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COMMENTARY

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Key Points:

- In African drylands, migration is already being altered by changes in climate with uncertain outcomes under a 1.5° warming
- Impacts in climate-sensitive sectors relying on migrants differ greatly, calling for an advancement of available evidence on regional scale
- A systems approach can address the urgent policy challenges regarding climate-induced human mobility

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Advancing the Evidence Base of Future Warming Impacts on Human Mobility in African Drylands

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Abstract A better understanding of climate change impacts and resulting human responses (climate-related human mobility) have been identified as a research priority by the climate science community. Here, we provide the basis for future research efforts by identifying knowledge gaps and consolidating published evidence in the IPCC 1.5 Special Report (SR15) with recent evidence from climate science and the literature on human mobility in African drylands, a region where migrants are particularly vulnerable to climate change. We first synthesize climatic changes and their projected impacts across the region to then contextualize the projected impacts with current knowledge regarding the effect of anthropogenic climate change on human mobility. We discuss these often indirect impact channels and argue that a systems approach is needed to address the interconnectedness of climate impacts and the cascading risks of adverse consequences for human mobility.

Plain Language Summary The Paris Agreement recognizes that climate change and extreme weather events alter human mobility patterns. Even under an optimistic scenario, an increase in global temperature of 1.5°C above pre-industrial levels is likely to increase the numbers of people vulnerable to climatic stress while limiting the capacity for effective climate change adaptation. Under a less optimistic scenario, the disruption is expected to be worse. Yet, the impacts of different warming scenarios, including observed warming, on human mobility remain insufficiently understood and discussed in policymaking. A synthesis of empirical evidence from the IPCC Special Report on Global Warming of 1.5°C and subsequently published literature on climate change effects in African drylands highlight implications of warming scenarios on human mobility in this region, where climatic change is a defining feature of local communities and predominantly agricultural economies. Adverse effects of climate change on African dryland communities may not necessarily cause mass migration but are likely to alter human mobility from more voluntary toward more forced displacement or entrapment. A systems approach can be used as a starting point to address the urgent challenges of climate-related human mobility.

1. Introduction

Displacement, forced migration, and other forms of human mobility have long been recognized as a potential major impact of anthropogenic climate change. Therefore, limiting climate-related human mobility has been important in informing the goal of capping global warming at 1.5°C above pre-industrial levels in the Paris Agreement (Hoffmann et al., 2020; Task Force on Displacement, 2018; UNFCCC, 2015).

The importance of addressing climate-related human mobility has further been recognized in a range of legal and policy frameworks (Intergovernmental Authority on Development, 2020; International Organization for Migration, 2019; United Nations Office for Disaster Risk Reduction, 2015). The Task Force on Displacement, established under the Warsaw International Mechanism for Loss and Damage, aims to develop recommendations for integrated approaches to avert and minimize internal displacement from extreme weather events and slow-onset adverse effects of climate change (Oakes et al., 2019; Task Force on Displacement, 2018).

Climate change will impact a wide range of sectors (Dasgupta et al., 2014) which in turn could have profound implications for human mobility. The most significant sectors impacting climate-related human mobility are covered by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C (SR15). While more recent IPCC reports have been released, including the Special Report

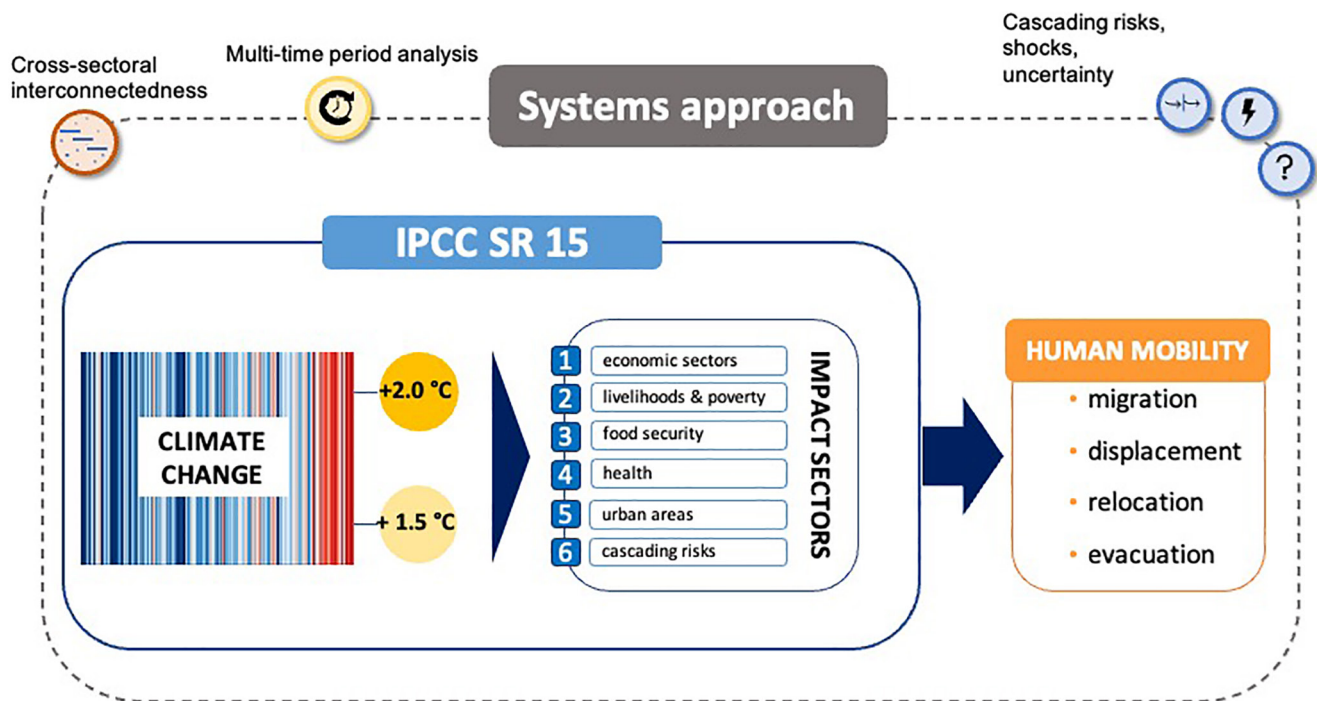


Figure 1. Schematic illustration of the interactions between climate change effects in the six climate change impact sectors and different types of human mobility in a systems approach framework.

on the Oceans and Cryosphere in a Changing Climate and the Special Report on Climate Change and Land (IPCC, 2019a, 2019b), SR15 was commissioned specifically with decision-makers and policy planners in mind. The report scientifically assesses the implications of pursuing efforts to implement the Paris Agreement by outlining sector-specific transitions and policy actions (Tokarska et al., 2019), as well as the expected societal impacts in six climate change impact sectors (Figure 1).

Human mobility in the form of migration provides a coping mechanism when facing extreme weather events and anomalous seasons (Geest & Warner, 2014; Harrington & Otto, 2018; A. D. King et al., 2018). However, without concrete climate and development action, situations of entrapment can become more prevalent globally (Adger et al., 2015; Ayeb-Karlsson et al., 2015). This is particularly relevant in regions where vulnerability and exposure are already high and even small changes in hazards amplify consequences on populations in situ (Harrington & Otto, 2018).

Here, we focus on one of the largest regions where such conditions apply. Home to over 38% of the Earth's population (Burrell et al., 2020; Huang et al., 2017), dryland communities are disproportionately affected and vulnerable to the impacts of climate change. Dryland regions are projected to experience a 3.2°C–4°C warming under a 2°C global warming scenario by 2050 (IPCC, 2018). This is particularly crucial for African dryland regions, where regional climate models further project increases in frequency and intensity of heat-waves, droughts, and floods, and adaptation is additionally hindered by high uncertainties and poor data availability (Harrington & Otto, 2020; Wartenburger et al., 2017). Therefore, we seek to answer: What is the current understanding of the implications for human mobility in African drylands under future warming?

In this study, we provide a comprehensive discussion of the impact channels through which future warming affects human mobility (climate-related human mobility). This Commentary aims to contribute to the ongoing, global effort toward a better understanding of climate-related human mobility (Boas et al., 2019) and to offer a directly usable approach for policy-makers. To this aim, we propose a systems approach to address the interconnectedness of climate impacts and cascading risks of future warming on human mobility in African drylands. Doing so, however, requires a thorough understanding of the systemic characteristics outlined in Figure 1 (ie., cascading risks, shocks, uncertainty, cross-sectoral interconnectedness, and the analysis of multiple time periods), and vulnerabilities of climate-related human mobility and the climate

system. Our systems approach recognizes dynamics and sectoral linkages (six impact sectors in Figure 1), which often-times align more closely with the realities of the complexities of climate-related human mobility. Conceptually, such an approach has been applied to a diverse range of fields such as food systems (Gaupp, 2020; Nicholson et al., 2020), but has been less used in the analysis of climate-related human mobility issues.

2. Climate-Related Human Mobility

Many weather and climate-related events have become more frequent and intense leading to widespread and disastrous impacts for populations globally (Hoegh-Guldberg et al., 2019). In extreme cases, populations have migrated away from locations frequently impacted by extreme weather events (Gray & Mueller, 2012) or are projected to move toward coastlines affected by sea-level rise (Bell et al., 2021). At the same time, human mobility decisions are often multi-causal and rarely due to extreme weather events alone. Climate change may influence human mobility both directly and indirectly through various channels ranging from economic, demographic, social, political, and environmental factors (Black et al., 2011). These factors ultimately lead to a decision between staying or going—and where to migrate to if needed. In this context, there are several climatic factors and cascading risks that can enhance and reduce human mobility, or even entrap populations (Cattaneo et al., 2019; Hoffmann et al., 2020).

In the existing literature, climate-related human mobility is often portrayed as a key impact of anthropogenic climate change (e.g., Biermann & Boas, 2008; Myers, 2002; Rigaud et al., 2018). Despite the increasing abundance of qualitative evidence (e.g., Groth et al., 2020; Wiederkehr et al., 2018) on how and where populations migrate due to the impacts of environmental change, surprisingly little research has linked such evidence to anthropogenic climate change (Borderon et al., 2019; Cattaneo et al., 2019); quantitatively or qualitatively. In East Africa, the confidence on attributable links regarding the climate change-human mobility nexus is low with evidence from climate science being in many cases underrepresented (Thalheimer et al., 2021). As the impacts of anthropogenic climate change are projected to fall disproportionately upon African countries (Harrington & Otto, 2020; Hoegh-Guldberg et al., 2019), this study focuses on climate-related human mobility in African drylands. To do so, an understanding of climate change effects, including evidence from extreme event attribution, and cascading risks in this region is needed.

In recent years, several meta-analyses have been published that study the multiple links between environmental change and human mobility nexus in Africa (e.g., Wiederkehr et al., 2018; Borderon et al., 2018). The reviewed case studies in these studies are mostly situated in Sub-Saharan African drylands. Climate change and extreme weather events play a central role in these studies and are found to drive different types of mobility, including temporary and longer-term migration over short and long distances. For example, Wiederkehr et al. (2018) find that 23% of 9,700 rural African households that were interviewed in 63 empirical studies, respond to environmental stressors with some form of migration. A review of African case studies by Borderon et al. (2019) shows how complicated it is to draw universal conclusions on the migration-environment nexus. However, based on their review, they do conclude that climate change will not generate mass migration from Africa to Europe and other continents. An important reason for this is that the people who are most affected by climate change in Africa do not have the financial resources and social networks that are needed to migrate intercontinentally. The picture is quite different for migration and displacement *within* countries, which is projected to increase sharply under more extreme climate change (Rigaud et al., 2018).

3. Mapping Climate Change Effects on African Drylands

SR15 lists projected climatic changes in a variety of climatological areas. We adopt the report's regional structure for Western, Southern, and Eastern Africa in which drylands are the predominant land zone (Cervigni & Morris, 2016), and summarize projected climatic changes (Table 1). The table updates findings from SR15 with recently published literature. The focus is on precipitation extremes and temperature extremes as they comprise the predominant natural hazards in African drylands.

Table 1

Summary of Regional Projected Climatic Changes and Their Effects in African Drylands (Including Confidence Levels)

	African drylands regions		
	Western Africa	Southern Africa	Eastern Africa
Precipitation and related extremes		<p>SR15</p> <p>Overall decrease in mean rainfall, stress in water availability (SR15, p. 197) (<i>medium confidence</i>).</p> <p>Overall decrease annually, increased water stress while less water available (SR15, p. 197, 213) (<i>medium confidence</i>);</p> <p>Increase in heavy precipitation events (<i>low confidence</i>), while region as a whole will experience precipitation decrease (SR15, p. 197, 204) (<i>high confidence</i>).</p> <p>Post-SR15</p> <p>Observed increase in heavy precipitation events (Barry et al., 2018) which is likely to increase in frequency and intensity by 2100 (Akinsanola & Zhou, 2019; Dosio et al., 2019).</p> <p>Drying is likely to increase (Dosio et al., 2019; Maure et al., 2018), especially under Regional Climate Models (RCM) (Ahmadalipour et al., 2019) and recent droughts have been attributed to climate change (Herring et al., 2019; Nangombe et al., 2020; Otto et al., 2018).</p>	<p>Increase in heavy precipitation events especially over Somalia and river flooding (SR15, p. 197, 201) (<i>low - medium confidence</i>);</p> <p>Increase in number of consecutive dry days (SR15, p. 199) (<i>high confidence</i>).</p> <p>Insufficient evidence from recent projections of rainfall over East Africa (Finney et al., 2020) to draw confident conclusions.</p> <p>Several attribution studies suggest no significant attributable link to climate change in observed drying trends (Herring et al., 2019; Kew et al., 2019; Otto et al., 2018; Uhe et al., 2018).</p>
Temperature and related extremes		<p>SR15</p> <p>Increase in heatwaves and number of hot nights (SR15, p. 259, 261). <i>Low confidence</i>.</p> <p>Rise in extreme temperature causing more frequent heatwaves and aridity, especially at +2°C (SR15, p. 177, 178, 190, 200, 261). <i>High confidence</i>.</p> <p>Post-SR15</p> <p>Throughout Sub-Saharan Africa: Exposure to dangerous heat projected to increase (Rohat et al., 2019).</p> <p>Observed frequencies of warm extremes are likely to increase.</p> <p>Increases in frequency of warm days and decrease in cold days.</p>	<p>No findings for East Africa specified.</p> <p>East Africa is a hotspot of increasing trends in heatwaves (Perkins-Kirkpatrick & Lewis, 2020).</p> <p>Lack of research on compound heat and drought events (Raymond et al., 2020).</p>

Note. We distinguish between effects listed in SR15 and new research published since.

In a warmer world, drylands are expanding globally (IPCC, 2018) while high population growth in drylands exposes more people to climate hazards (Koutroulis, 2019). Despite sparse literature, the current evidence concerning African dryland regions suggests that heat extremes will become more frequent in the region (Perkins-Kirkpatrick & Lewis, 2020; Rohat et al., 2019). For dry and wet extremes, the influence of climate change is less clear and varies across the continent, with a significant signal only in observed, attributed, and projected drying in Southern Africa, and an increase in heavy precipitation in Western Africa. In East Africa, increases in temperature have been found to be linked to anthropogenic climate change, while current rainfall deficits and subsequent droughts do not show a strong anthropogenic climate signal. Uncertainties are significant though, as is vulnerability to natural climate variability (Kew et al., 2019).

4. Climate Change Impact Sectors and Their Relation to Human Mobility in African Drylands

There is growing evidence that climate change and extremes primarily affect human mobility indirectly (Black et al., 2011; Hoffmann et al., 2020; Romankiewicz et al., 2018). With a focus on interconnectedness of climate impacts and cascading risks, this section consolidates and expands on the evidence provided in SR15 with relevant implications for human mobility in African drylands.

We find that the effects from interacting and cascading risks could imperil migration as an adaptation or coping mechanism across the region. Cascading risks are spatially compounding risks that involve multiple interacting hazards in the same location. Cascading risks lead to increased exposure (Piontek et al., 2014). The amount of people exposed to cascading risks is projected to double from 1.5°C to 2°C warmer world, with almost the entire global population affected either directly or indirectly under a 3°C warming scenario; the exposure in African regions to cascading risks is amongst the highest (IPCC, 2018). Poor communities affected by drought and water stress, as well as political instability and growing conflicts, could find themselves forced to move as a response to climate thresholds (Tol, 2018; Xu et al., 2020). Cascading risks are a cross-cutting theme and particularly impactful on people living in poverty (IPCC, 2018), highlighting the urgent need for a systems approach as a bridging framework.

Accessibility, trade, and distribution of food crops and livestock form an interconnected variable between human mobility and climate change (Adams & Adger, 2013; Afifi et al., 2016). Drylands have already experienced lower agricultural productivity and recurring weather shocks (van der Geest & Warner, 2014; Stavi et al., 2021). Even a warming of +1.5°C accelerates adverse risks of reduced water and food availability (Betts et al., 2018; Cheung et al., 2016). Constraining warming levels to 1.5°C can substantially minimize risks in crop yield losses in West Africa (Schleussner et al., 2016). Dryland areas, where rainfall levels are already increasingly uncertain, are projected to become less suitable for agricultural production (Läderach et al., 2013; Sultan & Gaetani, 2016; Zommers et al., 2016).

Further, food insecurity is projected to disproportionately affect poor populations in African drylands (Byers et al., 2018; Puma et al., 2018; Thalheimer et al., 2019). Related increases in local, regional, and global food prices could put an additional 122 million people in extreme poverty by 2030 (Guldberg et al., 2018). Climate change could adversely impact the livelihood security of seasonal migrants and pastoralists (Fanzo et al., 2018; Rademacher-Schulz et al., 2014). In regions with increased risk of water stress, pastoralists and their livestock will have to alter mobility patterns in the search for water and livestock fodder (Boone et al., 2018).

According to the Lancet Countdown on Health and Climate Change, current warming has already resulted in “profound, immediate, and rapidly worsening health effects” (Watts et al., 2021). Climate change is likely to impact workers' health conditions and their ability to perform labor-intensive work outdoors. Climate change has already increased the exposure and vulnerability to climate-related stress and related health issues (Haines & Ebi, 2019). Heatwaves in particular have shown adverse effects on occupational health (Rey et al., 2007). Among vulnerable populations, climate change can reduce food security and labor productivity, which has adverse health outcomes, while the functioning of healthcare systems may be reduced in the event of weather extremes. Taken together, heatwaves and long-term climate change can limit the physical work capacity, leading to diminished agricultural productivity and causing undernutrition in drylands. Droughts contribute to biodiversity loss and ecosystem collapse, increasing the likelihood and occurrence of vector-borne diseases (Watts et al., 2017). A half-degree temperature increase to 2°C adversely impacts health conditions globally (Haines & Ebi, 2019). SR15 states with very high confidence that heat-related mortality and morbidity will be higher under 2°C than under 1.5°C.

While there is some evidence of climate-related health impacts influencing human mobility decisions, the extent to which out-migration will increase remains uncertain and needs further empirical research (McMichael, 2020; Schwerdtle et al., 2018). Initially, negative impacts on human health may decrease the likelihood of migration due to reduced personal capacity for relocation. However, studies have demonstrated migrants willing to move into sites with increased exposure to natural hazards and potentially cascading risks for their health (McMichael, 2020) during stages of the migration journey (Schwerdtle et al., 2018, 2019). The combination of various vector-borne diseases, especially malaria, and climate-induced socio-economic

disruption is projected to have significant regional impacts such as increased outward migration (Piontek et al., 2014) to areas with less exposure to extreme weather events. Systemic shocks like the COVID-19 pandemic show that access to health care is limited during relocation processes which may undermine global health goals (Schwerdtle et al., 2019).

With an increasing number of people from rural dryland areas pursuing urban migration in the search for alternative occupation, there is a higher vulnerability to heatwaves and poor urban air quality exacerbated by climate change. Even under a 1.5°C of warming, the incidence of heatwaves is projected to increase, doubling the number of megacities affected by heat stress and exacerbating urban heat island effects. Under a 2°C warming scenario, a significant rise in heat stress-related mortality is projected, particularly for low-income countries in sub-Saharan Africa. Given the lack of reporting on current heat impacts, this provides particular challenges to adaptation (Harrington & Otto, 2020). Climate projections further indicate a decrease in the number of consecutive wet days, and an increase in consecutive dry days for sub-Saharan Africa. Despite large uncertainties in projections (J. King et al., 2020), if the amount of annual precipitation is to stay constant, it will increase the intensity of hydrological extremes in the form of floods, droughts, and water scarcity (IPCC, 2018).

In some cases, climate-related migration can lead to further risk accumulation in urban areas (Ayeb-Karlsson, 2020; Wilkinson, 2016). Increased rural-urban migration accelerates rapid urbanization, which is compounded by the inability of already overstretched cities and municipalities to provide affordable and safe housing (Williams et al., 2019). The resulting number of people residing in environmentally precarious areas rises, meaning they experience higher exposure to natural hazards. Most arriving migrants lack financial resources to relocate to areas with a significant level of access to basic services and less exposure to hazards (Adams & Kay, 2019; Williams et al., 2019). They are thus trapped in environmentally precarious areas in which the climatic risks under future warming scenarios are significantly more precarious (Adger et al., 2015; IPCC, 2018).

Despite limited research on the effects of a current and near-term warming, variabilities in rainfall and temperature extremes are associated with higher levels of internal migration in agriculture-dependent communities (Cai et al., 2016; Rigaud et al., 2018) highlighting wider economic implications for affected populations. In poorly endowed communities, climate change impacts can further amplify conflict over scarce resources (Serdeczny et al., 2017). In some cases, a warming up to 1.5°C (expected by 2030s, independent of scenarios) already significantly increases the risk of inter-group conflicts, which in turn can generate reinforced involuntary mobility (Hsiang et al., 2013).

We deduce that climate change effects adversely impact African dryland communities and are likely to alter human mobility in different ways. In some cases, climate change can lead to more population displacement, whereas in other cases it can lead to less human mobility for instance when people become trapped. Overall, climate change can shift more voluntary human mobility to more forced flows. There is consistent evidence on the relationship between climate change impacts on economic development and human mobility through economic losses in agriculture and food insecurity from droughts (Nawrotzki & Bakhtsiyarava, 2017), changes in temperature (Gray & Wise, 2016), and precipitation (Mastorillo et al., 2016). Cascading risks and compound events interlink all sectors and therefore indicate the biggest impact on human mobility under future warming. In East Africa, the ongoing locust spread and survival due to climatic stresses and socio-economic activities is yet another example that shows the importance of such cascading risks (Salih et al., 2020).

5. Systems Approaches to Advance the Current Evidence

In this paper, we highlighted that climate change impacts on African drylands mobility are not just a result of potential disruptions of a single impact sector, rather showcasing shocks to multiple sectors, cascading or even compounding risks. Given the increasing relevance of cascading risks from connected and compound events (Raymond et al., 2020), it thus seems reasonable to propose a systems approach as a starting point to address future warming impacts on human mobility in research and policy.

A first option to effectively respond to sectoral climate change impacts is to take a system-wide approach (Ratter, 2013), which requires decision-makers, policy planners, and various sectors to undertake a coordinated and concerted effort. The advantage of this method is that a holistic understanding of the interface between climate change and human mobility can be gained. Resulting interlinked concepts, dynamic relationships, and feedback behavior can be useful for enhancing cooperation and guidance, and for identifying resilience-enhancing pathways. However, a systems approach deems a form of cooperation that is currently constrained by a lack of cross-sectoral integration and political instrumentalization prevalent across regions affected by climate change (Williams et al., 2019). Further limitations lie in the governance context; in much of dryland Africa, fragile states are prevalent and have high poverty levels. Conversely, a systems approach could also be a bridging framework to address interlinked challenges.

Clearly, it is crucial to investigate and derive policy conclusions holistically, beginning with the interconnectedness of climate change, impact sectors, and human mobility. Climate change policies are likely to have significant impacts in economic, environmental, and social domains and on a wide range of stakeholders (Tol, 2018). It is therefore essential to take potential and unintended side-effects of the policy on other sectors into account. To exemplify, the livestock sector plays an important role across African drylands but global challenges make it difficult to navigate related policies and leverage positive impacts on the 17 sustainable development goals (Mehrabi et al., 2020). We have highlighted the importance of accounting for cascading risks, shocks, and uncertainties. Various policy alternatives and their trade-offs have to be accounted for. Cascading risks, and ways to deal with them, as well as risk criteria, have to be included from a systems dependency perspective. This is crucial for managing, analyzing, and governing those sectors that have global links such as food security (Gaupp, 2020). Management of risk also entails to capture uncertainty in the strength or in the direction of cross-sectoral interconnectedness. Short, medium, and long-term impacts of a policy need to be defined, for example, a trade-off between various types of proactive long-term (ex-ante) measures and reactive short term (ex-post) measures. Uncertain futures of climate change, including the possible occurrence of extreme weather events affecting human mobility versus life-spans of adaptation measures, have to be taken into consideration.

6. Outlook

We find ourselves at a crossroads. More research is needed on all aspects of the interface between human mobility and climate change, and the cascading risks associated with it. Evidence on the link between climate change and current extreme weather and slow-onset events as well as research on near-term changes at 1.5°C and 2°C warmings could provide ground-truthing of the above-described findings and be transformative in understanding human mobility if enhanced by a deeper understanding of the cross-sectoral interconnectedness of climate impacts that drive human mobility. From a research perspective, this requires global collaboration and truly transdisciplinary approaches that can inform policy aimed at preventing forced migration and facilitating safe and dignified human mobility in a changing climate.

Data Availability Statement

No additional data were used as part of this study.

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