fast versus slow-onset events	Different migration outcomes depending on the type of event	"Rare event" nature of migration in household surveys; need for high-frequency data and long panels; need of ad hoc surveys for fast-onset shocks	Small migrant samples; lack of high-frequency data and long panels	More focus on immobility and cumulative slow-onset changes; "mixed-mode" data collection solutions combining standard and phone surveys
Direct versus indirect effects	Identification of channels	Need for multi-topic and multi-purpose data	None (it is its main added value)	More empirical research using ad hoc tools (e.g., mediation analysis) to leverage this added value
Internal versus international migration	Inconclusive evidence of the two phenomena and their interconnectedness (climate-migration chain)	Need for longitudinal microdata on internal and international mobility	Lack of consistent information (across countries, within countries, over time)	Collection of migration histories and more systematic retrospective/recall data in panel waves for in-between years; associate module; potential links with complementary labor mobility data
Liquidity constraints, mobility versus immobility	Disentangling the relationship between migration, wealth. and resources	Dearth of data on potential migrants, intention-to-migrate, stated versus revealed preferences, reasons for migrating	Small migrant samples; indirect proxies/measures for migration; no information on potential migrants	Empirical focus on climate risk perception, intention to migrate, and immobility traps
Migration as adaptation	Understanding the linkage between agricultural practices, *in-situ* adaptation and migration; voluntary versus involuntary migration	Data gaps on a set of indicators capturing the interconnectedness between farmers' adaptation and decisions to migrate	Lack of an integrated and comprehensive framework on adaptation	Collection of data on migration as adaptation (in which migration appears as a strategy among a pool of other adaptation options)

integration of household surveys with these non-traditional data sources, our assessment is that while, at the moment, improving interoperability of household surveys with non-conventional data presents complex issues, this is likely to be the way to go in a not-so-distant future.

On the one hand, big data, such as mobile phone data or smartphone app data, have indeed the potential to complement traditional data and address significant spatial and temporal gaps (Lohr & Raghunathan, 2017). As emphasized by the IOM (2018), the main strengths of these new data sources lie in their wide and continuous coverage, flexibility, timeliness, frequency, high spatial, relatively low cost, and their potential to track temporary, circular, and seasonal patterns of migration, which are difficult to capture through traditional sources. For example, by tracking the approximate location of individuals, digital-trace data provide objective (rather than self-reported) measures of migration for large samples and on a continuous, almost real-time basis. Therefore, these data may allow distinguishing between different types of migration (both in terms of length and destination) with great accuracy and at a comparatively low cost. Such flexibility makes these new data sources particularly valuable in detecting and analyzing migratory patterns by sudden shocks such as rapid-onset climatic events or natural disasters, which typically tend to bring about short-run, transitory moves that would be difficult to observe with standard tools.

Additionally, big data can represent an innovative solution to improve ex-ante sample design (e.g., first-stage sample selection) and substantially lower the considerable costs associated with traditional operations. For instance, there are recent studies that try to link survey data with digital-trace data to recruit difficult-to-reach respondents (Iannelli et al., 2020) or to augment traditional data sources and provide more robust measures of the stocks of international migrants (Rampazzo et al., 2021). Developing accurate ways to detect migration events in big data (see, for instance, the paper by Chi et al. (2020)) can generate previously unthought opportunities to help address some of the intrinsic limitations of surveys associated with sampling issues, such as the rare event problem resulting in small sample sizes. Lastly, non-conventional data can also allow one to compute many new covariates that would otherwise be costly or difficult to collect at scale, such as labor market referrals, social networks, or mobility and social contact (Kirchberger, 2021).

On the other hand, the use of big data comes with significant challenges, among which: (i) ownership by the private sector; (ii) privacy, data protection, and ethical issues in using data automatically generated by users, and human rights concerns; (iii) their volume, complexity and "noisiness"; (iv) the fact that big data reflect behavioral patterns that may not be representative of the population (selection bias); (v) reliability of the self-reported information on social media; and (vi) difficulties in applying statistical definitions of migration. Using the case study of a data science challenge involving West African mobile phone data, Taylor (2016) argues that big data carries with it the dual risk of rendering certain groups invisible, and of misinterpreting what is visible and, in addition, raises concerns about the lack of information concerning the context of behaviors and activities "observed" using big data analysis. Others have argued that the distance between the researcher and the research looms large for remotely generated data, posing challenges to validity and ground truth, as well as for the reliability and interpretation of research results (Kraly & Hovy, 2020).

While the potential for using such data to better understand migration dynamics has yet to be fully explored, integrating multi-topic household surveys with varied sources of big data requires addressing the significant technical and ethical challenges just highlighted and also the development of new methodologies that consider complex interactions over differing geographical and temporal scales (Franklinos et al., 2020).

Interoperability refers to the ability to link different data sources through common identifiers for individuals, households, facilities, firms or administrative areas; geospatial coordinates; time

stamps; and common classification standards (Carletto et al., 2022). Such interoperability could be carried out either *ex-ante* or *ex-post* data collection. *Ex-post*, the common identifiers would not necessarily refer to specific individual identifiers—since household surveys, different from population censuses, only include a small representative subsample of the population, this could hardly be possible —but more realistically to area-level common identifiers (e.g., neighborhoods, villages, zip codes, etc.), which would allow for the generation of integrated datasets on mobility indicators at high levels of spatial (and temporal) resolution. From a privacy and confidentiality perspective, this *ex-post* integration should be conducted by applying appropriate and validated spatial anonymization methods to prevent possible identification and the leakage of sensitive information about households and individuals.

By *ex-ante* integration, we mean fostering interoperability between big and household survey data at design (Carletto et al., 2022). In such case, the common identifiers could, and ideally should, allow for the merging of individual-specific information. In terms of ethical requirements, in order to be able to link these data, explicit consent on the part of involved individuals and households would be needed (Al Baghal et al., 2021). Other than ethical criteria, fostering interoperability at design would also make it possible to prevent non-trivial statistical problems related to representativeness and selection bias, which are inherent features of big data products and would reappear in the case of *ex-post* integration.

That being said, fostering interoperability at design would still face important challenges related to data linkage, other than privacy protection, such as licensing, especially, since many big and non-conventional data sources—such as social media data—belong to private sector companies, have commercial value, and may disappear anytime. Furthermore, to leverage big data as a meaningful source of information for migration analysis, national statistical offices would need to work with all relevant stakeholders to manage the process of data production (IOM, 2018). These are hard challenges, but non-conventional data sources offer such great potential to complement (not substitute) survey data that, at some point, these challenges will have to be faced. Our assessment, therefore, is that while these challenges and drawbacks currently make their potential combination with household surveys challenging in the short-run, these sources appear promising for the future, especially because of their ability to provide a large amount of more timely and granular data.

Based on the above analysis, a summary of our assessment of the opportunities and limitations related to the use of household surveys *à la* LSMS-ISA is reported in Table 1, which provides a list of the most relevant conceptual and empirical issues, with the corresponding data gaps and a set of initial proposals to boost the potential of longitudinal multi-topic household surveys. These proposals aim at: (i) partially shrinking the data and empirical gaps—highlighted in the review section of this paper—of the specialized literature by exploiting the advantages of already-existing surveys; and (ii) addressing the current limitations of existing surveys in future data collection efforts to further boost research on climate migration.

5 | CONCLUSIONS

It is easy to envisage that, as climate change intensifies, the climate change-migration nexus will keep gaining prominence in the international agenda. In parallel, the empirical literature will keep growing. Further refinements to the conceptual framework, as well as developments in econometric techniques, will shed new light on the relationship between these complex, mul-

tifaceted phenomena. However, all of this cannot provide concrete benefits for policymaking without closing existing data gaps.

Based on the empirical review, we have identified the main data gaps on the climate-migration nexus. Using a household survey program currently at the forefront of methodological research, the LSMS-ISA project, we then identified the limitations and opportunities for household survey data to enhance our understanding of the causal relationship. We have stressed that household surveys currently allow limited exploration of the climate-migration nexus. At the same time, we have also documented, in light of the open issues and research gaps in the literature, the great potential that LSMS-type surveys to help address some of the most policy-relevant research questions in the field.

Our proposals are twofold: conceptual and operational. Conceptually, we call for researchers to make use of these data to investigate some of the most important, but still unclear aspects, of this nexus, such as the role of immobility, the complementarity or substitutability between migration and other adaptation strategies, and the migration potential of cumulative slow-onset events. Operationally, we propose to integrate multi-topic, multi-purpose, longitudinal household surveys with additional pieces of information enhancing both the quality and quantity of the information collected. In particular, with only slight modifications to the current questionnaires—such as short modules on adaptation and intention to migrate, the collection of migration histories or associate modules, and the integration of face-to-face surveys with phone surveys to increase the frequency of the longitudinal information—it would be possible to maximize the potential of these tools in a cost-effective way.

As noted by scholars and practitioners,[26] adding modules to existing surveys such as the LSMS-ISA has a non-negligible advantage in terms of both timing and cost, as it involves only the relatively small marginal cost (compared to the total survey cost) of adding questions to an ongoing survey program already funded and underway. In the medium term, solving technical and ethical challenges related to the interoperability with non-conventional data sources would unleash even more innovations and opportunities. For the moment, we see clear scope for general multi-purpose household surveys to play a leading role in the climate-migration field, as these tools hold key advantages over censuses and other administrative data sources due to their comprehensiveness and flexibility to collect more detailed data. Our review calls for the exploitation of these advantages.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

Not applicable.

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ENDNOTES

[1] For reference to the literature before 2010 see Piguet et al. (2011).

[2] Our survey is a data-oriented synthesis of selected recent findings relevant to the study of the potential of household survey data. For general and more comprehensive reviews and meta-analyses of the literature on the climate-migration relationship, we recommend readers to consult Cattaneo et al. (2019), Hoffmann et al. (2020), and Kaczan and Orgill-Meyer (2020).

[3] These five thematic subsections have been selected, among many topics, due to their relevance and prominence to the assessment of data gaps we conduct.

[4] Following Beine and Jeusette (2021), *direct* measures of migration can be typically found in sources such as household surveys, in which individuals or their relatives are directly asked about migration histories and decisions. In contrast, *indirect* migration measures are those in which mobility can only be inferred, as is the case, for instance, when migration flows are generated starting from differences in migration stocks found in census data.

[5] These studies are also important because they show how research based on the use of non-conventional data sources (such as mobile network data) can describe, at a high level of temporal resolution, important features of human mobility during and after extreme weather events, which are extremely hard to quantify using standard sources such as household surveys and censuses (see the discussion in Section 3.2).

[6] Cantons are the second-level subdivisions of Ecuador, below provinces.

[7] Albeit outside the main scope of this work, it is relevant to mention that some studies also found evidence in support of a causal link between climate change, weather shocks, and conflicts in Africa (see, *inter alia*, Harari & La Ferrara, 2018). Political instability may in turn lead to sizable migratory flows from such conflict-affected areas. These indirect hypothetical mechanisms are, indeed, difficult to detect empirically, due to the complex nature and uncertain unfolding of these interrelationships.

[8] Recent examples of works leveraging the potential of this methodology to unpack the black box of causal relationships in the development field are Azzarri et al. (2022), Pace et al. (2022), and Prifti et al. (2019). For a comprehensive review of the use of mediation analysis in economics, see Celli (2022).

[9] To note that the immobility issue is not specific to climate-induced migration. It has long been known that immobility often masks the inability of people willing to move to do so, due to liquidity constraints, lack of information, absence of networks, etc. When these obstacles are removed, migration trends increase. A recent example of international migration triggered by a program aimed at fostering migration through improved connection and information about employment opportunities (carried out as part of an experiment implemented in Mizoram, India) is provided in Gaikwad et al. (2022).

[10] For a comprehensive overview of the availability and quality of climate data in the context of Africa see, instead, Dinku (2019).

[11] A caveat is in order here to remind readers of the potential differences and inconsistencies between 'stated' and 'revealed' migration preferences, which compound over the already complex and multi-faceted nature of the migration phenomenon, which can take many different forms across space and over time. The issue is also related to the heterogeneity of the climate risk perceptions of the individuals interviewed.

[12] See Auffhammer et al. (2013) and Dell et al. (2014) for further discussion. For a comprehensive overview of the availability and quality of climate data in the context of Africa see, instead, Dinku (2019).

[13] In addition to LSMS, other major types of household surveys that are normally used to source data on migration are Labour Force Surveys (LFS) and Demographic Health Surveys (DHS) (Bilsborrow, 2016; Lucas, 2021).

[14] Also following some decisive initiatives at the international level such as the adoption of the 2030 Agenda for Sustainable Development and the UN Global Compact for Migration in 2018.

[15] Seasonal migrants are those who leave for a specified period of time each year and should be identified through questions about repeated, short migration spells. *Return* migrants migrated at some time in the past and have

returned to the country or household somewhat permanently. *Circular* migrants are those who have returned but plan to leave again for a significant period of time, or repeatedly migrate for long spells.

[16] We here refer only to studies exclusively focusing on the causal links between climate change and migration, and exclude works devoted to other research questions that incidentally find climatic impacts on migration decisions.

[17] Cf. https://microdata.worldbank.org/index.php/catalog/76/related-materials. Here, we use questionnaires from the second round (2008-2009) as the benchmark.

[18] In these cases, respondents will most probably indicate one of these motives (rather than the weather-related root cause) as the main reason for moving.

[19] The question on the main reason for moving to the current place of residence is currently not found in any other collection of surveys across other countries (cf. Table A.2) and has been dropped from the latest rounds of the Uganda panel collection as contained in a migration module for household members that was not administered in the last two waves (2018–2019 and 2019–2020).

[20] Related to this, it must be noted that the Living Standards Measurement Study-Plus (LSMS+) program established in 2016 is already working to enhance the availability and quality of intra-household, self-reported, individual-disaggregated survey data collected in low and middle-income countries on key dimensions of men's and women's economic opportunities and welfare.

[21] This specific aspect will depend on strategic decisions concerning the future of the LSMS-ISA project. However, it is worth highlighting the key role that LSMS-ISA plays in developing, testing, and validating improved survey methods that are then exported and scaled up to other similar data collection efforts. One example is the recently launched 50x2030 Initiative (https://www.50x2030.org/), which builds on the experiences of the LSMS-ISA and the FAO's Agricultural Integrated Survey (*AGRISurvey*) program to close the agricultural data gap in 50 low and lower middle-income countries by 2030.

[22] According to IOM, a short-term migrant is *a person who changes his or her place of usual residence for more than three months but less than a year*, whereas a long-term migrant is *a person who moves to a country other than that of his or her usual residence for a period of at least one year, so that the country of destination effectively becomes his or her new country of usual residence*.

[23] IOM defines temporary migration as *migration for a specific motivation and purpose with the intention to return to the country of origin or habitual residence after a limited period of time or to undertake an onward movement*; a circular migrant as *any migrant who repeatedly moves back and forth between two or more countries*; and a return migrant as a *person returning to their country of origin/place of habitual residence after having moved away from their place of habitual residence and crossed a border*.

[24] One well-known exception is the Mexican Family Life Survey (MxFLS), managed by the Ibero-American University and the Center for Economic Research and Teaching, which has been collecting information on a wide range of socioeconomic and demographic indicators for more than 7500 households over a 10-year period, as well as on individuals or households that grew out from the original sample, including those who migrated within Mexico or to the U.S. For details about the MxFLS, see http://www.ennvih-mxfls.org/english/index.html.

[25] In this respect, the latest innovations in the field of commercial-grade, high-accuracy *in-situ* weather sensors, offer the possibility of integrating the use of this technology into data-collection efforts of LSMS-ISA as part of side validation studies conducted, for example, on a specific sub-set of the household sample. This can also produce benefits in terms of generating the data needed for training models for satellite-based weather monitoring and, therefore, improve their accuracy (something along the lines of recent LSMS-led methodological research on crop-type mapping, see Azzari et al. (2021)).

[26] See, for example, here: https://migrationdataportal.org/blog/household-surveys-key-potential-source-data-migration.

[27] To help readers, we report, next to each reference, a number in bold and square brackets depending on the specific topic to which each reference belongs. The legend is as follows: [1] Migration and climate change; [2] Migration data sources, gaps, and methods; [3] Climate change impacts and weather data; [4] Other topics.

REFERENCES[27]

Alam, G. M., Alam, K., & Mushtaq, S. (2016). Influence of institutional access and social capital on adaptation decision: Empirical evidence from hazard-prone rural households in Bangladesh. *Ecological Economics*, *130*, 243–251. **[1]**.

Al Baghal, T., Wenz, A., Sloan, L., & Jessop, C. (2021). Linking Twitter and survey data: Asymmetry in quantity and its impact. *EPJ Data Science*, *10*(1), 32. **[2]**.

Auffhammer, M. (2018). Quantifying economic damages from climate change. *Journal of Economic Perspectives*, *32*(4), 33–52. **[3]**.

Auffhammer, M., Hsiang, S. M., Schlenker, W., & Sobel, A. (2013). Using weather data and climate model output in economic analyzes of climate change. *Review of Environmental Economics and Policy*, *7*(2), 181–198. **[3]**.

Azzari, G., Jain, S., Jeffries, G., Kilic, T., & Murray, S. (2021). Understanding the requirements for surveys to support satellite-based crop type mapping: Evidence from Sub-Saharan Africa. *Remote Sensing*, *13*(23), 4749. **[4]**.

Azzarri, C., Haile, B., & Letta, M. (2022). Plant different, eat different? Insights from participatory agricultural research. *PLoS ONE*, *17*(3), e0265947. **[4]**.

Bardsley, D. K., & Hugo, G. J. (2010). Migration and climate change: Examining thresholds of change to guide effective adaptation decision-making. *Population and Environment*, *32*(2-3), 238–262. **[1]**.

Barrett, C. B., & Carter, M. R. (2013). The economics of poverty traps and persistent poverty: Empirical and policy implications. *The Journal of Development Studies*, *49*(7), 976–990. **[4]**.

Bazzi, S. (2017). Wealth heterogeneity and the income elasticity of migration. *American Economic Journal: Applied Economics*, *9*(2), 219–55. **[1]**.

Becerra-Valbuena, L. G., & Millock, K. (2021). Gendered migration responses to drought in Malawi. *Journal of Demographic Economics*, *87*(3), 437–477. **[1]**.

Beegle, K., De Weerdt, J., & Dercon, S. (2011). Migration and economic mobility in Tanzania: Evidence from a tracking survey. *Review of Economics and Statistics*, *93*(3), 1010–1033. **[1]**.

Beine, M., & Parsons, C. (2015). Climatic factors as determinants of international migration. *The Scandinavian Journal of Economics*, *117*(2), 723–767. **[1]**.

Beine, M. A., & Jeusette, L. (2021). A meta-analysis of the literature on climate change and migration. *Journal of Demographic Economics*, 87(3), 293-344. **[1]**.

Bekaert, E., Ruyssen, I., & Salomone, S. (2021). Domestic and international migration intentions in response to environmental stress: A global cross-country analysis. *Journal of Demographic Economics*, *87*(3), 383–436. **[1]**.

Bengtsson, L., Gaudart, J., Lu, X., Moore, S., Wetter, E., Sallah, K., Rebaudet, S., & Piarroux, R. (2015). Using mobile phone data to predict the spatial spread of cholera. *Scientific Reports*, *5*(1), 1–5. **[2]**.

Bengtsson, L., Lu, X., Thorson, A., Garfield, R., & Von Schreeb, J. (2011). Improved response to disasters and outbreaks by tracking population movements with mobile phone network data: A post-earthquake geospatial study in Haiti. *PLoS Medicine*, *8*(8), e1001083. **[2]**.

Beria, P., & Lunkar, V. (2021). Presence and mobility of the population during the first wave of Covid-19 outbreak and lockdown in Italy. *Sustainable Cities and Society*, *65*, 1–15. https://doi.org/10.1016/j.scs.2020.102616 [2]

Biermann, F., & Boas, I. (2010). Preparing for a warmer world: Towards a global governance system to protect climate refugees. *Global Environmental Politics*, *10*(1), 60–88. **[1]**.

Bilsborrow, R. E. (2016). Concepts, definitions and data collection approaches. In M. White (Ed.) *International handbook of migration and population distribution. International handbooks of population* (Vol. 6). Springer. **[2]**.

Black, R., Bennett, S. R., Thomas, S. M., & Beddington, J. R. (2011). Migration as adaptation. *Nature*, *478*(7370), 447–449. **[1]**.

Blumenstock, J. E. (2012). Inferring patterns of internal migration from mobile phone call records: Evidence from Rwanda. *Information Technology for Development*, *18*(2), 107–125. **[2]**.

Boas, I., Farbotko, C., Adams, H., Sterly, H., Bush, S., Van der Geest, K., Wiegel, H., Ashraf, H., Baldwin, A., Bettini, G., Blondin, S., Bruijn, M. D., Durand-Delacre, D., Fröhlich, C. J., Gioli, G., Guaita, L., Hut, E., Jarawura, F. X., Lamers, M., … Hulme, M. (2019). Climate migration myths. *Nature Climate Change*, *9*(12), 901–903. **[1]**.

Bohra-Mishra, P., Oppenheimer, M., Cai, R., Feng, S., & Licker, R. (2017). Climate variability and migration in the Philippines. *Population and Environment*, *38*(3), 286–308. **[1]**.

Bohra-Mishra, P., Oppenheimer, M., & Hsiang, S. M. (2014). Nonlinear permanent migration response to climatic variations but minimal response to disasters. *Proceedings of the National Academy of Sciences*, *111*(27), 9780–9785. **[1]**.

Bosetti, V., Cattaneo, C., & Peri, G. (2018). Should they stay or should they go? Climate migrants and local conflicts. *Journal of Economic Geography*, *21*(4), 619–651. **[1]**.

Burke, M., & Emerick, K. (2016). Adaptation to climate change: Evidence from US agriculture. *American Economic Journal: Economic Policy*, *8*(3), 106–40. **[3]**.

Cai, R., Feng, S., Oppenheimer, M., & Pytlikova, M. (2016). Climate variability and international migration: The importance of the agricultural linkage. *Journal of Environmental Economics and Management*, *79*, 135–151. **[1]**.

Carletto, C., Chen, H., Kilic, T., & Perucci, F. (2022). Positioning household surveys for the next decade. *Statistical Journal of the IAOS*, *38*(3), 923–946. **[2]**.

Carletto, C., & Gourlay, S. (2019). A thing of the past? Household surveys in a rapidly evolving (agricultural) data landscape: Insights from the LSMS-ISA. *Agricultural Economics*, *50*, 51–62. **[2]**.

Carletto, C., Larrison, J., & Özden, Ç. (2014). Informing migration policies: A data primer. In *International handbook on migration and economic development*. Edward Elgar Publishing. **[2]**.

Carter, M. R., & Barrett, C. B. (2006). The economics of poverty traps and persistent poverty: An asset-based approach. *The Journal of Development Studies*, *42*(2), 178–199. **[4]**.

Carter, M. R., Little, P. D., Mogues, T., & Negatu, W. (2008). Poverty traps and natural disasters in Ethiopia and Honduras. In *Social protection for the poor and poorest* (pp. 85–118). Palgrave Macmillan. **[4]**.

Castells-Quintana, D., Krause, M., & McDermott, T. K. (2021). The urbanising force of global warming: The role of climate change in the spatial distribution of population. *Journal of Economic Geography*, *21*(4), 531–556. **[1]**.

Cattaneo, C., Beine, M., Fröhlich, C. J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., Millock, K., Piguet, E., & Schraven, B. (2019). Human migration in the era of climate change. *Review of Environmental Economics and Policy*, *13*(2), 189–206. **[1]**.

Cattaneo, C., & Peri, G. (2016). The migration response to increasing temperatures. *Journal of Development Economics*, *122*, 127–146. **[1]**.

Celli, V. (2022). Causal mediation analysis in economics: Objectives, assumptions, models. *Journal of Economic Surveys*, *36*(1), 214–234. [4].

Chi, G., Lin, F., Chi, G., & Blumenstock, J. (2020). A general approach to detecting migration events in digital trace data. *PLoS ONE*, *15*(10), e0239408. **[2]**.

Choquette-Levy, N., Wildemeersch, M., Oppenheimer, M., & Levin, S. A. (2021). Risk transfer policies and climate-induced immobility among smallholder farmers. *Nature Climate Change*, *11*(12), 1046–1054. **[1]**.

Cirillo, M., Cattaneo, A., Miller, M., & Sadiddin, A. (2022). Establishing the link between internal and international migration: Evidence from Sub-Saharan Africa. *World Development*, *157*, 105943. **[4]**.

Clement, V., Rigaud, K. K., de Sherbinin, A., Jones, B., Adamo, S., Schewe, J., Sadiq, N., & Shabahat, E. (2021). *Groundswell Part 2: Acting on internal climate migration*. World Bank. **[1]**.

Cottier, F., & Salehyan, I. (2021). Climate variability and irregular migration to the European Union. *Global Environmental Change*, *69*, 102275. **[1]**.

Cui, X., & Feng, S. (2020). Climate change and migration. In Zimmermann K.F. (ed). *Handbook of Labor, Human Resources and Population Economics*, Springer 1–15. **[1]**.

Dallmann, I., & Millock, K. (2017). Climate variability and inter-state migration in India. *CESifo Economic Studies*, *63*(4), 560–594. **[1]**.

De Brauw, A., & Carletto, G. (2012). Improving the measurement and policy relevance of migration information in multi-topic household surveys. *Living Standards Measurement Study Working Paper*, *14*, 3358986–1199367264546. **[2]**.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, *52*(3), 740–98. **[3]**.

Di Falco, S., Kis, A. B., & Viarengo, M. (2022). Cumulative climate shocks and migratory flows: Evidence from Sub-Saharan Africa. IZA Discussion Paper No. 15084. **[1]**.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829–846. **[1]**.

Dillon, A., Mueller, V., & Salau, S. (2011). Migratory responses to agricultural risk in northern Nigeria. *American Journal of Agricultural Economics*, *93*(4), 1048–1061. **[1]**.

Dinku, T. (2019). Challenges with availability and quality of climate data in Africa. In *Extreme hydrology and climate variability* (pp. 71–80). Elsevier. **[3]**.

d'Errico, M., Letta, M., Montalbano, P., & Pietrelli, R. (2019). Resilience thresholds to temperature anomalies: A long-run test for rural Tanzania. *Ecological Economics*, *164*, 106365. **[4]**.

Feng, S., Krueger, A. B., & Oppenheimer, M. (2010). Linkages among climate change, crop yields and Mexico–US cross-border migration. *Proceedings of the National Academy of Sciences*, *107*(32), 14257–14262. **[1]**.

Findlay, A. M. (2012). Flooding and the scale of migration. *Nature Climate Change*, *2*(6), 401–402. **[1]**.

Franklinos, L., Parrish, R., Burns, R. M., Caflisch, A., Mallick, B., Rahman, T., Routsis, V., Sebastián López, A., Tatem, A., & Trigwell, R. (2020). Key opportunities and challenges for the use of big data in migration research and policy. *UCL Open Environment, 3*. **[2]**.

Fröhlich, C. J. (2016). Climate migrants as protestors? Dispelling misconceptions about global environmental change in pre-revolutionary Syria. *Contemporary Levant*, *1*(1), 38–50. **[1]**.

Gaikwad, N., Hanson, K., & Tóth, A. (2022). How overseas opportunities shape political preferences: A field experiment in international migration. Unpublished manuscript. Available at: https://nikhargaikwad.com/resources/OverseasOpportunities.pdf **[2]**.

Grace, K., Hertrich, V., Singare, D., & Husak, G. (2018). Examining rural Sahelian out-migration in the context of climate change: An analysis of the linkages between rainfall and out-migration in two Malian villages from 1981 to 2009. *World Development*, *109*, 187–196. **[1]**.

Gray, C., & Bilsborrow, R. (2013). Environmental influences on human migration in rural Ecuador. *Demography*, *50*(4), 1217–1241. **[1]**.

Gray, C. L., & Mueller, V. (2012a). Drought and population mobility in rural Ethiopia. *World Development*, *40*(1), 134–145. **[1]**.

Gray, C. L., & Mueller, V. (2012b). Natural disasters and population mobility in Bangladesh. *Proceedings of the National Academy of Sciences*, *109*(16), 6000–6005. **[1]**.

Harari, M., & Ferrara, E. L. (2018). Conflict, climate, and cells: A disaggregated analysis. *Review of Economics and Statistics*, *100*(4), 594–608. **[3]**.

Helbling, M., Auer, D., Meierrieks, D., Mistry, M., & Schaub, M. (2021). Climate change literacy and migration potential: Micro-level evidence from Africa. *Climatic Change*, *169*(1), 1–13. **[1]**.

Henderson, J. V., Storeygard, A., & Deichmann, U. (2017). Has climate change driven urbanization in Africa? *Journal of Development Economics*, *124*, 60–82. **[1]**.

Hirvonen, K. (2016). Temperature changes, household consumption, and internal migration: Evidence from Tanzania. *American Journal of Agricultural Economics*, *98*(4), 1230–1249. **[1]**.

Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., & Peisker, J. (2020). A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change*, *10*(10), 904–912. **[1]**.

Hu, S., Xiong, C., Yang, M., Younes, H., Luo, W., & Zhang, L. (2021). A big-data driven approach to analyzing and modeling human mobility trend under non-pharmaceutical interventions during COVID-19 pandemic. *Transportation Research Part C: Emerging Technologies*, *124*, 245-267. https://doi.org/10.1016/j.trc.2020.102955 **[2]**.

Hunter, L. M., Murray, S., & Riosmena, F. (2013). Rainfall patterns and US migration from rural Mexico. *International Migration Review*, *47*(4), 874–909. **[1]**.

Iannelli, L., Giglietto, F., Rossi, L., & Zurovac, E. (2020). Facebook digital traces for survey research: Assessing the efficiency and effectiveness of a Facebook Ad–based procedure for recruiting online survey respondents in niche and difficult-to-reach populations. *Social Science Computer Review*, *38*(4), 462–476. **[2]**.

International Organization for Migration (IOM). (2018). Data Bulletin Series: Informing the Implementation of the Global Compact for Migration. Available at: https://publications.iom.int/books/data-bulletin-series-informing-implementation-global-compact-migration **[2]**.

Jalan, J., & Ravallion, M. (2002). Geographic poverty traps? A micro model of consumption growth in rural China. *Journal of Applied Econometrics*, *17*(4), 329–346. **[4]**.

Jessoe, K., Manning, D. T., & Taylor, J. E. (2018). Climate change and labour allocation in rural Mexico: Evidence from annual fluctuations in weather. *The Economic Journal*, *128*(608), 230–261. **[1]**.

Kaczan, D. J., & Orgill-Meyer, J. (2020). The impact of climate change on migration: A synthesis of recent empirical insights. *Climatic Change*, *158*(3), 281–300. **[1]**.

Karanja Ng'ang'a, S., Bulte, E. H., Giller, K. E., McIntire, J. M., & Rufino, M. C. (2016). Migration and self-protection against climate change: A case study of Samburu County, Kenya. *World Development*, *84*, 55–68. **[1]**.

Kattumuri, R., Ravindranath, D., & Esteves, T. (2017). Local adaptation strategies in semi-arid regions: Study of two villages in Karnataka, India. *Climate and Development*, *9*(1), 36–49. **[1]**.

Kelley, C. P., Mohtadi, S., Cane, M. A., Seager, R., & Kushnir, Y. (2015). Climate change in the Fertile Crescent and implications of the recent Syrian drought. *Proceedings of the national Academy of Sciences*, *112*(11), 3241–3246. **[1]**.

Kirchberger, M. (2021). Measuring internal migration. *Regional Science and Urban Economics*, *91*, 103714. **[2]**.

Koubi, V., Schaffer, L., Spilker, G., & Böhmelt, T. (2022). Climate events and the role of adaptive capacity for (im-) mobility. *Population and Environment*, 23, 367-392. **[1]**.

Koubi, V., Spilker, G., Schaffer, L., & Bernauer, T. (2016). Environmental stressors and migration: Evidence from Vietnam. *World Development*, *79*, 197–210. **[1]**.

Koubi, V., Stoll, S., & Spilker, G. (2016). Perceptions of environmental change and migration decisions. *Climatic Change*, *138*(3), 439–451. **[1]**.

Kraly, E. P., & Hovy, B. (2020). Data and research to inform global policy: The global compact for safe, orderly and regular migration. *Comparative Migration Studies*, *8*(1), 1–32. **[2]**.

Kubik, Z., & Maurel, M. (2016). Weather shocks, agricultural production and migration: Evidence from Tanzania. *The Journal of Development Studies*, *52*(5), 665–680. **[1]**.

Laczko, F., & Aghazarm, C. (2009). Migration, Environment and Climate Change: assessing the evidence. International Organization for Migration (IOM). **[1]**.

Lai, S., zu Erbach-Schoenberg, E., Pezzulo, C., Ruktanonchai, N. W., Sorichetta, A., Steele, J., Li, T., Dooley, C. A., & Tatem, A. J. (2019). Exploring the use of mobile phone data for national migration statistics. *Palgrave Communications*, *5*(1), 1–10. **[2]**.

Letta, M., Montalbano, P., & Pierre, G. (2022). Weather shocks, traders' expectations, and food prices. *American Journal of Agricultural Economics*, *104*(3), 1100–1119. **[3]**.

Letta, M., Montalbano, P., & Tol, R. S. (2018). Temperature shocks, short-term growth and poverty thresholds: Evidence from rural Tanzania. *World Development*, *112*, 13–32. **[4]**.

Liu, M. Y., Shamdasani, Y., & Taraz, V. (2022). Climate change and labor reallocation: Evidence from six decades of the Indian Census. *American Economic Journal: Economic Policy*, *15*(2), 395–423. **[1]**.

Lohr, S. L., & Raghunathan, T. E. (2017). Combining survey data with other data sources. *Statistical Science*, *32*(2), 293–312. **[2]**.

Lu, X., Bengtsson, L., & Holme, P. (2012). Predictability of population displacement after the 2010 Haiti earthquake. *Proceedings of the National Academy of Sciences*, *109*(29), 11576–11581. **[2]**.

Lu, X., Wrathall, D. J., Sundsøy, P. R., Nadiruzzaman, M., Wetter, E., Iqbal, A., Qureshi, T., Tatem, A. J., Canright, G., Engø-Monsen, K., & Bengtsson, L. (2016a). Detecting climate adaptation with mobile network data in Bangladesh: Anomalies in communication, mobility and consumption patterns during cyclone Mahasen. *Climatic Change*, *138*(3-4), 505–519. **[1, 2]**.

Lu, X., Wrathall, D. J., Sundsøy, P. R., Nadiruzzaman, M., Wetter, E., Iqbal, A., Qureshi, T., Tatem, A. J., Canright, G., Engø-Monsen, K., & Bengtsson, L., & Bengtsson, L. (2016b). Unveiling hidden migration and mobility patterns in climate stressed regions: A longitudinal study of six million anonymous mobile phone users in Bangladesh. *Global Environmental Change*, *38*, 1–7. **[1, 2]**.

Lucas, R. E. (2021). *Crossing the divide: Rural to urban migration in developing countries.* Oxford University Press. **[2]**.

Magrini, E., Montalbano, P., & Winters, L. A. (2018). Households' vulnerability from trade in Vietnam. *World Development*, *112*, 46–58. ISSN 0305-750X. **[4]**.

Marchiori, L., Maystadt, J. F., & Schumacher, I. (2012). The impact of weather anomalies on migration in Sub-Saharan Africa. *Journal of Environmental Economics and Management*, *63*(3), 355–374. **[1]**.

Martinez Flores, F., Milusheva, S., & Reichert, A. R. (2021). Climate anomalies and international migration: A disaggregated analysis for West Africa. World Bank Policy Research Working Paper n.9664. **[1]**.

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, L. D., & Oppenheimer, M. (2016). The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, *39*, 155–169. **[1]**.

McCarthy, N., Kilic, T., De La Fuente, A., & Brubaker, J. M. (2018). Shelter from the storm? household-level impacts of, and responses to, the 2015 floods in Malawi. *Economics of Disasters and Climate Change*, *2*(3), 237–258. **[3]**.

McKenzie, D., & Yang, D. (2012). Experimental approaches in migration studies. In C. Vargas-Silva (Ed.), *Handbook of research methods in migration* (pp. 249–269). Edward Elgar Publishing, Cheltenham. **[2]**.

McKenzie, D., & Yang, D. (2022). Field and Natural Experiments in Migration. World Bank Policy Research Working Paper, n. 10250. **[2]**.

McLeman, R., & Gemenne, F., Eds.. (2018). *Routledge handbook of environmental displacement and migration*. Routledge. **[1]**.

McNamara, K. E., Bronen, R., Fernando, N., & Klepp, S. (2018). The complex decision-making of climate-induced relocation: Adaptation and loss and damage. *Climate Policy*, *18*(1), 111–117. **[1]**.

Michler, J. D., Josephson, A., Kilic, T., & Murray, S. (2021). Estimating the Impact of Weather on Agriculture. Policy Research Working Paper; No. 9867. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/36643 **[3]**.

Michler, J. D., Josephson, A., Kilic, T., & Murray, S. (2022). Privacy Protection, Measurement Error, and the Integration of Remote Sensing and Socioeconomic Survey Data. arXiv preprint arXiv:2202.05220. **[3]**.

Milusheva, S., Lewin, A., Gomez, T. B., Matekenya, D., & Reid, K. (2021). Challenges and opportunities in accessing mobile phone data for COVID-19 response in developing countries. *Data & Policy*, *3*, e20. **[2]**.

Minet, J., Curnel, Y., Gobin, A., Goffart, J. P., Melard, F., Tychon, B., Wellens, J., & Defourny, P. (2017). Crowdsourcing for agricultural applications: A review of uses and opportunities for a farmsourcing approach. *Computers and Electronics in Agriculture*, *142*, 126–138. **[2]**.

Mueller, V., Gray, C., & Hopping, D. (2020). Climate-Induced migration and unemployment in middle-income Africa. *Global Environmental Change*, *65*, 102183. **[1]**.

Mueller, V., Gray, C., & Kosec, K. (2014). Heat stress increases long-term human migration in rural Pakistan. *Nature Climate Change*, *4*(3), 182–185. **[1]**.

Mueller, V., Sheriff, G., Dou, X., & Gray, C. (2020). Temporary migration and climate variation in Eastern Africa. *World Development*, *126*, 104704. **[1]**.

Muller, C. L., Chapman, L., Johnston, S., Kidd, C., Illingworth, S., Foody, G., Overeem, A., & Leigh, R. R. (2015). Crowdsourcing for climate and atmospheric sciences: Current status and future potential. *International Journal of Climatology*, *35*(11), 3185–3203. **[3]**.

Myers, N. (2002). Environmental refugees: A growing phenomenon of the 21st century. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *357*(1420), 609–613. **[1]**.

Nawrotzki, R. J., Riosmena, F., & Hunter, L. M. (2013). Do rainfall deficits predict US-bound migration from rural Mexico? Evidence from the Mexican census. *Population Research and Policy Review*, *32*(1), 129–158. **[1]**.

Niva, V., Kallio, M., Muttarak, R., Taka, M., Varis, O., & Kummu, M. (2021). Global migration is driven by the complex interplay between environmental and social factors. *Environmental Research Letters*, *16*(11), 114019. **[1]**.

Nordhaus, W. D., & Moffat, A. (2017). *A survey of global impacts of climate change: Replication, survey methods, and a statistical analysis (No. w23646)*. National Bureau of Economic Research. **[3]**.

IPCC. (2014). Summary for policymakers. In O. Edenhofer, R. Pichs-Madruga, E. F. Y. Sokona, S. Kadner, K. Seyboth, A. Adler et al. (Eds.) *Climate change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change* (pp. 1–33). Cambridge University Press. Available at: https://www.ipcc.ch/report/ar5/wg2/summary-for-policymakers/ **[3]**.

Ocello, C., Petrucci, A., Testa, M. R., & Vignoli, D. (2015). Environmental aspects of internal migration in Tanzania. *Population and Environment*, *37*(1), 99–108. **[1]**.

Oliver, N., Lepri, B., Sterly, H., Lambiotte, R., Deletaille, S., De Nadai, M., Letouzé, E., Salah, A. A., Benjamins, R., Cattuto, C., Colizza, V., de Cordes, N., Fraiberger, S. P., Koebe, T., Lehmann, S., Murillo, J., Pentland, A., Pham, P. N., Pivetta, F., … Vinck, P. (2020). Mobile phone data for informing public health actions across the COVID-19 pandemic life cycle. *Science advances*, *6*(23), eabc0764. **[2]**.

Overeem, A., Robinson, J. C. R., Leijnse, H., Steeneveld, G. J., Horn, B. K. P., & Uijlenhoet, R. (2013). Crowdsourcing urban air temperatures from smartphone battery temperatures. *Geophysical Research Letters*, *40*(15), 4081–4085. **[3]**.

Pace, N., Sebastian, A., Daidone, S., Prifti, E., & Davis, B. (2022). Mediation analysis of the impact of the Zimbabwe Harmonized Social Cash Transfer Programme on food security and nutrition. *Food Policy*, *106*, 102190. **[4]**.

Peak, C. M., Wesolowski, A., zu Erbach-Schoenberg, E., Tatem, A. J., Wetter, E., Lu, X., Power, D., Weidman-Grunewald, E., Ramos, S., Moritz, S., Buckee, C. O., & Bengtsson, L. (2018). Population mobility reductions associated with travel restrictions during the Ebola epidemic in Sierra Leone: Use of mobile phone data. *International Journal of Epidemiology*, *47*(5), 1562–1570. **[2]**.

Peri, G., & Sasahara, A. (2019). *The impact of global warming on rural-urban migrations: Evidence from global big data (No. w25728)*. National Bureau of Economic Research. **[1]**.

Piguet, E., Pécoud, A., & De Guchteneire, P. (2011). Migration and climate change: An overview. *Refugee Survey Quarterly*, *30*(3), 1–23. **[1]**.

Prifti, E., Daidone, S., & Davis, B. (2019). Causal pathways of the productive impacts of cash transfers: Experimental evidence from Lesotho. *World Development*, *115*, 258–268. **[4]**.

Rampazzo, F., Bijak, J., Vitali, A., Weber, I., & Zagheni, E. (2021). A framework for estimating migrant stocks using digital traces and survey data: An application in the United Kingdom. *Demography*, *58*(6), 2193–2218. **[2]**.

Rigaud, K. K., de Sherbinin, A., Jones, B., Adamo, S., Maleki, D., Abu-Ata, N. E., Casals Fernandez, A. T., Arora, A., Chai-Onn, T., & Mills, B. (2021c). *Groundswell Africa: Internal climate migration in West African Countries*. The World Bank. **[1]**.

Rigaud, K. K., de Sherbinin, A., Jones, B., Adamo, S., Maleki, D., Arora, A., Casals Fernandez, A. T., Chai-Onn, T., & Mills, B. (2021b). *Groundswell Africa: Internal climate migration in the lake victoria basin countries*. The World Bank. **[1]**.

Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McCusker, B., Heuser, S., & Midgley, A. (2018). *Groundswell: Preparing for internal climate migration*. The World Bank. **[1]**.

Riswantini, D., Nugraheni, E., Arisan, A., Khotimah, P. H., Munandar, D., & Suwarningsih, W. (2021). Big data research in fighting COVID-19: Contributions and techniques. *Big Data and Cognitive Computing*, *5*(3), 30. **[2]**.

Robalino, J., Jimenez, J., & Chacón, A. (2015). The effect of hydro-meteorological emergencies on internal migration. *World Development*, *67*, 438–448. **[1]**.

Schultz, K. A., & Mankin, J. S. (2019). Is temperature exogenous? The impact of civil conflict on the instrumental climate record in Sub-Saharan Africa. *American Journal of Political Science*, *63*(4), 723–739. **[3]**.

Schutte, S., Vestby, J., Carling, J., & Buhaug, H. (2021). Climatic conditions are weak predictors of asylum migration. *Nature Communications*, *12*(1), 1–10. **[1]**.

Selby, J., Dahi, O. S., Fröhlich, C., & Hulme, M. (2017). Climate change and the Syrian civil war revisited. *Political Geography*, *60*, 232–244. **[1]**.

Spyratos, S., Vespe, M., Natale, F., Weber, I., Zagheni, E., & Rango, M. (2019). Quantifying international human mobility patterns using Facebook Network data. *PLoS ONE*, *14*(10), e0224134. **[2]**.

Taylor, L. (2016). No place to hide? The ethics and analytics of tracking mobility using mobile phone data. *Environment and Planning D: Society and Space*, *34*(2), 319–336. **[2]**.

Tjaden, J. (2021). Measuring migration 2.0: A review of digital data sources. *Comparative Migration Studies*, *9*(1), 1–20. **[2]**.

Tol, R. S. (2018). The economic impacts of climate change. *Review of Environmental Economics and Policy*, *12*(1), 4–25. **[3]**.

United Nations Framework Convention on Climate Change. (2012). Slow onset events. Technical Paper FCCC/TP/2012/7. https://unfccc.int/resource/docs/2012/tp/07.pdf **[3]**.

Vicente-Serrano, S. M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J. J., López-Moreno, J. I., Azorin-Molina, C., Revuelto, J., Morán-Tejeda, E., & Sanchez-Lorenzo, A. (2012). Performance of drought indices for ecological, agricultural, and hydrological applications. *Earth Interactions*, *16*(10), 1–27. **[3]**.

Viswanathan, B., & Kumar, K. K. (2015). Weather, agriculture and rural migration: Evidence from state and district level migration in India. *Environment and Development Economics*, *20*(4), 469. **[1]**.

Wesolowski, A., Buckee, C. O., Pindolia, D. K., Eagle, N., Smith, D. L., Garcia, A. J., & Tatem, A. J. (2013). The use of census migration data to approximate human movement patterns across temporal scales. *PLoS ONE*, *8*(1), e52971. **[2]**.

Wilson, R., zu Erbach-Schoenberg, E., Albert, M., Power, D., Tudge, S., Gonzalez, M., Guthrie, S., Chamberlain, H., Brooks, C., Hughes, C., Pitonakova, L., Buckee, C., Lu, X., Wetter, E., Tatem, A., & Bengtsson, L. (2016). Rapid and near real-time assessments of population displacement using mobile phone data following disasters: The 2015 Nepal earthquake. *PLoS Currents*, *8*, **[2]**.

Wodon, Q., Liverani, A., Joseph, G., & Bougnoux, N., Eds.. (2014). *Climate change and migration: Evidence from the Middle East and North Africa*. The World Bank. **[1]**.

World Bank. (2021). World development report 2021: Data for better lives. **[2]**.

World Bank. (2022). *G5 Sahel Region Country Climate and Development Report. CCDR Series.*. https://openknowledge.worldbank.org/handle/10986/37620 **[4]**.

Zander, K. K., Richerzhagen, C., & Garnett, S. T. (2019). Human mobility intentions in response to heat in urban South East Asia. *Global Environmental Change*, *56*, 18–28. **[1]**.

Zickgraf, C., & Perrin, N. (2016). Immobile and trapped populations. In Ionesco, D., Mokhnacheva, D., Gemenne, F. *The Atlas of Environmental Migration*, Taylor & Francis **[1]**.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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