The Global Transboundary Climate Risk Report

Adaptation Without Borders

2023

IDDRI ODI SEI Stockholm Environment Institute

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2023

Credits

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Adaptation
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Acronyms and abbreviations

AWB	Adaptation Without Borders
CBFS	Central banks and financial supervisors
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CDC	Centers for Disease Control and Prevention
CSO	Civil society organization
ECDC	European Centre for Disease Prevention and Control
ECOWAS	Economic Community of West African States
EEZ	Exclusive Economic Zone
EIB	European Investment Bank
ENTSO-E	European network of Transmission System Operators for Electricity
FDI	Foreign Direct Investment
FSB	Financial Stability Board
GDP	Gross Domestic Product
GFCS	Global Framework on Climate Services
IEA	International Energy Agency
IHR	International Health Regulations
ILO	International Labour Organization
IMF	International Monetary Fund
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
MECIDS	Middle East Consortium for Infectious Disease Surveillance
MNC	Multinational corporation
NAP	National Adaptation Plan
NDC	Nationally-determined contributions
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
NGO	Non-governmental organization
PAHO	Pan-American Health Organization
PNA	Parties to the Nauru Agreement
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SIDS	Small-island Developing States
TCFD	Task Force on Climate-Related Financial Disclosures
UNFCCC	United Nations Framework Convention on Climate Change
UNHCR	United Nations High Commissioner for Refugees
VDS	Vessel Day Scheme
WCPO	Western and Central Pacific Ocean
WFP	World Food Programme
WHO	World Health Organization
WTO	World Trade Organization

Foreword

Teresa Ribera[1]

The world's economies, societies and ecosystems are deeply interconnected, and we are seeing how climate shocks can have cascading consequences that cross countries and continents, sectors and systems. However, while we are experiencing more cases, we are still unclear on how to treat such climate interconnectedness in a comprehensive way. We have made huge progress over the last decades to enhance collective action on greenhouse gas emissions, but on climate adaptation, we are still looking for a way to create such a sense of collective action, beyond the important funding lens.

This report by the Adaptation Without Borders partnership provides us with a first collection of cases of 'transboundary climate risks' across scales and geographies. The analysis reveals the tight networks and interconnections that transmit the effects of climate hazards over large areas. Interestingly, it also reveals that transboundary climate risks can be generated by our very adaptation responses, that is, when they have consequences on our neighbors and partners, even distances apart.

The report clearly shows the diversity of transboundary climate risks, beyond some relatively well known examples such as on agricultural commodities and international markets, and the management of natural resources and shared ecosystems such as rivers crossing several countries. Cascading and cross border risks are actually taking place in all sectors and regions, from water resources in high mountain environments, to fish stocks in the open ocean, industrial supply chains, and energy and global finance systems, as well as human health, livelihoods, mobility patterns, and physical and mental well-being. This report is therefore insightful in showing that climate impacts have far-reaching consequences across multiple borders; that emergency responses as well as long-term adaptation planning can lead to transboundary maladaptation; and that, as a result, climate risks are becoming more complex to manage and anticipate. Paradoxically, that also means that provided we are able to address these transboundary risks, we have a unique opportunity to make the world stronger.

A few years back, as we were all preparing for COP21 in Paris, the idea emerged that adaptation is not just a local challenge, but also needs to be considered a global public good. On the policy side, such a thought has been instrumental in the development of the Global Goal on Adaptation in the Paris Agreement. On the research side, it revealed the need to advance knowledge on what makes adaptation a global concern. This encouraged IDDRI, SEI and ODI to give birth to the Adaptation Without Borders partnership, and I find it encouraging to see how much progress has been made, in just a couple of years, on further understanding transboundary climate risks. New knowledge raises new questions, of course, but it also lays new foundations for collective action.

Reading the conclusions of the report today, I am convinced that dealing with transboundary climate risks is a promising way to enhance global cooperation on adaptation, beyond country-level challenges to which we still need to pay attention. The report tells us that we need to do more: addressing transboundary climate risks cannot happen in silos and by any nation working alone. The extent to which existing institutions and mechanisms from the regional to the global level are equipped to respond to these risks remains to be understood, but we have to remind ourselves that human creativity proved its capacity to address difficult challenges over the last million years. And to me, this year could be a decisive one if the first Global Stocktake that will take place at COP28 lands on recognizing that global adaptation is more than the sum of national adaptation efforts.

1 Deputy Prime Minister for the Ecological Transition and Demographic Challenge of the government of Spain

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Executive summary

Angela Hawke[1]

The insights emerging from this report demonstrate a blind spot in climate policy: complex climate risks that are transboundary and cascading. These risks represent a shared adaptation challenge and a global responsibility.

- Transboundary climate risks, which are triggered by a climate hazard in one country, cross borders, continents and oceans to affect communities on the other side of the world. So do the consequences of some adaptation actions.
- In a world that is increasingly interconnected, these risks are transmitted through shared natural resources and ecosystems, trade links, finance and human mobility.
- Transboundary climate risks are expected to increase as global warming accelerates to threaten entire societies and economies.
- No country is immune: transboundary climate risks can affect any country, at any time, regardless of its level of development. They combine with non-climate drivers such as poverty and conflict to undermine our collective wellbeing.
- Transboundary climate risks have the greatest impact on the poorest and most vulnerable people, exacerbating inequities and the root causes of their vulnerability.
- Evidence shows that transboundary climate risks are a global concern, yet the international, regional and local mechanisms to adapt to climate change are not yet equipped to meet this common challenge.
- We need a global response to transboundary climate risks if we are to build collective resilience to climate change.

Background

As their name suggests, transboundary climate risks do not respect national or international borders. They are being triggered by climate change and by our adaptation responses to that challenge. A climate hazard in one country may well have an impact that crosses national borders to affect its neighbours. In our interconnected world, however, its impact may also jump across entire regions and vast oceans to harm distant countries. From flooding in Bangkok that disrupts global industrial production, to the spread of diseases that hold back economies, transboundary climate risks are an immediate threat to our collective wellbeing. And they hinder the prospects of achieving global goals on climate adaptation.

Transboundary climate risks also include those transmitted by adaptation responses. While these responses can have positive results across borders and deliver shared benefits, they can also redistribute or even increase (rather than reduce) the risks, by shifting them to other countries, sectors and communities. This happens, for example, when countries impose export bans to protect domestic markets from food price shocks, which can turn a local shock into a global food crisis. This also happens when addressing climate-induced geographical shifts in fish stocks is considered on a national basis (hence triggering conflicts among fishing nations, e.g. in the North Atlantic), rather than through regional cooperation (e.g. under the Nauru convention in the Pacific). And one country's decision to build a dam to support their energy, water and agricultural policy objectives can jeopardize water supplies for its downstream neighbours.

This report by Adaptation Without Borders rings the alarm bell on transboundary climate risks. It is the first collection of evidence on risks that undermine effective responses to climate change, yet that remain largely unrecognized: a 'blind spot' in both climate policies and solutions. It brings together the best available knowledge, drawing on a wealth of case studies.

The characteristics of transboundary climate risks

How can the impacts of climate change in one place trigger a cascade of consequences for distant countries and for the world as a whole? Three key factors emerge from the report.

1 Consultant writer and editor

Transboundary climate risks are the result of two elements:

- Climate-related hazards generate cascading risks and impacts across borders and scales (local to global). They include a wide range of hazards, from extreme events (such as storms, droughts and floods), to gradual, slow-onset events, including rising sea levels and desertification.
- Adaptation actions can generate cascading consequences (negative or positive) for other countries. Transboundary climate risks can be driven by 'maladaptation' that shifts risks from one place or sector to another.

These risks flow across borders, regions and the world through four main transmission channels:

- biophysical connections through physical systems (such as rivers, lakes, oceans) and ecosystems that span neighbouring countries and entire regions
- trade links, including the flow of goods, services and commodities
- financial, including the flow of capital and foreign investment, and
- human mobility, including migration, forced displacement or tourism.

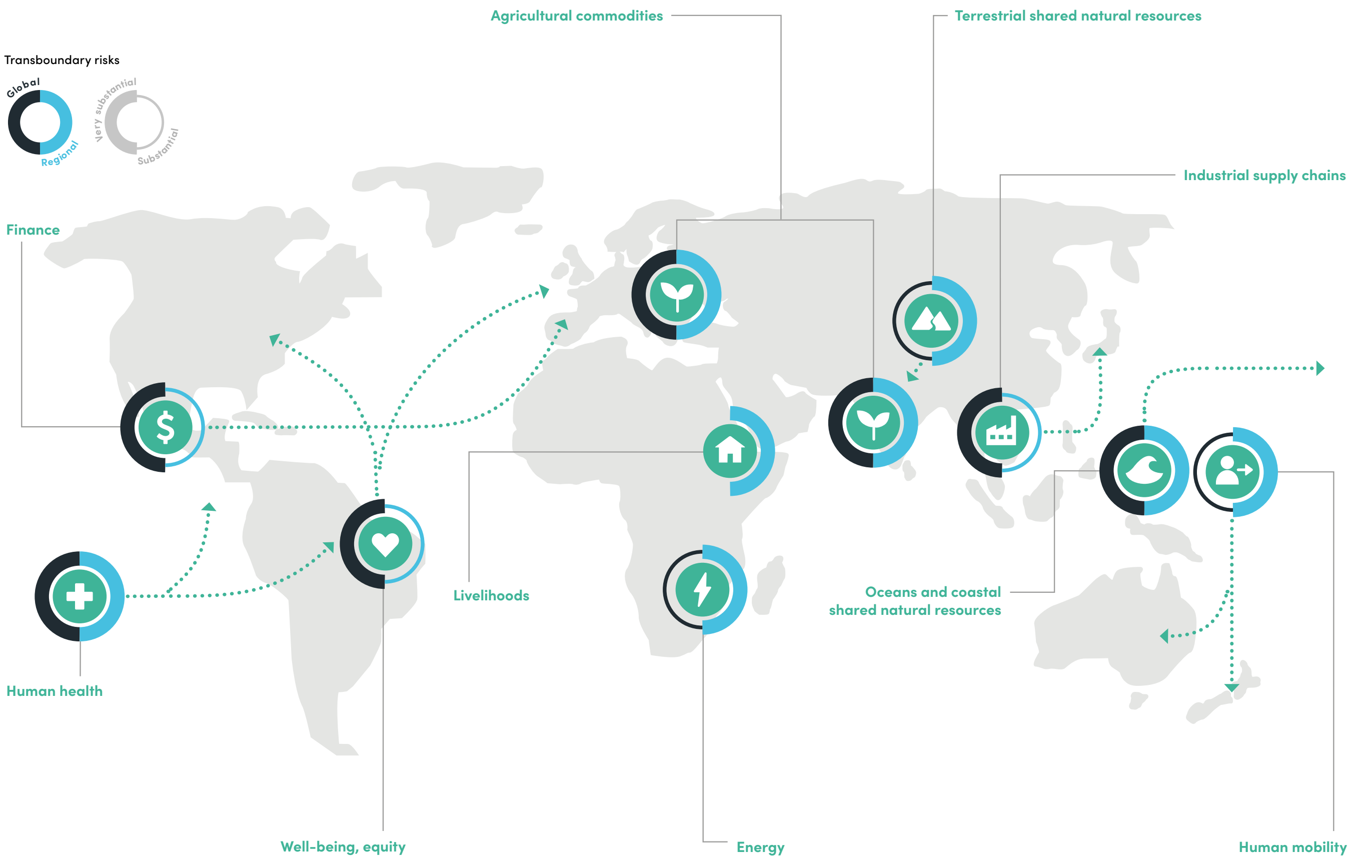
These risks interact with non-climate drivers to exacerbate systemic risks:

- Economic shocks, health crises, social unrest and geopolitical tensions can catalyse or exacerbate systemic risks. Escalating prices for fossil fuels, for example, threaten food security and energy access in the countries that are most dependent on imports.
- Global events interact with climate change to increase the magnitude and spread of transboundary climate risks. For example, Russia's war on Ukraine has undermined global supply chains of wheat and grain, highlighting vulnerabilities in the global system for agricultural commodities.

Building the evidence base: 10 globally significant transboundary climate risks

This report is unique in drawing on a series of case studies to explore 10 transboundary climate risks of global importance [Figure A.1]. An examination of the risks to terrestrial natural resources, for example, finds that the melting of glaciers accelerates the flow of meltwater and the growth of lakes that could burst their banks and flood communities further downstream. Meanwhile, the building of walls and other structures upstream to protect or exploit water resources can increase the velocity

Figure A.1. Overview of the 10 transboundary climate risks and case studies assessed in this report



Source: Authors' elaboration.

of mass flows of water and debris in countries downstream, with potentially disastrous consequences. These consequences include cascading risks to region-wide energy supplies and to livelihoods and can even uproot people from their homes and communities.

An examination of the risks to ocean resources notes the movement of tuna stocks away from countries in the Pacific in response to changing sea temperatures – and away from the communities that rely on them for their prosperity. Other case studies in this report paint a picture of transboundary climate risks that work in combination to threaten the world's economic, geopolitical and social prospects through agricultural commodities (case study: global food supply chains affected by climate threats to maize, wheat, rice and soybean production), industrial supply chains (case study: Japanese car industry affected by floods in Bangkok), energy (case study: electricity networks in east Africa affected by Tropical Cyclone Idai in 2019), finance (case study: investors and companies in Europe affected by a hurricane in Mexico), health (case study: spreading of the Zika virus through international travel and climate hazards), human mobility (case study: seasonal migration and guest worker patterns affected by climate changes in the Pacific region), livelihoods (case study: changes to pastoralism livelihoods in the Sahel region) and wellbeing (case study: just transitions hampered by climate threats to the Brazilian coffee supply chain).

The unequal impact of transboundary climate risks

No country, and no individual, is immune to the impact of transboundary climate risks. However, the most vulnerable people within any country – no matter how prosperous – are hit first and hardest by the direct impacts of climate change and the resulting transboundary climate risks. Even in the richest countries, the poorest and most marginalized people bear the greatest burden of price hikes triggered by transboundary climate risks to food security and markets, as well as of climate-induced spread of diseases, just to name a few examples here.

Some of the wealthiest and emerging economies are exposed to these risks because of their strong connections to global markets and networks. At the same time, some of the countries that have contributed the least to climate change face the largest gaps in terms of adaptation responses.

The report highlights five more high-level influential factors that combine and operate whatever the economies and development contexts :

- unmanageable climate change (global scale);
- increased unmanaged climate exposure and vulnerability to climate changes in the areas or sectors located at the beginning of the chain of cascading impacts;
- non-climate processes (e.g. geopolitics) hampering transboundary responses;
- inadequate conditions in the secondary-affected areas and sectors, and that amplify risk cascades;
- and the residual negative impacts on affected communities all along the risk cascade.

"Climate risk is a shared reality; adaptation must now become a shared responsibility. When we reframe adaptation from the local to the global, new forms of international cooperation and multilateral climate action will open up for us all."

If transboundary climate risks are not managed in a timely and adequate way, they will widen the adaptation gaps that many countries already face, making it more and more difficult to adapt to climate change at the global level. That is why strong governance mechanisms are essential to promote just and resilient adaptation efforts across jurisdictional scales, as well as domestically.

Rising to the challenge: the next steps

National, regional and international efforts to respond to climate change cannot succeed without understanding and addressing transboundary climate risks. These profound risks compel us not only to rethink climate risk, but also to expand the way in which we manage climate risk and plan adaptation.

The insights emerging from this report challenge a narrative that has long been embraced in climate policy: that adaptation is a local concern, while mitigation is a global responsibility. Rather, it tells us that climate change risks and adaptation responses can no longer be framed solely as domestic issues: they must also be seen as a regional-to-global concern. This in turn raises multiple governance challenges, as well as requires the development of new methods to assess complex risks to better inform climate change adaptation policy and planning.

The governance of transboundary climate risks cannot happen in silos and they cannot be managed by any nation working alone. It is critical to look beyond the classic 'one-risk-in-one-context approach' and prepare to deal with risks that are cascading and systemic. These risks must be addressed across all scales and sectors, which calls for the strengthening of existing sectoral policies, and the invention of new ones.

There are already policies and mechanisms that can be mobilized to address transboundary climate risks. The

Atoll nations are at existential risk from climate change, as here in Kabangaki island in Kiribati

UNFCCC and its global processes have clear mandates to address climate change, but full transboundary climate risk management will require leveraging other international frameworks and the synergies between as well. When taken together, frameworks and mechanisms such as the Agenda 2030 for Sustainable Development, the Sendai Framework for Disaster Risk Reduction, the Convention on the Protection and Use of Transboundary Water Courses and International Lakes, and the Global Compact for Safe, Orderly and Regular Migration are reducing various aspects of vulnerability at different scales that contribute to transboundary climate risks. While not all of these are legally binding, United Nations Member States are progressing on implementation of the targets of multiple frameworks. Frameworks and actions at the regional level, such as by the Regional Economic Communities of Africa, the Kailash Sacred Landscape Conservation and Development Initiative in the Hindu Kush Himalaya or the Caribbean Catastrophic Risk Insurance Facility, can also be used. What is needed now, across all of these policies and mechanisms, is a comprehensive approach to transboundary climate risks.[2]

The report sets out ways to reframe climate risk, adaptation policies at multiple scales, and international cooperation on adaptation, shifting from the local to the global. It argues for more research to inform the design of governance and policy solutions to prepare for and address transboundary climate risks. In particular, the report discusses the potential avenues for both indicator-based as well as foresight and scenario exercises to inform the characteristics of transboundary climate risks today and how they could change under changing climate conditions. It also advances new ideas to understand various policy pathways to address transboundary climate risks.

The report confirms that cooperation is vital for the management of transboundary climate risks, as seen in its various case studies. On health, for example, the global, regional and national response to the Zika virus has been truly transboundary – an example of coordinated responses at multiple scales. Cooperation is also the cornerstone for just adaptation in response to the impact of climate change on migration and on the remittances that are often so important for vulnerable people. In this case, cooperative and shared adaptation is crucial for wellbeing and justice, and policies and governance should support the choices made by people who leave home to work abroad.

An approach based on cooperative solutions to transboundary climate risks would be more equitable, more just – and have far more chance of succeeding – than today's country-centric approach. Despite the profound dangers posed by transboundary risks, they offer opportunities to build our collective resilience and to share the benefits of coordinated adaptation activities worldwide.

2 On Water Convention: https://unece.org/environment-policy/water/about-the-convention/introduction; on Global Compact on Migration: https://www.ohchr.org/en/migration/global-compact-safe-orderly-and-regular-migration-gcm; on Global Compact on Refugees: https://www.unhcr.org/the-global-compact-on-refugees.html.

Introduction

Ariadna Anisimov,[1,2] Katy Harris,[3] Alexandre K. Magnan[1,4,5]

> **Climate change does not respect borders and boundaries; it doesn't respect political election cycles. But what it does do is impact the lives of people globally.**
>
> (Simon Stiell, Executive Secretary of the UNFCCC)

The world's economies, societies and ecosystems are deeply interconnected. When a shock is experienced in one part of the world, the consequences can cascade across countries and continents, or ripple through a myriad of sectors and systems, to disrupt the lives of people distant from the initial point of impact.

When the Covid-19 pandemic hit in 2020, global poverty increased for the first time in a generation with long-term detrimental effects on equality and socioeconomic development (World Bank, 2022). When the Suez Canal was blocked in 2021, USD 9.6 billion of goods were held up every day for six days impeding international trade and the supply chains of critical manufacturing products (Harper, 2021). When Russia invaded Ukraine in 2022, prices of wheat reached a new global record (Kammer et al., 2022).

The global cascading impacts of the pandemic, food and energy crisis, debt and financial insecurity, and geopolitical instability combine with each other, and with climate change, to highlight systemic risks. Yet our approaches to climate adaptation fail to reflect our growing interconnections.

This report highlights "transboundary climate risks": climate change risks that cross borders and cascade. These risks have two origins. First, they are formed when a climate-related hazard in one place generates impacts that cross one or more national boundaries, with consequences for lives, environments and economies in another. Second, they form when actions to adapt to climate change have impacts beyond the areas or countries where they are first implemented: shifting vulnerabilities and risks and resulting in maladaptation (Magnan et al., 2022).

Transboundary climate risks are expected to increase as global warming accelerates. This calls for a better understanding of these risks and the design of policy responses. Emerging cases suggest governments, regional bodies and the private sector are unprepared to deal with these shared risks. What's more, some responses could result in "transboundary maladaptation".

The *2023 Global Transboundary Climate Risk Report* from the Adaptation Without Borders partnership aims to chart a course towards the better identification, assessment and management of these complex cross-border and cascading risks.

Part I outlines the state of knowledge on transboundary climate risk. It provides an overview of their key characteristics and pathways [Chapters 1.1 and 1.2] and identifies globally significant risks that are then assessed in subsequent chapters [Chapter 1.3]. This part of the report sets out what we need to know about these risks [Chapter 1.4]. In its latest assessment, Working Group II (WGII) of the Intergovernmental Panel on Climate Change (IPCC, 2022, p. 19) finds that "weather and climate extremes are causing economic and societal impacts **across national boundaries** through supply-chains, markets, and natural resource flows, with **increasing transboundary risks** projected across the water, energy and food sectors". The IPCC also finds that "multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and **risks cascading across sectors and regions**" (p. 18). Part I dives deeper into the characteristics, variables and dynamics of these risks to understand how they propagate and their direct and indirect effects. There is increasing evidence that the transboundary nature of climate

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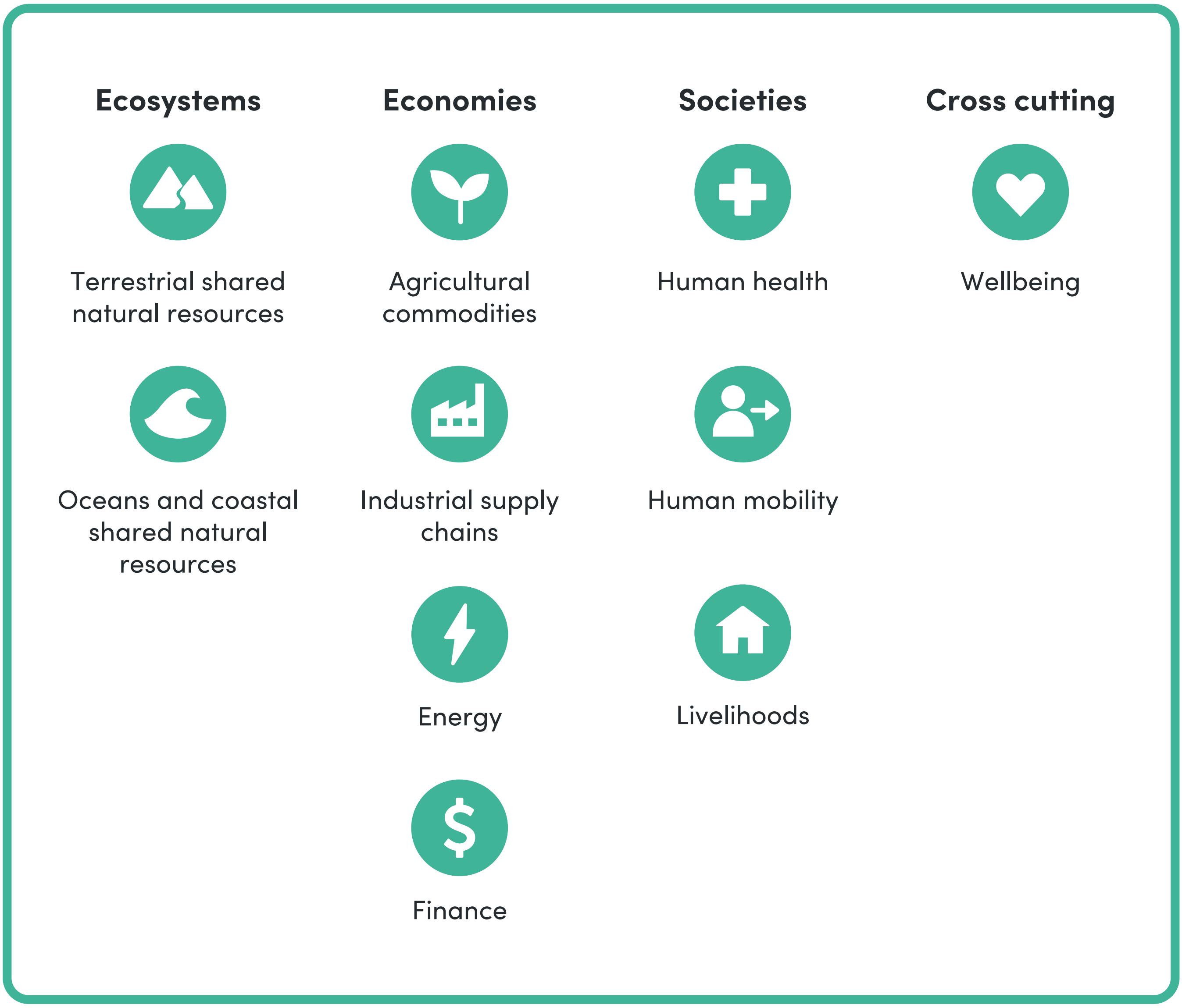
risks means more severe risks that last longer and that occur more often and at larger scales (Magnan et al., 2022). This cross-border lens demonstrates the need to reframe how we understand climate risk. It calls for innovative assessment methods to better understand the dynamics of these complex risks and to prepare policy options and risk ownership frameworks that are ready for a changing climate (Harris et al., 2022).

Part II showcases the assessment of 10 globally significant transboundary climate risks led by experts from international organizations [Figure A.2]. These reflect ecosystems (terrestrial- and ocean-based shared natural resources in Chapters 2.1 and 2.2); economies (agricultural commodities and trade in Chapter 2.3; global industrial supply chains in Chapter 2.4; energy networks in Chapter 2.5; and international finance in Chapter 2.6); globalized societies (human health in Chapter 2.7; mobility in Chapter 2.8; and livelihoods, peace and security in Chapter 2.9); and a cross-dimensional focus on wellbeing in Chapter 2.10. Illustrative case studies in each of these chapters demonstrate the severe consequences of these risks at multiple scales, from local to global [see Figure 3: case study map in Part II]. Together, these case studies suggest that, if left unchecked, transboundary climate risks could hinder progress towards global goals on climate change *and* sustainable development more broadly (the 2030 Agenda).

Part III explores the space for solutions: the policy and governance opportunities to address transboundary climate risks at different scales, from global and multilateral to regional, national and subnational [Chapter 3.1]. Sections detail the multiple benefits of integrating cross-border and cascading climate risks to strengthen multilateral processes under the UNFCCC (global goal on adaptation and the global stocktake [Chapter 3.1.1]), the Sendai Framework (which explicitly calls for each State to 'prevent and

Figure A.2. Transboundary climate risks assessed in the report



reduce disaster risk, including through international, regional, subregional, transboundary and bilateral co-operation') and regional initiatives to address shared risks. Examples of cross-border natural resource management and exposure to risks from abroad are highlighted in some regional initiatives [Chapter 3.1.2]. It analyzes the current limitations of national adaptation planning that is often carried out in silos and that focuses on domestic issues [Chapter 3.1.3], rather than contributing to regional or even global resilience and the development of shared benefits for all. The final sections of the report [Chapter 3.2] focus on knowledge gaps and areas for further innovative research to better inform policy solutions and governance mechanisms [Chapter 3.2.1]. These include the development of indicators to track progress towards building resilience to transboundary climate risks [Chapter 3.2.2], and of methods to assess the potential changes to these risks [Chapter 3.2.3], as well as the design of flexible policy pathways [Chapter 3.2.4].

In conclusion, the report discusses the need for a shift in the approach to adaptation from a local and domestic policy issue to an international concern that requires the involvement of new actors and new forms of coordinated action. Transboundary climate risks connect multiple countries, and this provides opportunities for more collaborative and cooperative action on adaptation. This could, in turn, help to revive and expand ambitions to meeting climate and sustainable development goals (Benzie et al., 2018). A transboundary lens shows that climate risk is a shared reality and adaptation a collective responsibility.

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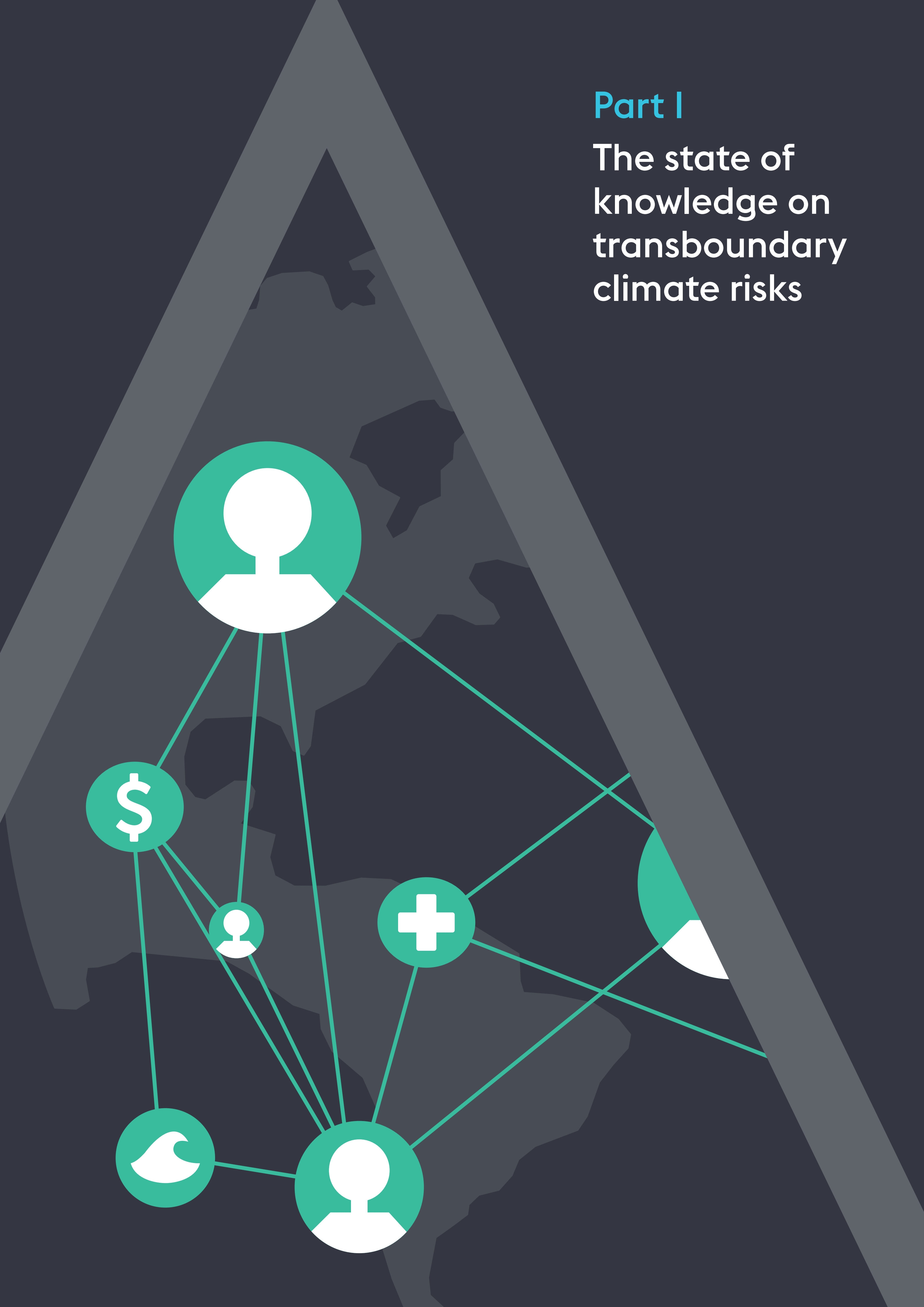
Part I

The state of knowledge on transboundary climate risks



Transboundary climate risks: definition and recent trends

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1.1 An overview

Transboundary climate risks are risks induced by climate change that cross national borders. They do not only move from one country to its immediate neighbours: they also leap across entire regions and continents, transmitting risks to countries and people many thousands of miles away from the initial point of impact. These countries and individuals may have been untouched by the original climate-related hazard, yet they feel the often heavy blow of the resulting transboundary climate risk.

Transboundary climate risks illustrate how the impact of climate change is propagated through the intricate networks that shape our increasingly interconnected societies, economies and ecosystems. And all the available evidence suggests that the climate hazards that trigger these risks are set to increase with global warming, particularly if emissions reductions do not meet the target of a temperature rise that is well-below +2°C (IPCC, 2022; Magnan et al., 2021).

Transboundary climate risks don't just affect neighbouring countries, they can cascade across countries many thousands of miles apart. Cross-border and cascading risks demonstrate that the impact of extreme weather events (such as storms, droughts and heavy rains) and more gradual changes (such as sea-level rise or land degradation) cascades far beyond the area most immediately and directly affected.

No country – or individual – is 'immune' to transboundary climate risks. By their very nature, these risks are indiscriminate: they affect all countries, regardless of their level of development, location, affluence or power. However, exposure to them is distributed unevenly across countries and social groups. Transboundary climate risks can undermine food and water security, trade and energy supplies, jobs and livelihoods, geopolitical stability, equity and wellbeing, and national social and economic development.

Emerging evidence suggests that the most exposed countries are not necessarily those that we tend to think of as being at greatest risk as a result of climate change: some middle- and higher-income countries are likely to be highly exposed because of their dependence on, and deep integration with, global markets and networks (Hedlund et al., 2018). Small trade-dependent countries such as low-income states that depend on imports for their food security are the most likely to feel the impact of transboundary climate risks, but this group also includes wealthy emirates in the Gulf, South-East Asian manufacturing powerhouses, European Union countries, large ocean states and landlocked countries in Central Asia. Emerging economic powers in Africa and Asia are also likely to face challenges in particular because of the climate exposure and vulnerability of their neighbours.

All countries are, potentially, exposed to both direct and transboundary climate risks and, therefore, face a double adaptation burden that has major implications for equity and justice. Some of the countries that have contributed least to global greenhouse gas emissions already face significant adaptation gaps and are increasingly vulnerable to transboundary climate risks because of their interdependence alongside vulnerable neighbours, as well as their dependence on food imports and cross-border financial flows (e.g. international remittances) (Benzie & Lager, 2022; Paavola & Adger, 2006).

It also seems certain that the most disadvantaged people within any country face the greatest threats to their wellbeing from both climate change and from the resulting transboundary climate risks. Even in high-income countries and emerging economies, people on the lowest incomes – particularly those who are socially marginalized – may feel the greatest pressure as a result of, for example, price hikes induced by the cascading impacts of transboundary climate risks on energy and food con-

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sumption, as seen in growing demand for food banks and social welfare during global food crises (Carter et al., 2021).

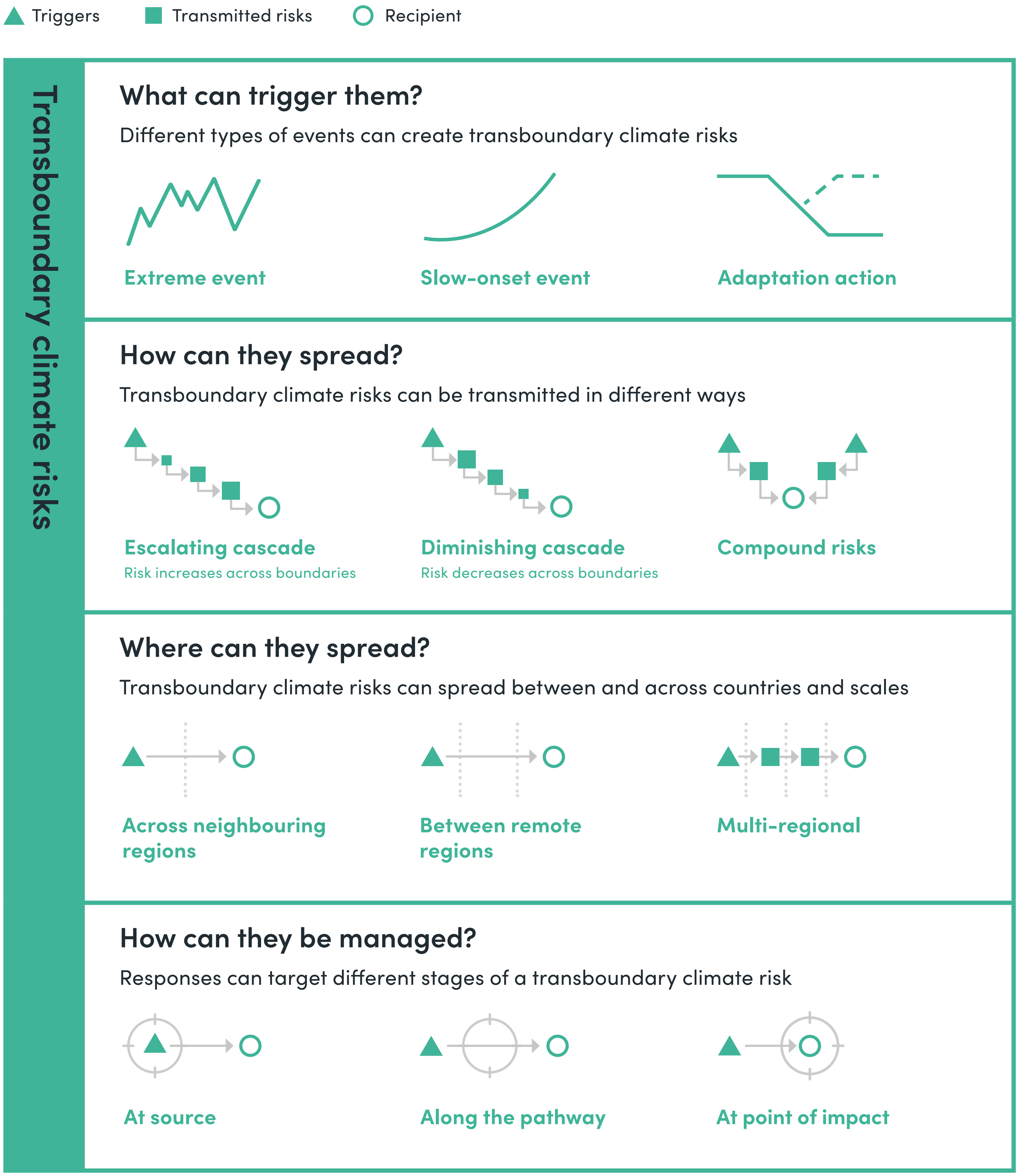
This section outlines the current state of knowledge on transboundary climate risks, including their definition, their characteristics and their impact, as well as the knowledge gaps that need to be filled in order to address them.

1.2 Defining transboundary climate risks

As suggested in Figure 1, transboundary climate risks are comprised of two intertwined sets of risk associated with:

- the transboundary impacts of climate change across borders and at different scales (local, regional, global).

Figure 1. Transboundary climate risks at a glance



- the transboundary repercussions for other countries – negative or positive – of national responses to climate stress through different adaptation actions.

Pathways of transboundary climate risks

Transboundary climate risks can flow through four main channels:

- **biophysical connections**, such as shared rivers like the Nile or the Colorado, basins like Lake Chad, or ecosystems like the Himalayas and the Amazon
- **trade links**, such as the flow of goods and services in auto manufacturing or commodities like wheat, rice or coffee
- **financial** interdependencies, including the flow of capital and other assets, such as foreign investment, and
- **people**, through migration, forced displacement or tourism.

In some cases, transboundary climate risks also result from multiple climate hazards that occur concurrently and the interaction of multiple risks that are then compounded and transmitted through the world's increasingly interconnected systems (IPCC, 2022). As a result, their cascading effects are becoming complex and more difficult to manage (IPCC, 2022) and their transmission and propagation across borders and systems [see Figure 1] are being exacerbated by social and economic processes that are under growing pressure from climate change.

The interactions of multiple drivers of risk – underlying exposure, vulnerability and climate hazards – increase the likelihood of systemic disruptions, with serious implications for the capacity of countries to adapt and achieve the sustainable development envisioned in Agenda 2030 (UN, 2015), as well as the response measures adopted by governments. Transboundary climate risks are systemic risks, and as such, they can transfer risks from one system to another, generating a multiplier effect by aggregating or shifting risks across systems of a different nature.

> **"Adaptation can create winners and losers by contributing to shared resilience, or unintentionally redistributing vulnerability rather than reducing it."**

Food security, for example, is a key policy objective that depends on systemic interactions of critical agricultural commodities, yet international trade routes face exposure to climate change combined with non-climate variables (institutional, political, economic, and more). In this area, as in so many others highlighted in this report, climate and non-climate drivers shape context-specific transboundary climate risks that are subject to varying dynamics. These dynamics are embedded in the networks that connect countries through trade relationships, global supply chains, international financial flows, industry and infrastructure, the movement of people (through migration and tourism for example), shared natural resources (such as air, land and ocean) and more. Through these

Figure 2. Three aspects of adaptation to climate change

> **"Adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions"**
>
> **The Paris Agreement, Article 7.2**

1 Climate impacts in one country may spill over and lead to cascading effects in other countries (neighbouring and distant)

2 Adaptation in one country may redistribute or increase risk in other countries

3 Adaptation in one country may provide benefits to other countries, regionally or globally

Source: UNFCCC (2015).

multiple connections, transboundary climate risks spread across systems and sectors, and as a result, across distances and scales.

The transboundary impacts of adaptation

The measures governments take to respond to the effects of climate change on resources, activities and people may be subnational and national policy issues, but in the vast majority of cases, they also transcend national boundaries. Actions to adapt to climate change can leap across national borders, generating risks that go far beyond the jurisdiction of the government that implements them to affect countries and people elsewhere [see Figure 1] and at all scales (Benzie & Harris, 2021). For example, local-level coastal adaptation measures to control flooding and erosion can generate downstream effects in neighbouring shoreline areas. This, in turn, contributes to increased flood risk, land degradation, salinization and dangers to ecosystems, resulting in cascading consequences for agriculture and livelihoods in the region. This report explores transboundary climate risks triggered by adaptation-related actions. For example, when a producer country decides to shift to more climate-resilient crops, this can affect the international commodity market, or when a Pacififc country decides to accelerate fishing tuna stocks that are expected to move away from its Economic Exclusive Zone because of the climate-induced warming of the ocean.

Adaptation can create winners and losers by contributing to shared resilience, or unintentionally redistributing vulnerability [see Figure 2]. Indeed, adaptation can lead to unequal and unjust outcomes across borders – but also within them. Some actors may take advantage of the urgent need to adapt to gain power or economic strength at the expense of others (Anguelovski et al., 2016). More commonly, however, any negative consequences are unintended. The term "maladaptation" captures the possibility of such consequences, referring to adaptation that shifts the risks to other sectors, locations or communities (Juhola et al., 2016), rather than reducing the overall burden of risk.

Avoiding maladaptation is crucial, but it is not enough. This raises the issue of climate justice that relates to adaptation as well as mitigation, and that is cross-border. To be both effective and just, adaptation measures in an increasingly globalized world need to recognize systemic and cascading cross-border effects (Lager et al., 2021). Otherwise, actions designed to reduce climate risk and vulnerability simply reinforce or redistribute them across countries, deepening existing inequalities and threatening human security (Atteridge & Remling, 2018).

It is important to remember, however, that the redistribution of risk from one place to another may also yield benefits. Indeed, adaptation in one location could strengthen the resilience of communities in another. This reinforces a key conclusion: the current emphasis on a local framing of adaptation – considering only the benefits of actions in one location – might overlook important links, both trade-offs and synergies, to the larger dynamics of interconnected processes. It also confirms that effective adaptation requires coordinated action at multiple scales as a global public good (Banda, 2018; Khan & Munira, 2021).

1.3 Identifying globally significant transboundary climate risks

Processes at work

There is, to date, no universally agreed framework to assess transboundary climate risks and measure their significance. However, some of their characteristics help to explain their dynamics, notably across scales and different means of transmission. The real-world cases developed in this report help to identify transboundary climate risks, explain their complex dynamics, and the ways in which they transmit across borders and systems along varying pathways.

Risks can be transmitted, for example, through transboundary ecosystems – the "biophysical pathway" – such as shared river basins, oceans and coastal resources, mountains, forests and air, which are increasingly under pressure from climate change. Trade routes can transmit climate risk by affecting the availability of goods and services on international markets across key global value and supply chains or by catalyzing or escalating price shocks and spikes. Financial flows also face transboundary climate risks, including via overseas investment and development assistance. And global tourism and migration – the "people pathways" of transboundary climate risks – can evolve as a result of direct climate change impacts, and/or in combination with the indirect effects on, for example, remittances and livelihoods.

The consequences of transboundary climate risks also propagate across spatial and temporal scales [see Figure 1]. The spatial dimension is framed either by physical borders (between neighbouring countries), with effects on local markets, jobs and industries, or non-physical (between distant countries) through cascading and teleconnected impacts.

The temporal scales of transboundary climate risks describe either immediate or delayed impacts that can occur at any point along the network of impacts and potentially through generations. As the risk flows through the pathway, the spatial and temporal dynamics could also be affected by the response measures taken along the way. Such decisions can influence the propagation of the risks (by limiting or expanding the spatial distribution of impacts) and their magnitude (by decreasing or amplifying their effects), while response options can also be anticipatory, influencing the distribution of second- and third-order impacts in the short, medium and long term.

Characterizing and mapping the different modes of propagation can help to better identify the variables that influence spatial and temporal scales of transboundary climate risks. These propagation modes have been described as transmission dynamics [see Figure 1]. For example, cascade tiers might resemble a domino effect, whereby knock-on effects generate higher-order impacts to different risk recipients along the pathway. In other cases, cascading impacts could escalate or diminish where the initial impact either generates increasing risks or where the risks dwindle as they flow across different components of the network.

Other types of propagation modes include compound impacts (i.e. cumulative interactions between several risks and/or risk drivers), further demonstrating the complexity of transboundary climate risks. These transmission dynamics matter for spillover effects across systems, such as the impacts of drought or lower precipitation levels on water availability and hydro-energy production, with consequences for energy accessibility across borders. In turn, transitions in the energy sector and global value chains of critical minerals can also lead to the propagation of impacts – either positive or negative.

To frame the many dimensions concerned with and affected by transboundary climate risks, this report identifies risks across different kinds of pathways that span ecosystems, economies and societies. Within these broader categories, we identify key sectors and systems, drawing from frameworks elaborated under the European Union's revised Adaptation Strategy 2021 and the recent report by the IPCC Working Group II on *Impacts, Vulnerability and Adaptation* (IPCC, 2022).

Drawing on the insights of these reports and the expertise of the Adaptation Without Borders partnership, we have identified 10 thematic categories of transboundary climate risks that are globally significant:

- two that reflect transboundary ecosystems (terrestrial- and ocean-based shared natural resources)
- four that reflect transboundary economies (agricultural commodities, finance, energy and industrial supply chains)
- three that reflect our transboundary and globalized societies (human health, mobility and livelihoods, the latter with implications also for peace and security), and
- one that provides a cross-dimensional focus on well-being and equity.

Table 1 outlines the multiple and complex characteristics of these risks, which are explored in more detail in Part II of this report.

Drawing on the case studies for these themes, as well as the wider literature, we can identify some of the demonstrable characteristics of transboundary climate risks and, more importantly, what they do.

Climate triggers are associated with the immediate shocks of extreme weather events, such as the extreme flooding in Thailand in 2011, which generated cascading risks for interdependent industries in Japan and other parts of Asia [see Chapter 2.4]. The economic damage to the Thai economy was estimated to be USD 46.5 billion (World Bank, 2012). However, many of the industries affected produced electronic parts for car manufacturers. As a result, Japanese automobile exports fell by 20% in December 2011 alone, and insured losses for Japanese firms were as high as USD 15 billion (Meehan, 2012). The shock to international supply chains also triggered an estimated loss of 2.5% of annual global industrial production (METI, 2012).

This shows that the impact of climate disasters beyond the multinational manufacturing entities within one country can have a huge impact on the countries in which those manufacturing entities have a presence. It also confirms that the damage to multinational companies has the highest potential to take the risks across borders. This illustrates how an extreme event in one place can transmit regionally in a cascade effect, and reach global industrial supply chains through a trade pathway [see Chapter 2.3].

Climate triggers are also linked to more gradual changes, such as those induced by ocean warming. These affect, for example, migratory fish species, particularly tuna in the Pacific [see Chapter 2.2]. Fish stocks are shifting their position, with cascading risks to livelihoods across the ocean's small island developing states (SIDS). As ocean warming drives tuna further to the east of the Pacific and further out into the high seas, the annual catch from the combined exclusive economic zones (EEZs) of 10 SIDS is expected to fall by 20% by 2050, reducing government revenue by up to 13% per year. Lower catches will undermine the economic benefits of tuna fishing for Pacific SIDS and this has been raised as a climate justice issue, given that Pacific SIDS contribute very little to global greenhouse gas emissions (Bell et al., 2021). This gradual event demonstrates regional transmission of a transboundary climate risk via an ecosystem [see Chapter 2.1 and 2.2].

As noted, transboundary climate risks are characterized by a combination of climate and non-climate triggers that induce initial impacts in one place that then transmit risks to other locations. A number of non-climate factors exacerbate the potential consequences of transboundary climate risks. Economic shocks, health crises, social unrest and geopolitical tensions can interact with climate change impacts and adaptation responses to catalyse or exacerbate systemic risks. Covid-19 recovery processes, for example, have led to increased debt burdens and these have, in turn, put more pressure on the availability of finance for adaptation activities and exacerbated existing climate vulnerabilities (Ringsmuth et al., 2022). Escalating fossil fuel prices further threaten food security and energy access in the most vulnerable grain import-dependent countries. The Russia-Ukraine conflict (with Ukraine itself

Table 1. Transboundary climate risks explored in the report

● Ecosystem ● Economy ● Society

Transboundary climate risk	Description of the transboundary climate risk category and the focus of each assessment in Part II
1. Terrestrial shared natural resources	Terrestrial shared natural resources cover a range of ecosystems on land (e.g. soils, freshwater lenses, forests) that face climate change risks across borders including risks triggered by adaptation activities to manage these resources. Vulnerability to transboundary climate risks can result from changes in these resources' quantity, quality or management. The transboundary management of forests, deltas, wetlands, rivers or grasslands, for example,and all their associated ecosystem services, poses complex risks stemming from a combination of climate and socioeconomic pressures (e.g. upstream dams and urbanization). Meanwhile, adaptation responses in one country can create risks in neighbouring countries (e.g. fluvial sediment management or groundwater over-pumping). Further, pressure on resources that can be traded (virtual water, wood, food, etc.) can be exacerbated by variations in market settings and their management with transboundary climate risks. Chapter 2.1 assesses transboundary climate risks in shared river corridors in mountain regions that are facing increasing risks of melting glaciers, flood disasters and cross-border risks to infrastructure, energy distribution and livelihoods.
2. Ocean and coastal shared natural resources	Ocean and coastal shared natural resources cover a range of ecosystems and species that rely on habitats spreading from shorelines to the deep ocean – increasingly facing climate change related risks – and at all latitudes. It is well known that the implications of climate change on the ocean's physics and chemistry transcend national jurisdictions (e.g. ocean warming, acidification and sea-level rise), but far less is known about the transboundary implications of adaptation responses to these climate-driven changes. Chapter 2.2 provides an assessment on the risks of shifting open-ocean fish stocks in the Pacific region due especially to ocean warming. It focuses on the challenges in governance and collective management across borders, with a view of potentially high consequences for global food security, the stability of entire regions and countries, and livelihoods at local scales.
3. Agricultural commodities and food security	Climate change consequences on agricultural production and commodities can create transboundary climate risks in the global food system. This refers to cascading risks to international supply chains, national economic stability and, ultimately, food security, triggered by the effects of both climate change hazards, and climate adaptation and risk management activities. The scale of risks is wide as there are also implications for local communities and their livelihoods as well as for economies in general, as they respond to risks in the production of agricultural commodities, yields, supply chains, trade relationships and food security, including the risk of price spikes and social unrest. Chapter 2.3 assesses the cross-border and cascading risks of climate change and adaptation decisions in the production and trade of key agricultural commodities (maize, wheat, rice and soybean) in global food supply chains.
4. Industrial supply chains	Transboundary climate risks in industrial supply chains refers to the cascading risks of climate change across interconnected and interdependent networks that are vital for critical manufacturing sectors. This includes the disruption of logistics, manufacturing and value chains (e.g. industry products) that cross multiple borders with severe risks to economies and foreign investments in both the country originally affected by the triggering climate hazard(s) and its economic partners. These include risks to labour markets and the right of individuals to a just transition (consequences of poorly coordinated risk management and adaptation across industrial supply chains to communities – including job losses and the redistribution of labour across borders). Chapter 2.4 assesses how transboundary climate risk cascades via global industrial supply chains, making local risks global relatively quickly. It also explores gaps in integrated risk assessment across global supply chains, and a lack of information sharing and coordinated decision making across stakeholders that is critical for building resilience.
5. Energy and sustainable energy transformation	Transboundary climate risks in energy systems refers to the consequences of climate change and adaptation decisions in interconnected energy networks, and more broadly via global energy markets and their implications for geopolitics, including their impact on national-level decisions about renewable energies (e.g. hydropower, marine renewable energy) and sustainable energy strategies. Chapter 2.5 presents an analysis of climate change and extreme weather events on interconnected energy networks across borders, and the cascading risks to disrupted energy supplies on people. Further, it presents developments in policies for building more climate resilience in interconnected energy networks.

Transboundary climate risk	Description of the transboundary climate risk category and the focus of each assessment in Part II
6. Finance	Transboundary climate risks on the global interconnected financial system can trigger economic crises, reverse development progress and increase poverty with consequences at multiple scales, from the local to international. This transboundary climate risk refers to the systemic nature of interdependent financial markets and the flow of international capital, including development aid. This can damage national sustainable finance and government fiscal stability, putting pressure on public spending, with the risk of social needs becoming sidelined and of increased inequalities and wealth disparities. Chapter 2.6 assesses transboundary climate risks in global financial systems, with a specific focus on risks to foreign direct investment (FDI). It explores climate risk assessment methods to better integrate these risks in international financial networks.
7. Human health	Human health is affected by transboundary climate risks through many climate-related processes. Forest wildfires, for example, lead to increased air pollution that crosses borders to affect health not only locally but also in neighbouring countries. Changing weather patterns affect the nutritional quality of agricultural export produce and can lead to harvest failures, compromising nutrition and food affordability not only for the local population but also for the importing countries. Other examples of transboundary climate risks for human health include the spread of infectious diseases. The way the affected systems and countries respond to such impacts and anticipate future ones also matters. Chapter 2.7 assesses climate change risks on the accelerated geographical spread of some vector-borne diseases by expanding the habitat for the vectors and by inducing human mobility. It looks at how adaptation responses in one country, such as enhanced climate-sensitive disease surveillance and control, can help neighbouring countries adapt to climate change and even reduce the global risk of disease spread.
8. Human mobility	Human mobility across borders in the context of climate change is complex, given its diverse and often compounded drivers, from environmental to socioeconomic pressures. There is evidence that human mobility related to environmental risks takes place mostly within national borders, and in contexts where there are several structural impediments to sustainable development. While climate-related human mobility across borders is less well-documented, it is now gaining traction in the climate policy and climate change adaptation landscape. Transboundary climate risks can potentially modify and/or influence human mobility patterns, regionally and internationally, with risks to livelihoods, identity and culture, and loss and damage in both origin and destination communities. Chapter 2.8 takes a deep dive on transboundary climate risks and international labour markets, specifically looking at seasonal and guest worker arrangements and the indirect risks to the international flow of remittances.
9. Livelihoods	Transboundary climate risks to livelihoods are transmitted through the direct impacts of climate hazards on natural assets (forests, rangelands), capabilities and activities that allow people to make a living and contribute to the economy. In addition, they can manifest indirectly through interconnected and interdependent systems such as supply chains, trade relations or economic instability to livelihoods. The direct and indirect impacts on local to global systems can be both positive and negative, and spill over into livelihoods; in turn, these impacts on livelihoods cascade back upwards through local to global systems. This highlights the potential for vicious cycle effects across scales. Chapter 2.9 explores the multiple ways that climate change risks and adaptation responses can trigger cross-border risks to different livelihoods, and takes a deep dive on the implications for pastoralism in the Sahel region.
10. Wellbeing	This theme refers to the risks to wellbeing at large, and is used in this report to illustrate a cross-cutting transboundary climate risk. It explores the indirect impacts and cascading risks to inequality and wellbeing. It therefore highlights in particular the transboundary consequences of adaptation-related responses to climate impacts or threats. For example, some adaptation decisions can result in maladaptation by increasing inequalities and exacerbating climate injustice through, for example, lack of access to resources across borders. Chapter 2.10 explores transboundary climate risks to wellbeing in different adaptation contexts. It analyzes the potential opportunities and challenges for a just transition in the context of transboundary climate risks, including how adaptation responses to equity issues can displace risks from one community or sector to another.

representing a major world "bread basket") has added to the pressure on global supply chains of wheat and grain, shining a light on weaknesses in the global system for agricultural commodities [see Chapter 2.3].

The direct impacts of climate change can destroy human lives and livelihoods as well as the critical services, infrastructure and ecosystems on which they depend. Take pastoral livelihoods, for example, which are often transboundary by their very nature [see Chapter 2.9]. In West Africa, pastoralism accounts for around 40% of agricultural gross domestic product (GDP) (de Haan, 2016). Yet, pastoral livelihoods are directly exposed to a range of climate hazards, and climate extremes and slow-onset hazards in one country or across a region, such as the Sahel, can impact the livestock-based livelihoods of millions. There is agreement that the productivity of rangeland in West Africa could shrink by up to 40% above a mean global warming of 2°C (O'Neill et al., 2022). Climate change also facilitates the spread of livestock (and human) diseases across national borders, and bans on livestock and livestock products from East Africa have severe impacts on livestock-based livelihoods and economies in many of its countries (Peyre et al., 2015; Trisos et al., 2022).

There are cascading transboundary implications for economic and financial systems. Climate hazards usually deliver a supply shock to the economy [see Chapter 2.6]. Tropical cyclones, for example, destroy firms' productive capital and damage their production, limiting their ability to meet demand. They lay people off, unemployment increases, household incomes and consumption levels go down, and GDP falls. Lower real GDP means lower tax revenues and rising government deficits, and countries need more external financing (e.g., by issuing sovereign bonds). This, in turn, increases public debt. As a result, the sovereign cost of borrowing on international capital markets increases, reducing governments' fiscal space and, in turn, their ability to react to future climate-related crises (Dunz et al., 2021).

Transboundary climate risks have a profound impact on health that goes beyond the cross-border impact of poor air quality and water shortages (Cissé et al., 2022). Take the spread of the Zika virus, for example [see Chapter 2.7]. The virus is thought to have been introduced into the Americas through air travel from French Polynesia to Brazil and vectored by the local *Aedes* mosquito (Baker et al., 2022). Outbreaks in the Pacific in 2007 and in South America in 2015/16 followed record high temperatures and severe drought conditions (IPCC, 2022). Subsequent research showed that the warm temperatures caused by the combination of the El Niño and continuous global warming trend enhanced the transmission of Zika virus in South America in 2015 by increasing mosquito biting rates, lowering their mortality rates, and shortening the incubation period (Caminade et al., 2017). It is estimated that in the worst-case scenario of high warming combined with a continued population change trajectory, 2.7 billion people globally are likely to be exposed to temperatures suitable for Zika virus transmission by 2050 (Ryan et al., 2021).

Notably, these effects can compound in a snowball effect, ultimately leading to threats to peace and security in places where livelihoods are already precarious. Such a snowball effect, fed by transboundary climate risks, is likely to mean that severe climate risks last longer, occur more frequently, and at larger scales, as noted in the report on impacts, adaptation and vulnerabilities released by the Intergovernmental Panel on Climate Change (IPCC) in 2022 (Magnan et al., 2022).

Illustrations of the variables across countries, systems, location, time and mode of propagation

As shown in Figure 1, countries or systems can be affected to different extents by transboundary climate risks depending on several factors, including the extent of their integration into global processes. The risk recipients are entities (countries, communities, industries) that face the consequences of risks within complex webs of impacts. Multiple entities may be impacted, both positively and negatively and at different magnitudes. Exposure and vulnerability to such impacts depend on, for example, a country's geographical setting, the location of critical biodiversity and natural resources, the predominance of a transborder network for the economy or society, and the existence of multiple dependencies with other countries that are vulnerable to climate triggers**.**

Some countries may have higher dependencies on transboundary processes because of their natural resources and ecosystems (when they are part of a larger watershed or EEZ, for example) [see Chapter 2.1 and Chapter 2.2] or trade (when importing or exporting substantial parts of their production). In Senegal, for example, imported rice from Asia (Thailand, Viet Nam and India) supports food security, but rice yields in those countries are subject to climate conditions, adding to Senegal's overall climate risk exposure [see Chapter 2.3]. Furthermore, price shocks can occur if rice-exporting countries implement bans or other importing countries start accumulating stocks. A combination of impacts from the direct risk and responses to the risk (internal or external to the country) could lead to food insecurity, malnutrition and health risks as well as wider knock-on socioeconomic effects – illustrating risk escalation across components of the system (Bednar-Friedl et al., 2022).

In response to Russia's war on Ukraine, for example, India's Ministry of Commerce and Industry announced on 12 May 2022 that India would help to make up for the loss of global wheat supplies from Ukraine. On the same day, however, worrying data on the rising rate of inflation in India, coupled with dire forecasts for the country's wheat harvest as a result of a staggering heatwave, led to an abrupt U-turn by the Indian Government. By mid-

Box 1. A note on the ownership and shared nature of risk

The spillover effects of both climate change impacts and adaptation responses underpin the shared nature of risk and the need for coordinated decision making to mitigate or manage the risk. Policy processes and governance arrangements to manage systemic risks involve several stakeholders at different scales, operating within varying contexts of vulnerability and coping capacities and with different levels of influence in policy processes.

In the context of the global trade of critical commodities, for example, several stakeholders are part of a chain of decision making in multiple jurisdictions. Each one is subject to varying institutional arrangements and regulatory environments in addition to context-specific vulnerabilities, capacities and response options. As a result, the risk is not limited to the exposure of crop yields to climate variability, for example: it is also a consequence of the interdependencies of the risk-management decisions taken by producers, traders and consumers across the globe. The problem is that responding and adapting to transboundary climate risks often falls between the remits of government departments and national jurisdictions, and ends up being "nobody's job".

night the next day, India had banned wheat exports, resulting in an immediate 6% jump in the global price of wheat on the Chicago futures market (Jadhav et al., 2022). India's reaction is just one example of systemic risk in the global food system. Furthermore, the risk of food insecurity depends on impacts and responses elsewhere in the food system: export restrictions and panic buying turn shocks into crises [see Chapter 2.3].

1.4 What do we still need to know?

Efforts to enhance adaptation policy, implementation and finance are not considered at an adequate and global scale (IPCC, 2022). Transboundary climate risks demonstrate that the risks are broader than their often local framing and that all countries are – or should be – deeply concerned. Coordinated and cooperative adaptation action at regional and international levels is therefore critical to reinforce collective efforts to build resilience. This is acknowledged for example in the Sendai Framework for Disaster Risk Reduction, which states that 'in the context of increasing global interdependence, concerted international cooperation . . . [is needed] for disaster risk reduction at all levels'.

The transboundary, cascading, systemic risks posed by climate change impacts represent a major blind spot in our current approaches to adaptation. Despite their

> "The transboundary, cascading, systemic risks posed by climate change impacts represent a major blind spot in our current approaches to adaptation."

importance, transboundary climate risks have received limited attention to date. In addition, their global interconnections create complex dynamics that are challenging to trace and understand, which adds to the complexity of designing and implementing adaptation responses. It is important, therefore, to characterize cross-border impacts as a first step in the building of a conceptual framework to support the assessment of transboundary climate risks and evaluate policy responses (Carter et al., 2021).

As an emerging field of research and practice, there is a clear need to develop a robust evidence base on the diversity and complexity of transboundary climate risks. At the most basic level, we still lack knowledge on the exposure of countries to different kinds of risks; the magnitude of those risks, particularly in comparison to more direct threats; the respective influence of climate and non-climate risk drivers in their triggering and propagation; how adaptation strategies influence their propagation; and the within- and cross-border options and instruments available to reduce or manage them.

The analysis of the 10 themes outlined in this report aim to contribute to a nascent evidence base that can inform assessment methods and policy response options. In this way, the thematic chapters assessing different kinds of transboundary climate risks in Part II of this report lay the foundations for further work to understand these risks regionally and globally.

As a start, scoping reviews should take stock of the current state of knowledge, including existing methodologies and approaches to assess transboundary climate risks. Direct support is needed to ensure that the next generation of national adaptation plans takes these issues into account in order to build the resilience of people and ecosystems to the risks. Concrete proposals on how this can be achieved are set out in Part III of this report.

In terms of adaptation, there is a pressing need for more analysis that captures the bigger, global picture and a new analytical framework to account for the transboundary effects of climate change and their implications for a truly just transition (Persson, 2019; Schlosberg et al., 2017). This report adds to the scientific literature on how to deal with the interconnected nature of people and places in our modern, globalized world. While research approaches focus primarily on adaptation within an individual community or country, we also need to consider how a more just form of adaptation might be achieved between communities or countries, particularly where there are differences in vulnerability, capability and power.

Reflections

The transboundary and systemic nature of climate risk cements the need for equity and just resilience as leading principles in approaches to adaptation. It also highlights the challenge of the effective governance of such risks, when responsibilities for the management of the risk (risk ownership) are unclear and coordination and cooperation across borders is required (Harris et al., 2022). This report addresses this challenge by providing initial insights into the role of policy processes and governance arrangements at multiple scales [see Chapter 3.1 in Part III].

Transboundary climate risks present us with a profound challenge: they demonstrate that climate risks – and our adaptation to them – can no longer be framed solely as a local domestic issue. They now represent a regional, global and urgent concern, as shared risks in an interconnected world. But they also present us with opportunities to build our collective resilience and to share the benefits of adaptation activities undertaken in coordination and cooperation across the world (Benzie et al., 2018).

The governance of transboundary climate risks cannot happen in silos and they cannot be managed by any nation working alone. Yet current approaches to climate change adaptation are based entirely on the actions and policies of nation-states because these are the sovereign entities through which international agreements, treaties and legal instruments are negotiated, mediated and agreed. The transboundary effects of climate change suggest that it is time to change this pattern, and raise a central question: what forms of new international cooperation and multilateral climate action await us?

Taken together, the 10 transboundary climate risks assessed in Part II build the case for change, demonstrating the impact of transboundary climate risks across a wide range of spheres and sectors, from the depths of the ocean to industrial supply chains, and from finance and livelihoods to human health, mobility and wellbeing (Table 1). Their analysis suggests that the international community must find a response that is grounded in robust multilateralism: a response that frames and uses the governance of transboundary climate risks as a way to support global public goods and, more broadly, the pursuit of the Sustainable Development Goals.

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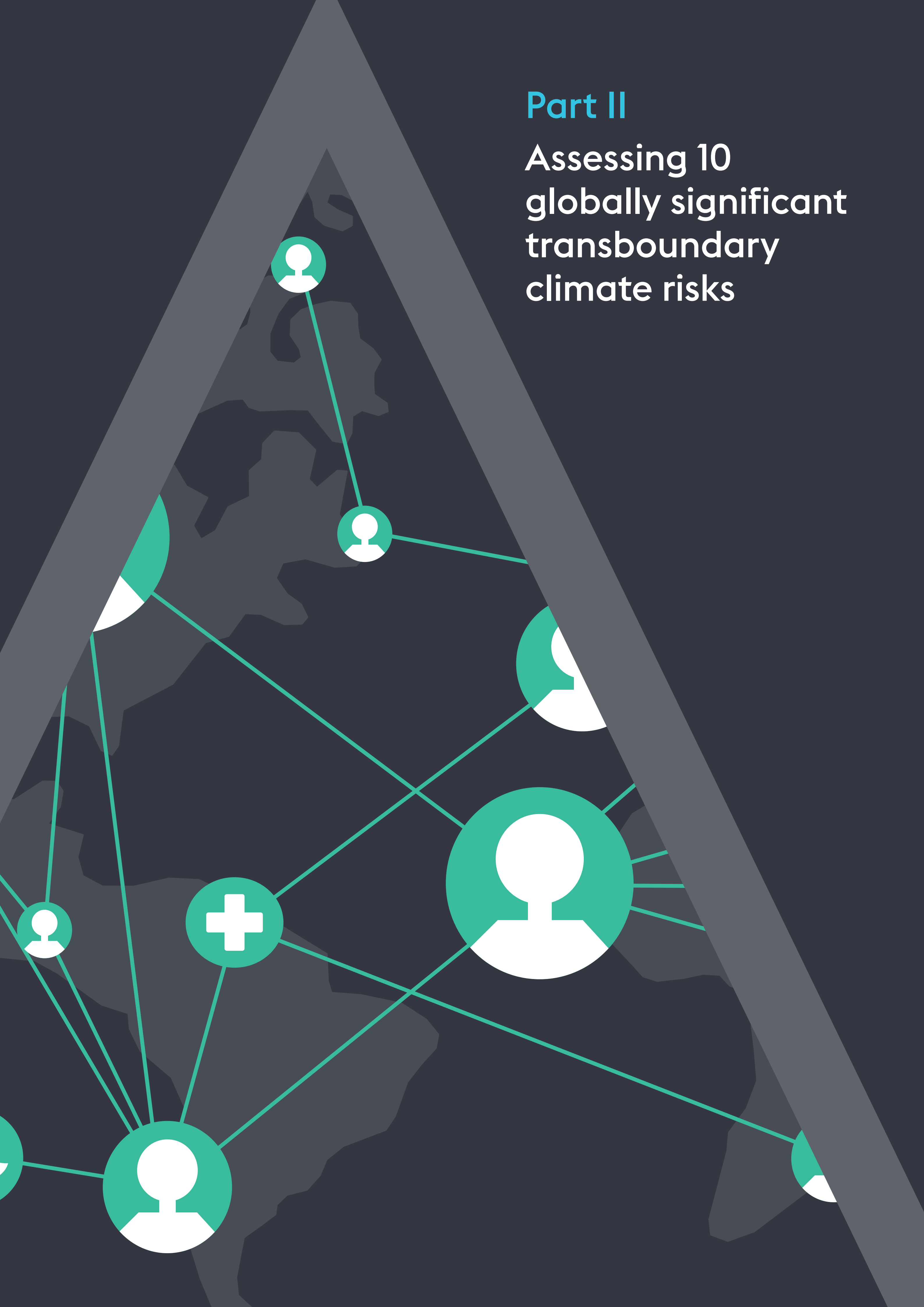
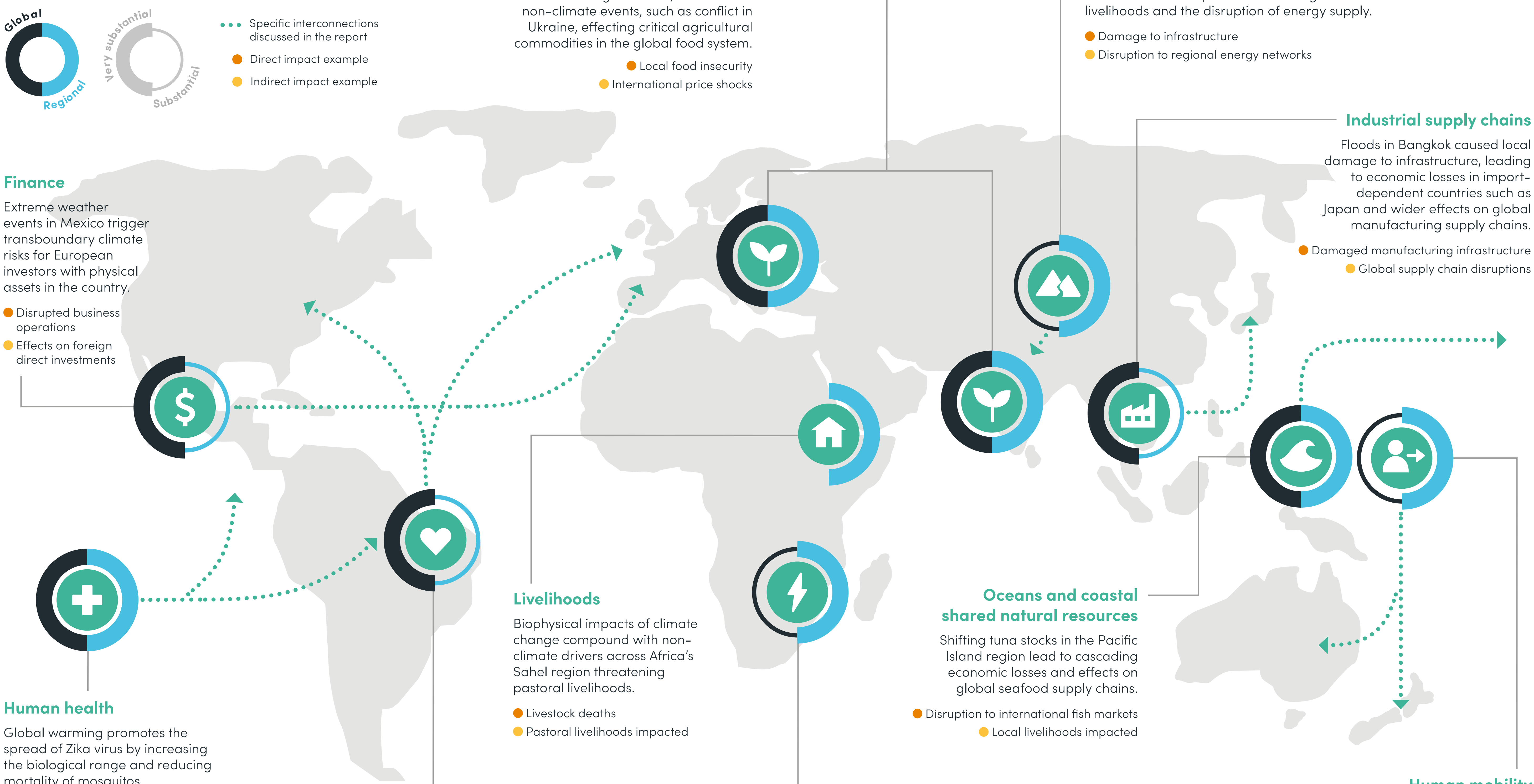


Part II

Assessing 10 globally significant transboundary climate risks

Figure 3. Transboundary climate risks assessed in this report



Agricultural commodities

Compound climate impacts, such as heat and drought in India, interact with non-climate events, such as conflict in Ukraine, effecting critical agricultural commodities in the global food system.

- Local food insecurity
- International price shocks

Terrestrial shared natural resources

Mass flows in shared river corridors across the Koshi River Basin damaged roads, houses, and hydropower infrastructure in Nepal with cascading effects on livelihoods and the disruption of energy supply.

- Damage to infrastructure
- Disruption to regional energy networks

Industrial supply chains

Floods in Bangkok caused local damage to infrastructure, leading to economic losses in import-dependent countries such as Japan and wider effects on global manufacturing supply chains.

- Damaged manufacturing infrastructure
- Global supply chain disruptions

Finance

Extreme weather events in Mexico trigger transboundary climate risks for European investors with physical assets in the country.

- Disrupted business operations
- Effects on foreign direct investments

Livelihoods

Biophysical impacts of climate change compound with non-climate drivers across Africa's Sahel region threatening pastoral livelihoods.

- Livestock deaths
- Pastoral livelihoods impacted

Oceans and coastal shared natural resources

Shifting tuna stocks in the Pacific Island region lead to cascading economic losses and effects on global seafood supply chains.

- Disruption to international fish markets
- Local livelihoods impacted

Human health

Global warming promotes the spread of Zika virus by increasing the biological range and reducing mortality of mosquitos.

- Higher risks of disease
- Health systems overburdened

Wellbeing, equity

Climate change impacts on smallholder coffee growers in Brazil can reduce yields, affecting local livelihoods and causing cascading effects across global coffee supply chains.

- Land suitable for cultivation declines
- Declining yields, livlihoods impacted, risks across global coffee supply chains

Energy

Flooding and debris from Tropical Cyclone Idai damaged interconnected energy networks and have caused cascading electricity disruptions throughout eastern Africa.

- Damage to homes
- Disruption to regional energy networks

Human mobility

Transboundary climate risks across international labour markets can effect seasonal and guest workers, and cause indirect risks to international remittance flows.

- Shifting migration patterns
- Cross-border flow of remittances

Source: Authors' elaboration.

Introduction

Madison Cilk,[1] Alexandre K. Magnan[2,3]

Part II develops 10 thematic chapters on different kinds of globally significant transboundary climate risks (see Table 1 in Part I) spanning ecosystems, economies and societies. The assessments take a deep dive into how transboundary climate risks impact local livelihoods, and critical sectors such as finance, health and global supply chains (e.g. agricultural commodities and manufacturing components). Each chapter explores, for a given transboundary climate risk, its likelihood in a changing climate, its impacts across different distances and time scales, and its method of transmission, as well as provides readers with an in-depth analysis of a representative real-world case study (case study boxes) [Figure 3].

The following chapters show the multidimensional nature of transboundary climate risks and how climate change binds communities around the world through direct and indirect impacts. The overview of transboundary climate risks assessed in this report (see Figure 3) demonstrates that climate risks can have direct and indirect impacts that manifest across multiple geographies, and ultimately have far-reaching consequences on local communities.

Part II lays the foundations for new thinking on climate adaptation beyond national borders, both at the scale of various transboundary risks, and across them. This is key information for a wide range of stakeholders including the international climate community (e.g. through multilateral cooperation agreements, climate finance, loss and damages), regional organizations in charge of managing shared resources, national decision makers in charge of adaptation policies and their non-domestic effects, and the private sector especially major companies.

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3 World Adaptation Science Programme

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Chapter 2.1

Transboundary climate risks for terrestrial shared natural resources

Jakob Steiner,[1] Philippus Wester,[1] Veruska Muccione,[2] Arun Bhakta Shrestha[1]

Events that compound to trigger mass flows are expected to increase risks globally as a result of more intense precipitation, rising temperatures and construction activities that affect river sediments, with cascading effects for transboundary river corridors.[12]

- The risk of mass flows across transboundary river corridors is expected to increase as a result of extreme rainfall, melting of ice and snow, and thawing permafrost triggered by climate change compounding with non-climate drivers such as increased development in highly exposed areas.
- The transboundary risks of climate hazards in shared river corridors can have far-reaching consequences, as direct damage of mass flows to agricultural lands and hydropower infrastructure result in a ripple effect on food supply, distribution of energy and livelihoods.
- Transboundary terrestrial resources lack policy tools and adaptation strategies to manage cross-border and cascading risks such as mass flows.
- Further, unpredictable and uncoordinated policy responses in multiple countries to an unknown climate future and its potential impact on mass flows lead to more uncertainties.

Overview

This chapter illustrates transboundary climate risks related to terrestrial natural resources, particularly transboundary river corridors. Many of these corridors are now at risk of mass flows – mixtures of water and solid materials – that pour down rivers as a result of extreme rainfall and the melting of ice and snow. Strong melt and rainfall events are compounded by the instability of slopes as a result of previous heavy rains or permafrost thaw – conditions seen more frequently as a result of climate change.

In addition, non-climate drivers of exposure to mass flow events, such as the development of and growing dependence on infrastructure (e.g. for hydropower or mobility) in upstream areas, exacerbate transboundary vulnerability to mass flow events. Climate risks associated with mass flow events are increasing in frequency, particularly in remote areas at high elevation along national boundaries and in regions where the timely provision of information across borders is critical yet limited. There are risks for populations in these remote areas, but also risks for national assets, including hydropower infrastructure (Adler et al., 2022). These risks can be exacerbated by fragmented responses to manage the risks between upstream and downstream neighbours.

It is critical to better manage transboundary climate risks and inform climate change strategies by reinforcing coordinated governance arrangements. This can be achieved through the sharing of climate and satellite data between governments and non-state actors in a watershed, and by establishing efficient communication channels.

Introduction

Events that compound to trigger the risk of mass flows are expected to increase risks globally as a result of more intense precipitation, rising temperatures and construction activities that affect river sediments, with cascading effects for transboundary river corridors. The heightened intensity of such events as a result of global warming, as well as the increased exposure of infrastructure and human life to mass flows, means higher cumulative transboundary climate risks through the impacts of these flows on livelihoods, power infrastructure and ecosystems across borders [Figure 4].

In the Himalayas, which straddle a number of countries, permanent and temporary settlements are built close to rivers as a result of a lack of suitable land on steeper slopes, more accessible valley floors and the economic opportunities found along riverbanks. However, this heightens the vulnerability of both the wealthy (through the risks

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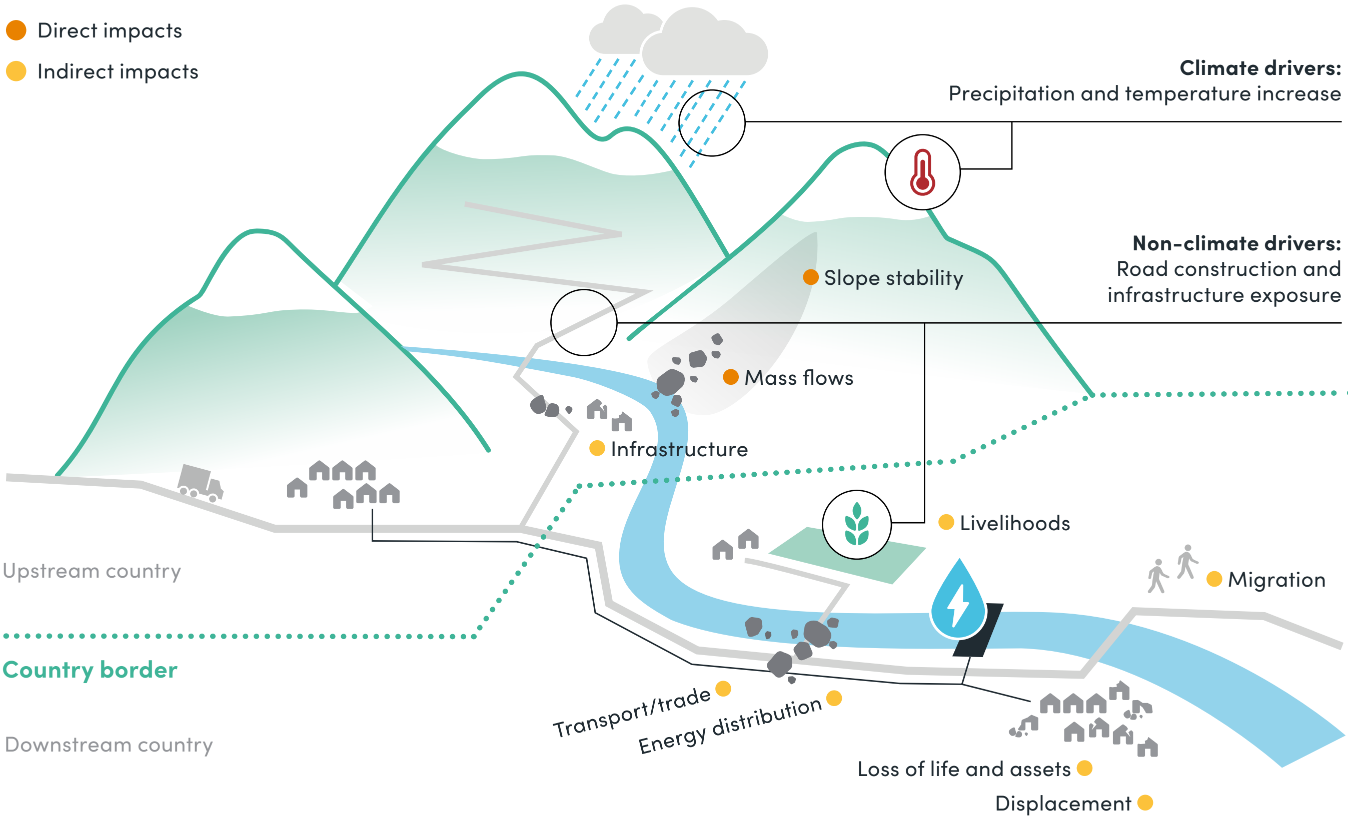
Figure 4. Transboundary climate risks for shared terrestrial natural resources: the example of mass flows in cross-border river corridors



Notes: Conceptual overview on transboundary climate risks for terrestrial shared natural resources, using the example of mass flows in river corridors that cross multiple countries. The drivers of risk are related to both climate and non-climate variables, and potentially related directly or indirectly to anthropogenic drivers. The impacts can be direct (orange) and transboundary (e.g. flooding crossing borders threatening lives, damaging agricultural land and hydropower infrastructure), and indirect (yellow), the latter potentially transmitting risks across borders in the reverse direction (e.g. disruption of food or energy supply, effects on livelihoods). Different examples related to the concepts are discussed in the text.

Source: The authors.

to their assets) and the less fortunate (through the risks to their lives). Crucial trade routes between Nepal and China, for example, run along valleys heavily exposed to mass flows.

The impacts of mass flows include loss of life and livelihoods and damage to critical infrastructures with spillovers for health and safety as a result of the damage to water and energy facilities or blocked road connections [Chapter 2.5, Chapter 2.7, Chapter 2.9]. Agricultural land and transport infrastructure are already vulnerable to fluctuating food and fuel prices, a situation that can exacerbate food insecurity when combined with climate-induced extreme weather events [Chapter 2.3].

Countries and their respective governments, through their dependence on energy and food, are at risk while also being the prime manager of climate risk and adaptation. The state creates infrastructure development strategies, regulates waterways, develops forecasts and gathers data on temperature and precipitation. Yet cumbersome deliberations between neighbours that share river resources mean that risk management and adaptation carried out by one single government is unlikely to succeed. The governance of managing transboundary climate risks requires participation and collaboration with scientific organizations to provide evidence as well as local and indigenous knowledge, in addition to regional arrangements to address cross-border effects.

Characterizations of the transboundary climate risk

A number of climate and non-climate drivers are crucial for transboundary mass flow events, with temperature increases the main direct climate driver. Temperatures have been rising in high latitudes and altitudes faster than elsewhere, resulting in increased meltwater production from glacier ice (Roe et al., 2021) and snow (Barnett et al., 2005) as well as slope instability as a result of permafrost thaw (Davies et al., 2001). This has also resulted in the growth in the size and number of proglacial lakes (Shugar et al., 2020). The growth of these lakes, the movement of slopes and the subsequent accumulation of sediments are slow-onset climate triggers that exacerbate events triggered by more rapid weather shocks (Carter et al., 2021). Extreme precipitation, for example, is projected to increase as a consequence of rising temperatures (Fowler et al., 2021).

The non-climate drivers of mass flows include infrastructure development and mining. The construction of infrastructure in unstable terrain without considering the environmental impact has increased exposure to mass flows and the risks of landslides (McAdoo et al., 2018). Hydropower construction, in particular, is expanding upstream and retaining river sediments, often with no management strategies in place (Li et al., 2022), exposing critical national infrastructure to hazards (Schwanghart et al., 2016). Other drivers include riverine sand mining, which has direct impacts on sediment (Kondolf et al., 2018) and the stability of riverbanks (Hackney et al., 2020). Meanwhile, upstream water diversions deprive downstream neighbours of the river's ecosystem service through environmental flows.

The compound effects of these climate and non-climate drivers exacerbate the risk of flood disasters. This has already had a negative impact on agricultural productivity. This can be attributed, in part, to a lack of consideration of transboundary flood risks. Further, there is limited evidence of the long-term effectiveness of local adaptation measures such as early warning systems (Adler et al., 2022). Many of the world's mountainous regions have faced climate-related risks of mass flow events. In 1998, a glacier lake outburst flood occurred when rising temperatures caused a sudden melt from small glacial lakes in Kyrgyzstan. This led to massive erosion downstream, and to the deaths of more than 100 people, mainly in neighbouring Uzbekistan (Petrakov et al., 2020). Strained political relations between both countries, coupled with a lack of early warnings, hindered access to the site for years.

Events of similar magnitude in high mountain areas, with downstream impacts well beyond 100 km along the river corridor, are being recorded more frequently, raising questions about how to address them if they occur across national boundaries in a context of increasing human pressure in areas prone to climate risks. With a high probability of drivers such as receding glacier ice, thawing permafrost and slope instability increasing under a changing climate, such cascading events – and their cross-border impacts – are projected to become more frequent in the future.

Cross-border climate risks (Carter et al., 2021) can propagate along the path of the hazard but also through, for example, the interruption of trade. The timeframe for their impact on transmission systems can vary from just a few hours (e.g. a rapid flow event) to many years or even decades (e.g. the continued erosion of riverbanks).

The climate and non-climate drivers of subsequent transboundary climate risks are already transboundary in nature. Irrigation in Asia, for example, affects precipitation patterns as well as extremes far across national borders (Devanand et al., 2019). Increased wildfires and fossil fuel burning are melting glaciers and snowpacks, accelerating the production of meltwater and the growth of potentially hazardous lakes (Gul et al., 2021). More sediment is carried by rivers to fill reservoirs, diminishing their utility as flood buffers and energy providers. At the same time, riverbeds further downstream erode when upstream structures inhibit the transport of sediment.

The transboundary climate risks also travel across borders as demand for energy on the regional market rises – driven in part by increasing temperatures (van Ruijven et al., 2019). Growing demand is prompting the construction of hydropower structures further upstream, increasing exposure to hazards as well as their impact on river sediments and ecosystems. In the other direction, the migration of populations as a result of water-induced hazards, within and across borders, is projected to increase (Adler et al., 2022).

Responses to these transboundary climate risks need to be evaluated from all angles, including anticipating the drivers of risk as well as adaptation measures to large-scale impacts across borders. Anticipatory responses include the observation as well as prediction of high intensity precipitation or temperature events and adequate projection of their consequences.

In many countries these assessments are carried out by national weather monitoring bodies that disseminate information to populations that are likely to be affected, as well as, for example, hydropower operators. However, the data are not always shared immediately with neighbouring nations or regions that may be affected by incoming adverse weather. As such data become more publicly available, non-governmental actors have a bigger role to play in their dissemination and interpretation.

The transmission of data on a potential risk will not have any adverse effects. The same cannot be said for response interventions based on structural measures. The erection of walls to protect upstream riparian infrastructure can increase the velocity of flows downstream, resulting in increased erosion and potential damage to infrastructure. In addition, they result in the so-called levee effect: a false sense of safety that invites infrastructure establishment in potentially risky terrain (Kates et al., 2006).

Similarly, the presence of an early warning system may mean that people do not react in a timely way in the event of an unfolding risk. In addition, releasing water from reservoirs in anticipation of a flood upstream without adequate communication about the release to those downstream poses an added flood risk (as one example, between Tajikistan, Kyrgyzstan and Uzbekistan). Conversely, sensitive riparian ecosystems and tourism are impacted when lake levels are reduced to alleviate drought impacts downstream, a source of constant disputes between Switzerland and Italy.

The increased construction of hydropower infrastructure, often for the export of power to downstream neighbours (Harlan & Hennig, 2022) contributes to transboundary climate risks related to energy and the shift towards renewables [Chapter 2.5]. Investment in hydropower energy is heavily promoted, especially in high mountain areas where its raw potential remains unexploited.

For countries in these mountainous regions – so-called "battery" nations – energy exports to downstream neighbours that are often more prosperous and industrial provide an attractive revenue stream. However, the risks are transferred alongside the energy. For example, the exploitation of riverine sand as an export product connects vulnerable upstream areas to a growing global financial market (Torres et al., 2017) [Chapter 2.6]. As a result, transboundary mass flows cause repeated interruptions of international supply chains [Chapter 2.4],

Box 2. Case study:
Mass flows in the Koshi River Basin

The Koshi River Basin spans nearly 90 000 km², with 33% of its expanse in upstream China, 45% in Nepal and 22% in India and a number of river corridors crossing two national borders – covering an elevation difference of more than 8700 m.

The river basin provides the main traffic artery between Nepal and China, and several important hydropower plants in Nepal are located along its corridor. An estimated 5000 people on the Chinese side, and 16 000 on the Nepalese side have been affected by transboundary mass flows in recent years (Khanal et al., 2015). Mass flows have carried sediments in the river corridor that were deposited by landslides from previous years or by road construction, exacerbating downstream impacts. All recorded mass flows have had cascading effects.

In 1981, for example, a glacier lake outburst flood on the Chinese side triggered a cascading event, killing five people, damaging houses, bridges and a hydropower plant on the Nepal side and affecting cross-border trade for three years. A mass flow in 2016 reached far downstream into Nepal, damaging roads, houses and a hydropower plant. Both events started as drainage from lakes that had been growing in previous years (a slow-onset climate trigger) but were finally caused by above average temperatures in the first case that disintegrated the ice core dam and, in the second case, a debris flow that hit the lake during the monsoon.

In 2021 a flood caused by river damming and a subsequent breach due to debris flows in China hit the biggest hydropower plant of Nepal, where further downstream damage was averted by a timely drawdown of the reservoir storage to buffer the flood wave.

Electricity shortages are already being triggered by increasing heat in South Asia . The added stress on the system through diminished supply as a result of damage generates a compound effect induced by climate change, exacerbated by the socioeconomic imperative for increased prosperity that fuels growing demand for power.

Given the importance of the Koshi river corridor for both China and Nepal, there have been many unilateral attempts by both countries to assess past events and future risks. Early warning systems have been installed in many locations, particularly at the outflows of glacial lakes, but such systems are limited to national jurisdiction, which limits their utility for transboundary risks.

While there have been repeated commitments by national governments to address these transboundary risks, especially under a changing climate, a lack of institutional response pathways – and some political tensions – result in limited progress on adaptation strategies. Climate change adaptation measures have been taken up, including structural measures for flood control, institutional measures such as the creation of village committees, insuring crops, and adapting land-use planning, as well as opting for seasonal migration. However, these measures, as seen in the wider global governance context, lack regional coordination (Adler et al., 2022; Bastakoti et al., 2017).

Adaptation measures remain limited to personal contacts between regional politicians responsible for their respective areas, who tell each other directly about imminent transboundary developments. They do not, in general, include any long-term planning. This personal approach has, however, facilitated some crisis management, enabling hydropower operators on the Nepal side to react in time to use their reservoirs as buffers to protect areas further downstream. Risk assessments for such structures tend to rely exclusively on remote sensing data – the result of a lack of data sharing across borders.

The very close links between the road connection to and from Nepal and China and the resulting economic development along this river corridor (as seen in very high property prices) ties this transboundary risk directly into the issues of financial flows and human mobility [see Chapter 2.6 and Chapter 2.8] in the context of climate change. While investment in infrastructure along the corridor remains exceptionally high (increasing the risk of exposure), more than 60% of the households on the Nepal side of the corridor are labour migrants, many of whom note that water-related hazards influence their decisions to migrate (Banerjee et al., 2013).

often for years at a time. The transboundary climate risks are also closely linked to human mobility, with migration from remote rural areas to more urban settings along river corridors as a result of water-related hazards (Banerjee et al., 2013) [Chapter 2.8].

Critical reflections on existing policy tools and their limitations

Policy tools for the management of transboundary terrestrial resources are found in treaties on most large transboundary waterways, conventions on transboundary mountain regions and their associated resources and, more recently, conventions and agreements on air quality. The focus, however, remains on mitigation, with a clear lack of adaptation strategies, particularly strategies that address transboundary issues.

There are exceptions, including white papers on coordinated adaptation policies for some transboundary waterways (e.g. the Rhine) and terrestrial resources in mountainous environments (e.g. soil, forests and air in the European Alps) (Alpine Convention, 2021; IPCR, 2015). However, their focus in terms of climate change adaptation is subnational, with decisions on implementation falling within national adaptation frameworks to, for example, safeguard the water quality of transboundary rivers or manage forest stock.

Policies on adaptation need to account for the multifaceted and transboundary aspects of terrestrial resources. This is often referred to as a "nexus approach" (Adamovic et al., 2019) and is emphasized in adaptation guidelines on resources as a potential "win-win" or "no-regret" strategy for governments. The management of forest resources, for example, needs to consider international demand for wood, the use of forests for tourism, their role in mitigating potential mass flows across borders and as regional ecosystems, recognizing that the lifetime of a tree will, like climate change, span many decades.

This is crucial in relation to anticipatory responses to compound and cascading hazards. Addressing only a single socioeconomic driver at an often high cost – even in the best case – leaves many stakeholders unsatisfied. In the worst case, it has negative impacts on other ends of the system. For example, channelling flows to protect land or riparian infrastructure increases the intensity of the impact of mass flows downstream. Similarly, any upstream structure that traps water or sediment has an impact on the ecological connectivity of a river that was previously able to adapt to repeated downstream flood events in a natural way.

It often takes a disaster to bring riparian nations together for sustainable cooperation (Huisman et al., 2000). For the Rhine, for example, it has been acknowledged that transboundary measures rely solely on voluntary compliance and that such measures should encompass multiple

"Policies on adaptation need to account for the multifaceted and transboundary aspects of terrestrial resources. This is often referred to as a 'nexus approach'."

sectors and issues to ensure success. In general, however, it can take decades to establish water governance arrangements across national borders and demonstrate any perceptible effect.

Evidence from international scientific collaboration is a crucial component for successful and timely transboundary policies, and non-state actors need to be engaged in processes to find solutions (Armitage et al., 2015) as well as the monitoring and adaptation of strategies. Coordinated responses have been necessary in the Rhine region to address the impact of both propagating droughts (in 2018 and 2022) and floods (in 2021). Scientific insights on climate effects on the mountains upstream in Switzerland are crucial for a country like the Netherlands, as the increasing absence of glacier ice makes itself felt in years of drought, where glacier melt acts as a buffer when water from rain or snow melt is diminished.

The Koshi Basin clearly demonstrates the political challenges in climate change adaptation in transboundary watersheds. There is a strong political power and trade imbalance dominated by upstream China, with any risks shouldered predominantly by downstream Nepal. However, the scientific community on both sides of the border has a keen interest in the evolving and increasingly complex nature of hazards along this transboundary watershed. Transboundary working groups have been established to foster exchanges across borders and sectors and among scientists, civil society and governments (ICIMOD, 2022). Depoliticizing the issue by using evidence on present and projected risks, rather than prescribing legally binding frameworks, enables communication and potential uptake for policy formulation by both national as well as regional decision makers. This soft approach ties into existing international law (e.g. legislation by the European Union on air quality or soil protection) and is the favoured approach in long-standing conventions on transboundary resources in Europe.

One challenge with compound events is that there is no clear definition of responsibilities within governments, which creates fragmented responses. Climate drivers tend to fall under the responsibility of ministries concerned with hydro-meteorological monitoring, while mass flows involving sediments or seismic shocks are covered by departments of geology or mining. Similarly, hydropower falls under energy ministries while any other anthropogenic drivers, such as spatial and economic planning, fall under completely different divisions of government. There are often separate non-ministerial entities that deal with risk drivers in general, while communications with riparian neighbours are conducted through entirely different entities.

Evidence from other transboundary settings suggests that the successful establishment of bilateral or multilateral networks by the respective governments will take years if not decades (Huisman et al., 2000). Meanwhile, climate change adaptation is needed urgently. It is advisable, therefore, that non-governmental organizations that collect and synthesize scientific evidence as well as the Indigenous knowledge and demands of all associated transboundary stakeholders take the lead in developing adaptation policies in this context. This would enable an exchange between transboundary corridors across different mountain ranges to facilitate learning from best practices and identify the processes that drive mass flows, as well as adaptation strategies – whether successful or not.

Unpredictable policy responses in multiple countries to an already uncertain climate future and related effects on mass flows will only lead to more uncertainty. Adaptation strategies need to be flexible enough to deal with shifting needs, tipping points and the unforeseen results of initial adaptation responses. In the context of transboundary water management, including that of the Rhine and the Mekong, this has been addressed by designing adaptation pathways (Haasnoot et al., 2013).

Developing a multitude of potential scenarios along a transboundary landscape, including all stakeholders as well as hypothetical external events, would allow the exploration of potential adaptation strategies to a changing resource across borders. This landscape could be a transboundary watershed with many potential future discharge scenarios; different frequencies and intensities of hazards and socioeconomic pressures; and changing demands for the water source, the ecosystem and the irrigated land. A number of alternative strategies and mutually agreed targets could be developed, working in combination with the existing national policies of all upstream and downstream nations. This would lead to convergence on the best tools to apply in the future for monitoring as well as adaptation.

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Chapter 2.2

Managing transboundary ocean resources under a changing climate

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There are now serious concerns about the growing risk of shortfalls in open-ocean fish stocks, and the effects on economic imperatives to access the remaining stocks, global-scale inflation and resulting inequalities in access to marine proteins for the most deprived people in society, as well as fractured regional and international relationships beyond the fishery sector itself.

- There is growing evidence on the cascading impacts of climate change on ocean and coastal ecosystems, from the surface to the deep ocean. In particular, climate-driven geographical shifts are affecting fish stocks, exacerbating economic and geopolitical tensions.
- The risk of overfishing in exclusive economic zones (EEZs) results in the loss of fish stocks driven by an incentive to "catch fish before they go away", which will accelerate with climate change and trigger cascading risks on global supplies.
- Current global frameworks are not equipped to deal with the permanent loss of fish stocks within national jurisdictions, while regional arrangements to compensate for shifting ocean resources have serious limitations. This illustrates a broader gap in policy and governance arrangements addressing transboundary climate risks in ocean and coastal shared resources, covering large regions, and allowing to adapt to and manage, for example, the movement of fish stocks to the high seas under climate change.
- There is therefore an emerging need to design international compensation mechanisms to support countries' coping capacities to adapt to transboundary climate risks for ocean resources.

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Overview

Climate change is now causing major geographical shifts of natural ocean resources, particularly fish stocks. The climate-driven transboundary shifts of these resources between EEZs have implications for fisheries management and for global markets. When these shifts combine with other challenges, such as overfishing, there is a risk that the ways in which countries address the threats to their fisheries will disrupt markets and create or exacerbate bilateral and multilateral geopolitical tensions. This highlights the need for agreements to manage migratory fisheries and ocean resources that include international mechanisms to counteract the limitations of regional governance.

Introduction

Ocean and coastal resources play an essential role in feeding humanity, through both small-scale coastal fisheries that take between one-quarter and one-third of the total fish catch from the sea, and the industrial fishing operations found across more than half of the world's oceans. Marine fisheries are, however, increasingly affected by climate change (IPCC, 2019): ocean warming forces species to move to waters more suitable for their feeding and growth; ocean acidification damages fish habitats; changes in extreme sea levels and long-term sea-level rise affect fishing infrastructure, such as harbours; and ocean deoxygenation increases "dead zones" (areas of water where low oxygen levels limit aquatic life).

There is growing evidence on the cascading impacts of climate change on ocean and coastal ecosystems, from the surface to the deep ocean. Significant and widespread impacts on warm-water coral reefs are already detectable and possibly irreversible (Hoegh-Guldberg et al., 2018), and there are high risks to the abundance and distribution of other marine fauna and flora, for example krill and sea snails and slugs at high latitudes, seagrasses at mid-latitudes, and finfish fisheries at low latitudes. Bivalves and their fisheries, aquaculture, mangrove forests, estuarine ecosystems, salt marshes, sandy and rocky shores, and deep-sea ecosystems are all considered to be vulnerable to continued climate change in the coming decades.

A synthesis of risk assessments developed under the IPCC Special Reports of the Sixth Assessment Cycle published in 2018 and 2019 suggests that every additional 0.5°C of global warming will increase the risks to ocean and coastal systems by 30-40% globally (Magnan et al., 2021).

These predictions raise serious concerns for three reasons. First, about 11% of humankind lives in low-lying coastal areas (a percentage expected to increase by 2050), and food from the sea currently represents 17% of the global availability of edible animal protein, possibly increasing to 25% by 2050 (Costello et al., 2020). Second, some coastal ecosystems, such as coral reefs, mangroves and seagrasses, provide important nursery areas for species caught offshore, and any impacts on coastal ecosystems will, inevitably, have knock-on effects beyond the area that is initially impacted. Third, some open-ocean fish species respond to climate stress through geographical shifts, moving towards the poles and into deeper waters in response to warming seas, which challenges the bases for sustainable development (Pecl et al., 2017) and for established fishing practices and agreements. This last point, in particular, illustrates the transboundary risks to ocean resources from climate change and from adaptation responses.

On a longer-term perspective, it is estimated that about half of transboundary fish stocks (i.e., stocks currently crossing neighbouring EEZs) will have shifted by 2100, and about 80% of the world's EEZs will include at least one shifting stock (Palacios-Abrantes et al., 2022). Any change in the geographical distribution of fish stocks leads to a decrease or increase of catches and revenues for the countries that lose or receive fish, respectively.

In addition to national and local economic impacts, shifts in the distribution of fish species have the potential to generate political tensions, as illustrated by the "cod wars" from the 1950s to the 1970s between Great Britain and Iceland over rights to cod fishing or the tensions that occurred in the 1990s between the US and Canada as a result of the shift of Pacific salmon towards the poles (Pinsky et al., 2018). While these two examples were not attributed to climate change, it is likely that climate-driven geographical shifts will exacerbate such bilateral and even multilateral economic and geopolitical tensions (see, for example, "mackerel wars" in Pinsky et al., 2018).

Scientists also warn against the risk of overfishing in EEZs that are expected to lose fish stocks in the coming decades, driven by an incentive to "catch fish before they go away" (Oremus et al., 2020). There are now serious concerns about the growing risk of losing open-ocean fish stocks, economic imperatives to access the remaining stocks, global-scale inflation and resulting inequalities in access to marine proteins for the most deprived people in society, as well as fractured regional and international relationships beyond the fishery sector itself (Lam et al., 2020).

"The transboundary risks associated with geographical shifts of high-value fish species are very likely to increase in the coming decades."

Characterization of the transboundary climate risk

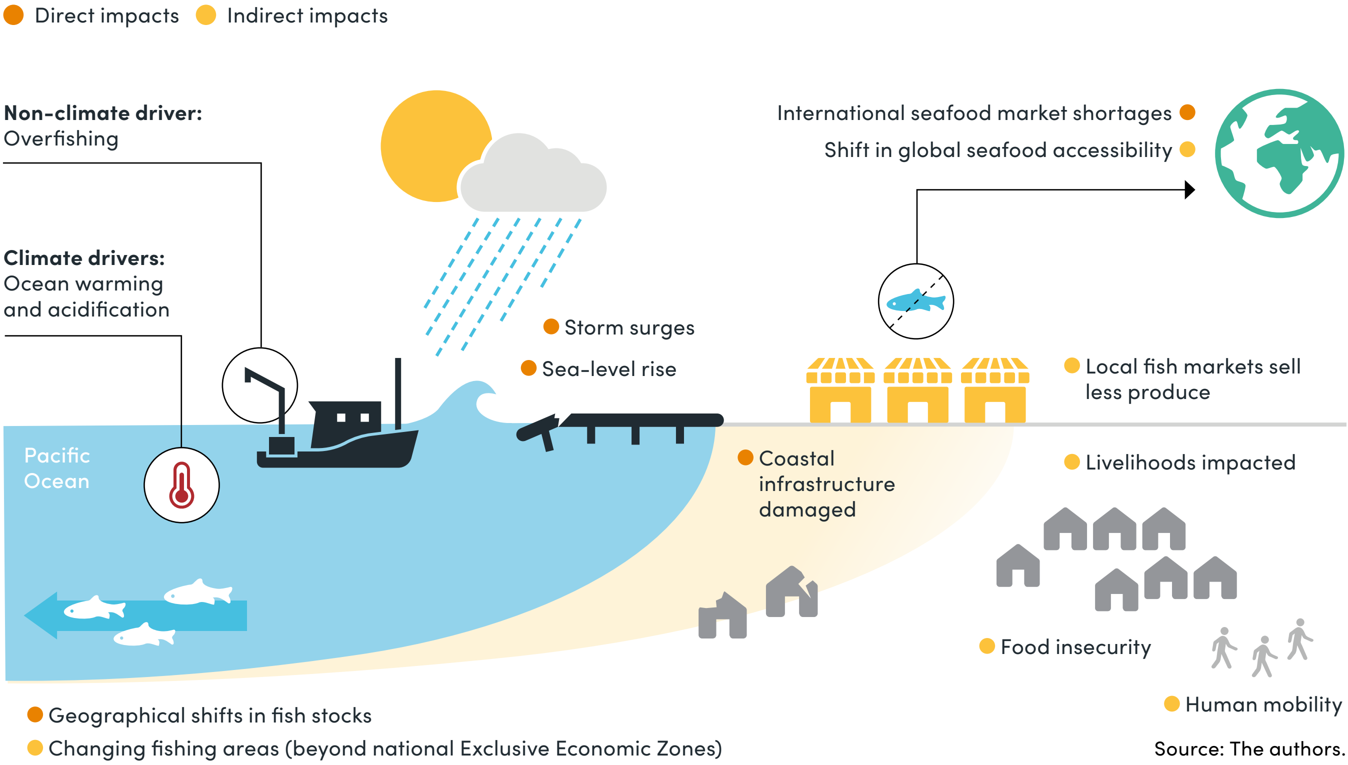
This section explores shifting fish stocks in the open ocean to highlight the key characteristics of the transboundary implications of climate change. These are the likelihood of detrimental consequences, transboundary propagation modes, timing, risk pathways and possible responses.

In terms of likelihood of detrimental consequences, the transboundary risks associated with geographical shifts of high-value fish species are very likely to increase in the coming decades as a result of a combination of three factors. First, the global consumption of marine products is expected to continue to increase (Lam et al., 2020). Second, the maximum fish-catch potential of global fisheries could be reduced by 20% to 25% by the end of the 21st century under a high greenhouse gas emission scenario (Representative Concentration Pathway RCP8.5) because of a net decline of fish stocks driven by changing climate conditions (Bindoff et al., 2019). Third, climate change will lead to fish redistribution among EEZs as well as between EEZs and the high seas: the areas beyond national jurisdictions that represent two-thirds of the global ocean surface (Kroodsma et al., 2018). By the end of this century, most coastal states, especially in some temperate regions and in shared Antarctic fishing grounds, are expected to receive up to 30% of their fish catch potential from newly redistributed stocks, while the tropics are likely to see a decline in fish stocks (Pinsky et al., 2018).

The chain of impact illustrates two propagation modes of transboundary climate risks across borders (including across sectors and systems in different countries at different spatial distances) (Carter et al., 2021). First, between neighbouring countries, with subsequent cascading effects on local markets, jobs and industries. Second, between distant countries through cascading impacts of changing fish catches on the international seafood market, including on supply chains and financial markets (Lam et al., 2020). As a result, the spatial dynamics of ocean transboundary risks from climate change will run from small-scale regions (e.g., affecting the boundary between two EEZs) to wider regions (e.g., at ocean scale, involving more than two countries), and through distributional impacts on trade and markets at the global scale [Figure 5].

These climate-induced cascading impacts remain understudied, but there are some initial thoughts on the potential

Figure 5. Transboundary impacts of shifting fish stocks



Source: The authors.

timing of impacts, response implementation, response outcomes, and the autonomous adaptation of species. First, impacts are likely to be substantial well before the end of this century, in particular, if the world continues on its path towards a high emissions scenario. By 2050, for example, the total biomass of three species of tuna is projected to decline by an average of 13% in the combined EEZs of 10 Small Island Developing States (SIDS) in the Western Pacific region as the fish move out to the high seas (Bell et al., 2021). And as soon as 2030, an estimated 20% of transboundary stocks will have shifted across EEZs (Palacios-Abrantes et al., 2022).

Second, the timing of human response remains largely unknown, making it hard to assess how much time it takes for a policy to deliver results or reveal its collateral effects, and whether these positive or negative outcomes will be short-lived or permanent. However, it can be argued that the more complex the cascade of impacts, the deeper the outcomes and the higher the probability that societies are affected for generations (e.g., in the case of radical economic shifts).

Third, the recovery time of marine species depends on natural parameters as well as exogenous stressors (climate, pollution, etc.) and potential climate change adaptation policies. There is general agreement that the time needed to design and implement adaptation policies and, therefore, to benefit from them, is longer than the timeframe over which the abundance and distribution of natural resources will be affected under accelerating climate change (IPCC, 2022; Palacios-Abrantes et al., 2022). Recovery times for species ranges from sometimes 10 years or less for some oyster and coral reefs, to 10-30 years for exploited fish stocks (including tuna species), and up to 40-100 years for whales and sea turtles. Overall, however, marine species and fish stocks have recovery times that could be supported by active interventions, particularly if their loss has been triggered primarily by mismanagement (Duarte et al., 2020; Fromentin & Rouyer, 2018).

The combination of several transboundary risk pathways includes a "biophysical pathway" that encompasses changing flows of ecosystem services and resources, a "trade pathway" involving changing flows of goods and services in international supply chains and global markets [Chapter 2.4] and, to a lesser extent, a "people pathway" through the movements of people and human activities across EEZs and the related issue of remittances from fishermen [Chapter 2.8] (Hedlund et al., 2018).

Two types of influence shape the connections with other transboundary climate risks. On the one hand, the increased risk of overfishing associated with the climate-induced geographical shifts of fish stocks has implications not only for biodiversity, but also for livelihoods and living standards in fish-dependent communities and countries, such as in the Pacific Ocean, across the whole fishing industry and among the most deprived people in distant fish-consuming countries [Chapter 2.9]. This, in turn, presents threats to food security (e.g., in terms of food availability) and poses indirect risks to human health (e.g., through increased poverty and difficulties in accessing affordable food) and possibly mobility (e.g., through loss of jobs) [Chapters 2.3, 2.7, 2.8, 2.9]. Indeed, there is a general view that non-voluntary (inter)national migration is influenced increasingly by the transformational consequences of climate change on livelihoods (increased precariousness, gender inequities, etc.) and social capital (i.e., the erosion of community networks as a result of exacerbated tensions within and between communities and countries) (Loiseleur et al., 2021) [Chapters 2.8, 2.9].

On the other hand, cascading transboundary risks related to fisheries will themselves be exacerbated by external factors. Sea-level rise, for example, will affect coastal infrastructure for transportation (e.g. harbours and airports), and possibly energy production (e.g. power plants) and the supply of commodities (e.g. waste management and freshwater supply), with ramifications for economic development and, in turn, the ability of countries to respond to a shift in fish stocks beyond EEZs.

Box 3. Case study:
Geographic shifts in tuna stocks in the Pacific and transboundary governance responses

The projected redistribution of tuna in the Pacific Ocean is an opportunity for a deeper assessment of ocean transboundary risks from both climate- and adaptation-related responses. Tuna fishing in the Pacific makes a substantial contribution to global fish catches and to the island economies of the region. In particular, the 10 Pacific SIDS where most tuna fishing occurs — Cook Islands, Federal States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, Tokelau and Tuvalu — receive an average of 37% of their non-grant government revenue from tuna fish access fees (Bell et al., 2021). However, as ocean warming drives tuna further to the east, the purse-seine catch of tuna from their combined EEZs is expected to decline by 20% by 2050, reducing government revenue by up to 13% per year for individual SIDS (Bell et al., 2021). The redistribution of tuna biomass will, however, increase the catch from the surrounding high seas, which currently play a negligible role in global seafood production (Schiller et al., 2018).

In all, 9 of the 10 tuna-dependent Pacific SIDS participate in a regional fisheries management arrangement that enables them to deal with the geographic shifts of tuna within their EEZs as a result of climate variability. This arrangement, known as the Vessel Day Scheme (VDS), was established in the 2000s by the Parties to the Nauru Agreement (PNA) (Aqorau et al., 2018). The VDS has been designed as a cross-border tool to achieve sustainable tuna harvests and optimal outcomes for island economies from their shared tuna resources in response to the profound influence of El Niño and La Niña events on fish distribution (Aqorau et al., 2018; Clark et al., 2020).

El Niño and La Niña are characterized by temperature anomalies at the scale of the entire Pacific basin, resulting in conditions for purse-seine fishing in the Western and Central Pacific Ocean (WCPO) that are more favourable in the eastern part of the WCPO during El Niño episodes and in the western part during La Niña events. This climate variability does not affect the total purse-seine catch from the combined EEZs, but it does have important consequences for the distribution of catches and, therefore, for the revenues received by Pacific SIDS which they depend on for health, education and infrastructure programmes, etc.

The VDS sustains annual purse-seine catches by limiting total fishing effort to ~45 000 days per year and allocates those days among the nine Pacific SIDS that participate in the scheme based on the catch history from their EEZs over the past 7 to 10 years (Clark et al., 2020). In essence, the VDS is a "cap and trade" scheme that allows participants to respond to the profound effects of the El Niño on the prime fishing grounds for tuna.

During La Niña events, countries in the west buy days from members in the east to enable fleets to keep fishing in their EEZs, with this arrangement reversed during El Niño episodes. Therefore, regardless of where the tuna are caught, all PNA members receive revenue each year as long as the fish remain within their combined EEZs.

The VDS is also designed to govern fisheries in a non-confrontational way (Bell et al., 2021) as the tuna are redistributed to the east as a result of climate change. Over time, PNA members in the east are expected to accumulate a greater catch history and receive more days. However, the "pooling" and "roaming" provisions of the VDS (Clark et al., 2020) provide practical ways for PNA members in the western area of the WCPO to maintain much of their catch history, thereby minimizing the risks to their economies by movement of the fish to other EEZs.

One important limitation of the VDS, however, is that it is restricted to the management of tuna within the combined EEZs of the participating Pacific SIDS. As tuna are redistributed to the east and progressively into the high seas by climate-related changes, lower catches from the EEZs will undermine the socioeconomic benefits that the Pacific SIDS derive from tuna fishing, and weaken the strong existing management arrangements for tuna resources. This has been raised as a climate justice issue, given that Pacific SIDS contribute very little to global greenhouse gas emissions. A solution needs to be found that enables Pacific SIDs to retain the benefits they currently enjoy from tuna fishing, regardless of the redistribution of the fish (Bell et al., 2021).

Regional-level agreements can help address climate-related shifts in fish stocks. © Francisco Blaha

Critical reflections on existing policy tools and their limitations

As demonstrated by the example of the Vessel Day Scheme (VDS) for the Pacific SIDS in the case study, regional arrangements have limitations, even though they are essential for effective governance of transboundary ocean resources under a changing climate. Both the general ethos of the VDS (i.e., a cross-border tool to promote the use of migratory fisheries resources in a collectively beneficial and non-confrontational way), and the specific management arrangements (e.g., equitable distribution of fishing days) are important foundations for the strengthening or design of regional-scale mechanisms to address transboundary risks triggered by the effects of climatic variability. However, rapid climate change under continued high greenhouse gas emissions will present profound challenges to the foundations of existing regional arrangements as the fish move eastwards in the high seas.

Beyond the VDS example, there is a widespread need for governance tools that cover larger regions to address climate-driven redistribution of transboundary fish stocks at large spatial scales. The development of such tools could be supported by the international community, for example, by the United Nations Framework Convention on Climate Change (UNFCCC) encouraging governments to include transboundary climate risks in their official adaptation documents (National Adaptation Plans, Adaptation Communications), and even calling for the development of Regional Adaptation Plans dedicated specifically to the collective management of transboundary climate risks. Other frameworks and conventions, such as the UN Convention on the Law of the Sea and the Water Convention also offer binding mechanisms through which some maritime transboundary climate risks could be managed.

Nevertheless, mechanisms are needed to overcome weaknesses in international policy on the movement of fish stocks to the high seas. Unfortunately, global frameworks are not equipped to deal with transboundary risks such as the permanent exit of fish stocks from national jurisdictions (Oremus et al., 2020; Pinsky et al., 2018). The 1995 United Nations Fish Stock Agreement, for example, recognizes the need to manage highly-migratory stocks but operates "at a high level and do[es] not mandate specific management mechanisms" (Oremus et al., 2020, p. 1).

This raises a critical question: how can the international community define clear and adjustable regulatory policies that can account for new knowledge on transboundary climate impacts in areas beyond national jurisdictions? Likewise, there are continued constraints to monitoring, control and surveillance measures in the high seas (Cremers et al., 2021). These issues, in turn, call for improvements in the scientific collection and sharing of data (e.g., on the spatial structure of fish stocks and fish catches), the harmonization of national legislations and deterrent sanctions, and greater investment in the capacity of coastal states to implement monitoring, control and surveillance measures and adjust their fishing policies and practices over time.

Finally, scientists warn that even the combination of highly aggressive greenhouse gas mitigation and ambitious adaptation efforts will not fully eliminate risk (IPCC, 2022; Magnan et al., 2021), so that residual risks will remain. This highlights the need for international compensation mechanisms to help countries face the unavoidable consequences of transboundary climate risks. At present, however, the UNFCCC Warsaw International Mechanism for Loss and Damage, which focuses on residual climate risks within national boundaries, does not address transboundary dimensions (Oremus et al., 2020).

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Chapter 2.3

Transboundary climate risks on agricultural commodities and food security

Magnus Benzie[1]

Transboundary climate risks demand adaptive measures along every part of the agricultural commodity supply chain, from farm to fork.

- Extreme weather events have always been major triggers for food insecurity. Today, climate change threatens food security by disrupting the distribution of vital agricultural commodities.
- Climate change interacts with non-climate factors – from pandemics to conflicts – to drive cross-border, cascading risks in the global food system. And when domestic droughts, floods and other extreme events coincide with global crises, the current global food system has no room for manouevre.
- The fate of billions of food consumers depends on adaptation to climate change in the world's breadbasket regions, backed by enhanced international cooperation. The aim should be to build a global food system that is just and resilient: a system that meets the needs of billions of people as the climate changes, rather than fuelling new crises.

Overview

The impact of climate change on the production of agricultural commodities, as well as their distribution via international supply chains and markets, triggers cascading effects on food security across borders. Climate change can heighten risks for those who rely on agricultural commodities for manufacturing, and for energy production, as well as for feed and food for animals and humans.

Transboundary climate impacts on agricultural commodities include price changes and shocks and the risks to commodity availability and business continuity for traders, processors and retailers, as well as energy and food security risks for people across the world. Agricultural commodity price shocks can also disrupt national economies – especially in wealthier countries. This chapter assesses the implications of transboundary climate risks for food security via trade in agricultural commodities.

Introduction

Agricultural commodities are critical for the global food system, spanning different countries linked by trade, logistics and supply routes. From the location of their production to their eventual consumption, the flow of these commodities is increasingly vulnerable to climate hazards. These climate hazards combine with non-climate drivers (e.g. political, economic and social development contexts) to compound the risks to agricultural commodities, with severe implications for global food security.

Low-income and marginalized people in low-income countries, particularly in the least-developed countries that depend on imported food, are at high risk of disruptions to agricultural commodities in international supply chains. In addition, low-income groups in middle- and high-income countries, who spend much of their income on food, are sensitive to fluctuations in food prices that hamper their ability to afford a sufficient and nutritious diet.

At the same time, a few producers are responsible for a major share of the export of agricultural commodities onto global markets, including the staple crops that form the basis for many diets worldwide. Given the reliance on international supply chains, particularly for the flow of and access to agricultural commodities, the fate of billions of food consumers rests on the success – or failure – of adaptation to climate change in the world's breadbasket regions.

Characterization of the transboundary climate risk

Climate change already threatens the production of agricultural commodities in farms and fisheries. Extreme weather events, particularly droughts, floods and marine

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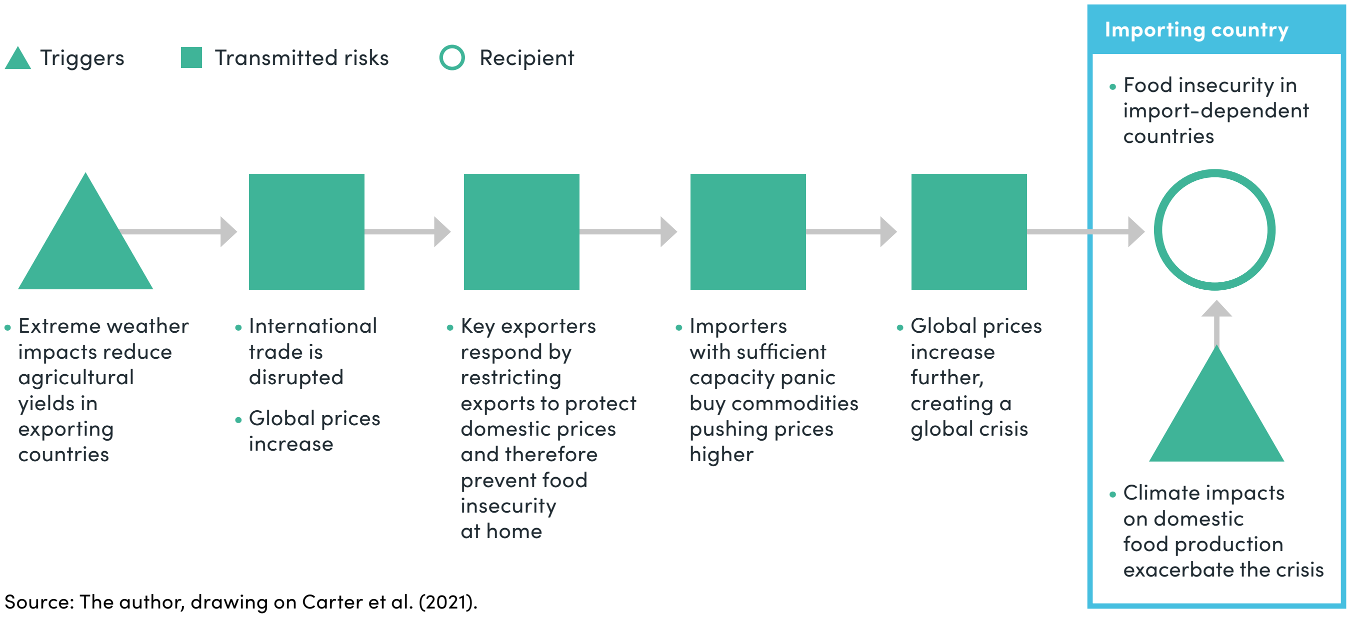
Figure 6. From farm to fork: the impact of climate change on agricultural commodities and food security



Source: The author, drawing on Carter et al. (2021).

heatwaves, radically alter growing conditions for plants and animals through, for example, changes in soil moisture and evapotranspiration,[2] while rising sea levels threaten food production in many low lying and coastal areas (Bezner Kerr et al., 2022).

Shocks triggered by climate hazards that cause sudden losses in food production have increased in recent years and are projected to accelerate under higher emissions scenarios, with a particular impact on global staple grains. Maize production, for example, is projected to decrease most severely – according to some estimates by up to 80% – followed by wheat and rice, with a less certain outlook for soybean production (Bezner Kerr et al., 2022).

Climate change also reshapes the timing and patterns of key biological events (e.g. flowering and insect emergence, which affects pollination), as well as the suitability of growing areas. This, in turn, undermines harvest stability and food quality (Bezner Kerr et al., 2022). Increased climate variability also affects the fertility, mortality and recovery rates of livestock. Long-term climate changes will shrink the area suitable for crop and livestock production by 30% by 2100 under a high emissions scenario. Taken together, these climate variables, combined with more extreme weather events, mean greater losses in major food-producing regions, triggering global food crises that increase the number of people at risk of hunger, malnutrition and diet-related mortality.

Climate change has more indirect impacts on food systems that have spillover effects on agricultural commodity production and global distribution. These include the effects of greenhouse gas emissions on air, soil and water quality, which make food production more difficult, more costly and less predictable. Climate-driven increases in pests, disease and weeds affect crop production, forests and livestock.

In addition, climate change threatens food security by affecting the distribution of commodities from farm to fork. Extreme weather, for example, presents physical risks to food supply chain logistics, including transport, storage, processing and food retail facilities [Chapter 2.4]. Higher temperatures and humidity damage food quality via increases in fungi, pathogens and algal blooms, as well as contamination following extreme weather events like flooding. Furthermore, extreme weather events have social impacts that affect the health, availability and productivity of agricultural workers. This can be critical for harvests and, therefore, for food prices and shortages.

It is difficult to project the precise climate change impacts on food production. Some regions may become more suitable for certain types of food production, particularly crops that are fertilized by elevated CO_2 levels, provided other growing conditions remain suitable. However, extreme heat can counteract the positive impact of CO_2 fertilization, which can also reduce the nutritional quality of food crops even where yields increase.

Extreme weather events have always been major triggers for food insecurity. Yet modelling assessments struggle to capture an accurate picture of their future impact on food production. More assessments are needed to explore the consequences of changes in food production (e.g. at farm level), on food quality (e.g. micronutrient or protein content) and on food availability and prices (e.g. in markets and via global supply chains). Such assessments could provide vital insights into transboundary climate risks to

2 The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

food security in the interconnected and interdependent global food system.

Situations of acute food insecurity are rarely caused by climate impacts alone, though they may generate the initial impact that triggers a shock. Non-climate triggers in cross-border systems include energy policies that promote biofuel consumption, agricultural input prices (e.g. fertilizers and energy), volatility in other commodity markets, financialization and speculation, inflation, and economic shocks and conflict, as well as trade policy decisions by governments (perhaps the main non-climate driver).

Risks are also driven by socioeconomic developments that put pressure on the overall food system and, therefore, magnify the consequences of shocks. These include global population growth, urbanization, economic growth, and changing diets and lifestyles. These increase the level of agricultural commodities needed to maintain food security, leading to a greater dependence on imported staple

Box 4. Case study: Compound climate impacts in the context of the global food crisis

The world faces a new food crisis as a result of the cascading effects of the Covid-19 pandemic and Russia's invasion of Ukraine, as well as the impact of climate change on agriculture. This current crisis demonstrates how climate risks magnify existing risks in cross-border systems, such as the global food system.

Russia's invasion of Ukraine has generated cascading effects on grain exports worldwide. In response, on 12 May 2022, India's Ministry of Commerce and Industry declared that, after years of bumper harvests, India would help to make up for the global shortage of wheat. This declaration – following orthodox trade theory – suggests that production shortfalls in one exporting country can be filled by increases in other parts of the world. On the same day, however, worrying data on the rising rate of inflation in India, coupled with dire forecasts for the country's wheat harvest as a result of a staggering heatwave, led to an abrupt U-turn by the Indian Government. By midnight the next day, India banned wheat exports, resulting in an immediate 6% jump in the global price of wheat on the Chicago futures market (Jadhav et al., 2022).

India's reaction is just one example of systemic risk in the global food system. Export restrictions covering 10% of world trade in cereals were implemented within the first weeks of the crisis, in early summer 2022, fuelling a global food crisis – a cascade of impacts and responses – that is pushing millions of people into food insecurity.

Many countries now face both cross-border and domestic climate impacts on food production. Persistent droughts and unpredictable rains have eroded food security in the Sahel – one of the world's climate crisis frontlines. Further east, the Horn of Africa is experiencing its worst drought in 40 years, with millions at risk of starvation (Desmidt et al., 2021). Climate variability and acute droughts undermine sustainable development and fuel a general context of insecurity, which includes forced displacement and violent conflict. In 2021, Niger's cereal harvest was 40% lower than usual (Harter, 2022). And in 2022, the war in Ukraine contributed to steadily rising food prices there.

Meanwhile, the same cascading effects that are driving up food prices for people in Niger – the Covid-19 pandemic and war in Ukraine – are hitting families in countries like Somalia. In normal times, smallholder production of traditional staples, fruit and vegetables can smooth out food price fluctuations on local markets, which are influenced by global trade patterns. But when domestic drought and global crises coincide, there is no room for manouevre. The World Food Programme (WFP) is struggling to meet the demand for food aid in the region, partly as a result of cuts in aid spending by rich countries and the legacy of the Covid-19 pandemic on public finances throughout the world (Snowdon, 2022).

At the first ministerial meeting of the World Trade Organization (WTO) in over three years in June 2022, members agreed to exempt non-commercial purchases of food by the WFP from export restrictions in response to this current crisis (WTO, 2022). However, no further agreement could be reached to adapt the global food system to prevent such crises, which have been repeated in recent decades. Despite regional attempts to build resilience to drought in the Horn of Africa, the world has failed to learn the lessons of the 2010/11 famine, which killed 260 000 people in Somalia (Checchi & Robinson, 2013).

These interconnected examples show that compound climate change impacts – simultaneous or sequential climate events that reduce agricultural yields in multiple countries at the same time – interact with non-climate factors to drive cross-border, cascading risks in the global food system. Furthermore, the risk of food insecurity depends on impacts and responses elsewhere in the food system: export restrictions and panic buying turn shocks into crises.

There is, therefore, a major – but unfulfilled – role for enhanced international cooperation to govern the global food system in ways that reduce its propensity to create crises as the climate changes. This includes multilateralism, as well as focused trade diplomacy to avoid excessive or prolonged export restrictions. A far more proactive approach to build the resilience of the global food system is clearly and urgently needed to prevent the escalation of food crises in future. Without fundamental adaptation within the global food system, compound climate change impacts will accelerate and intensify.

crops in daily diets and a more concentrated dependence on a small number of countries that are efficient exporters. As such, even without climate change, many countries are becoming more exposed to risks in the global food system (Kummu et al., 2020).

Knowledge of the spatial and temporal dynamics of transboundary climate risk for agricultural commodities via the food trade remains nascent as a result of the complex nature of international commodity supply chains and markets, and a research focus on climate impacts at local scales. However, recent research uses trade data on globally significant agricultural commodities to provide insights into how transboundary climate risk will be distributed in spatial terms via trade networks, based on national-level data about the embeddedness of these commodities in consumption (see Adams et al., 2021). The results show that climate risks to food security are transmitted from a small number of integral commodity exporters (Brazil, China, Russia and the US), and that geopolitical dynamics present an additional transboundary risk for smaller import-dependent countries.

This highlights the equity and justice issues around food security. Indeed, countries at various levels of development, including least-developed countries, emerging economies and smaller high-income countries, are highly exposed to transboundary climate risk because they depend heavily on a small number of trade partners who are projected to experience lower yields as a result of climate change.

Critical reflections on existing policy tools and their limitations

There is a pressing need for enhanced international cooperation to plan and implement effective adaptation to transboundary climate risks to agricultural commodities and food security. Traditional approaches to managing trade risk, such as substitution and diversification, are not enough, given the systemic nature and global distribution of transboundary climate risk in a world that faces accelerating climate change impacts simultaneously in all countries. Transboundary climate risks demand adaptive measures along every part of the agricultural commodity supply chain – from farm to fork.

At the source, planning adaptation at the farm level (e.g. irrigation, resilient seeds, resilient farming techniques) can help to reduce the impact of extreme weather events and slower changes on agricultural yields. Further along the pathway, governance measures could seek to reduce the propagation of risk through markets. These measures include: adhering to WTO rules on (or simply avoiding) export restrictions, reducing food price speculation in financial markets, and establishing and administering strategic grain reserves to cushion the effect of global price crises on regional and local markets.

"There is a pressing need for enhanced international cooperation to plan and implement effective adaptation to transboundary climate risks to agricultural commodities and food security."

At the point of impact, reactive local measures can reduce the effects of global price crises on food security by subsidizing access to food for low-income households (i.e. by governments), or through local provision of free or subsidized food (e.g. by food banks, or through NGOs, faith groups, etc.). Reactive measures at regional, international or global scale include the provision of emergency food aid (e.g. via WFP) at the point of impact (i.e. in import-dependent food-insecure countries). Proactive measures include national food security strategies that balance domestic agricultural climate risks and trade-related risks by, for example, reducing import-dependence through investment in domestic production (Benzie & John, 2015), enhancing regional trade in agricultural commodities, and incentivizing the diversification of diets to avoid import-dependence and reduce the commodity intensity of diets.

Longer-term resilience-building measures could include reform to global agricultural trade, such as reduction in agricultural subsidies to enable importing countries to develop competitive domestic markets, maintaining and expanding the openness of agricultural trade, and upscaling cooperation and investments in climate-resilient agriculture. Other measures to increase the resilience of global food trade include investments in climate-resilient infrastructure, such as inland road and rail networks, storage facilities and ports, and food distribution infrastructure.

There is, however, a real prospect of "maladaptive responses" – specifically, those that reduce risk in one place while magnifying it elsewhere, or those that reduce one risk while exacerbating another. These include self-sufficiency drives in import-dependent countries, where planners "overshoot" and displace more resilient crops in an effort to reduce import dependence. Such measures are politically tempting as they boost local jobs and reduce trade deficits, but they can intensify dependence on domestic agriculture and reduce overall resilience by concentrating farming on staple crops at the expense of a more diverse agricultural portfolio that is better suited to hedging future climate risks. Other examples include stockpiling, export restrictions and the "securitization" of access to agricultural commodities via bilateral trade agreements or more overt geopolitical deals that exchange resource-access (including land acquisitions) for diplomatic support or security assurances.

Maladaptation to transboundary climate risks is linked to the unclear ownership of risk in the global food system. Purchases of many staple commodities on international markets are often made by government agencies, while the vast majority of non-staple food commodities are managed by private actors such as investors, traders, multinational food and drink companies and large whole-sale and retailers. This complicates risk governance and means that private and public risk management strategies may have different objectives. For example, even when

Climate risks to agricultural commodities cascade through global supply chains to threaten food security eastward.

private risk management strategies are "successful" from the perspective of the companies implementing them, they may undermine public adaptation objectives by restricting access to commodities (or the resources required to produce them, like water), or may undermine community resilience in other ways.

Agricultural commodity trade is a sensitive topic in international politics and increasingly subject to competition and geopolitical tensions. For example, reform of the WTO's Agreement on Agriculture, which provides a framework to regulate agricultural subsidies, is politically challenging. Enforcement of existing WTO rules on export restriction is inconsistent, with observers noting low levels of transparency on export restrictions and ambiguity between WTO signatories on the interpretation of WTO rules when exercising clauses that exempt countries from imposing export restrictions.

This has prompted new negotiations about agricultural trade under the WTO. However, the most recent Ministerial negotiations, known as MC12, could only generate agreement on measures to provide emergency *responses* to global food crises, rather than *prevent* them or build resilience in the food system (WTO, 2022). As a result, while the drivers of risk are increasing rapidly, the global food system is not governed to adapt, or to support systemic resilience.

There is also a governance blind spot when it comes to addressing agricultural commodity supply chains operated by private-sector actors. Various voluntary commitments on, for example, deforestation or supply chain labour conditions, are applied by consortia of NGOs and companies willing to participate. But the ability of state actors to regulate international supply chains is severely limited.

Banks and investors can act as "risk governors" in complex supply chains by pushing for the disclosure of climate risk information from the companies in which they invest (incentivizing companies to identify and manage their climate-related supply chain risks to reduce the overall exposure of investors). While this might help to support food security for consumers when, for example, it drives investments in climate resilience, it may also result in business decisions that protect investors at the expense of food security if it leads companies to abandon "high risk" assets, such as plantations of certain commodities in areas projected to be impacted increasingly by climate extremes. This may undermine local resilience and even reduce the diversity and total stock of certain food products on the market.

A key governance gap therefore relates to the need for a just transition for climate change adaptation. This can ensure that investments in adaptation build systemic resilience in a just manner, benefiting producers and consumers throughout the food system, rather than redistributing or exacerbating vulnerability (Atteridge & Remling, 2018; Lager et al., 2021).

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Chapter 2.4

The globalization of local risks through globally interconnected industrial supply chains

Sivapuram Venkata Rama Krishna Prabhakar[1]

The expansion of industries and the manufacturing of critical industrial components across multiple territories has set the stage for the perpetuation of transboundary climate risks in global supply chains by taking local risks to the global scale.

- Direct climate risks, non-climate drivers and adaptation responses along global industrial supply chains interact with each other and compound, increasing the likelihood of supply chain disruptions.
- Many developing countries are highly vulnerable to climate change and disasters, and this has exposed global production processes, including industrial supply chains, to new risks that are neither fully understood nor addressed.
- There is a lack of transboundary climate risk assessments to analyze natural and climatic hazards on global industrial supply chains, which is a first step towards inclusive multi-stakeholder dialogue for designing risk management and adaptation planning across interconnected components.

Overview

Supply chains are critical for global industrial processes – they connect production centres with resources and consumers around the world and have enabled industrial production to connect national, regional and international economies. They are the backbone of our modern economies, yet supply chains are highly vulnerable to shocks, including the compound impacts triggered by climate change and non-climate shocks such as pandemics. These impacts can span diverse geographic locations and take place over varying timeframes, exacerbating the consequences. Against this backdrop, the transboundary climate risks to the global supply chains of critical industries illustrate the globalization of localized risks. To date, national adaptation planning has focused on risks within borders, overlooking the need to address the threat of transboundary climate risks to global supply chains. Integrating industrial risk assessments as a part of national and subnational climate change risk assessments and adaptation planning can help to address this systemic risk.

Introduction

Industrial production has evolved over the last century as seen most notably in the shift from locally procured raw materials, human labour and financial capital with a largely local consumer base to outsourcing and globalization. The factors that have expanded industrial production across borders include product specialization, resource scarcity, cost minimization and profit maximization, time and geographical advantages, political and social environment advantages and more. As a result, the various stages of industrial production have changed in terms of their geography and timescales to create highly interconnected and interdependent systems across manufacturing components that link countries across the globe. Boeing, for example, procured more than 1.7 billion parts from 58 countries for manufacturing aircraft in the US, as well as many services in 2019 alone (Boeing, 2020).

Outsourcing and dependency on global supply chains have increased both direct and indirect exposure to climate-related risks (extreme events and slow-onset changes). For example, flood damage to Klang port in Malaysia after heavy rainfall in December 2021 disrupted the semiconductor supply chain (Leslie, 2022; Lim, 2021). The floods damaged semiconductor production facilities and blocked access to the port, disrupting its operations. This event compounded an existing shortage of semiconductors in a sector affected by the Covid-19 pandemic. This demonstrates how non-climate drivers such as pandemics exacerbate risks to supply chains, with cascading consequences downstream that affect, in this case, the manufacturing of consumer electronics and cars.

A number of efforts have been made to understand and address these global supply chain issues, but more

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research is needed to understand the transboundary climate risks through global and regional interconnected supply chains.

Characterization of the transboundary climate risk

Direct climate risks, non-climate drivers and adaptation responses along the world's industrial supply chains interact with and compound each other, increasing the likelihood of supply chain disruptions.

Transboundary climate risks involving global supply chains are characterized by components of supply chain management that are vulnerable to climate risks and adaptation responses (long-term risk reduction and resilience building). Critical components of this management are vulnerable to climate hazards such as extreme events and slow-onset changes in planning, sourcing raw materials, manufacturing, delivery and returns.

Indirect transboundary climate risks are also critical for global supply chains. For example, supply chains are not independent of the manufacturing facilities they serve: they reflect the practices and choices of those manufacturing units. It is, therefore, of paramount importance to understand the production decisions made by manufacturing units that can contribute to supply chain risks, including responses to climate hazards and adaptation planning.

Production processes that are widely distributed enable companies to bring production to the source of the need, and to store and distribute products to different markets – the dominant form of distributed manufacturing. With the expansion of consumer demand and markets outside the areas where industries have operated for a long time and where those industries already understand the local risks, more manufacturers are eager to install production facilities in emerging markets in developing countries.

Entering new markets is an opportunity to expand market reach to new consumers and target products to their needs and choices while taking advantage of local cheap labour and often lax environmental regulations. The expansion of industries into relatively unknown territories has set the stage for the perpetuation of transboundary climate risks to the global scale.

The expansion of production beyond traditional markets, accompanied by production economics that have pushed industries to "expand or perish" has made it possible to capture emerging markets, supported by the "early bird incentive". However, this has happened without an understanding of the many local risks in immature emerging markets. Many developing countries are highly vulnerable to climate change and disasters, and this has exposed global production processes, including industrial supply chains, to new risks that are neither fully understood nor addressed.

> "Direct climate risks, non-climate drivers and adaptation responses along the world's industrial supply chains interact with and compound each other, increasing the likelihood of supply chain disruptions."

Many of these countries do not have fully developed institutional systems to address climate risks and adaptation planning. At the same time, new industries entering these countries are often isolated from the local societies and linkages that are often the forte of locally developed industries. As a result, these new industries miss out on vital social capital and undermine their own prospects for long-term sustainability.

Physical risks

Climate hazards pose a direct risk to industrial supply chains through, for example, the immediate vulnerability and exposure of manufacturing units to such hazards. However, the extent of their exposure is unknown, given the lack of climate risk assessments in many developing countries, until they are surprised by an extreme climate event – an example of the accumulation of hidden vulnerability in many developing countries. As the result of a lack of land-use regulations, combined with poor standards and by-laws that fail to impose construction regulations for flood and typhoon resistance, many manufacturing units are highly vulnerable to such climate hazards. Other physical elements of supply chains – roads, ports, trains and telecommunications, among others – are vulnerable to disruptions triggered by climate change and related hazards. Such infrastructure in many developing countries is not well developed and its strengthening remains a long-standing development gap. Further, much of the infrastructure in many developed countries is not designed to cope with climate change and related climatic disasters. Ports, in particular, are crucial for supply chains, yet they are highly vulnerable to climate risks because of their physical proximity to coastal areas exposed to typhoons and sea-level rises.

Foreign direct investment

Foreign direct investment (FDI) is crucial for global industrial supply chains as a non-climate variable. FDI influences the propagation of transboundary climate risks as it enables external players to invest in new opportunities in emerging markets [Chapter 2.6]. It provides an easy conduit for foreign investors and companies to expand beyond their boundaries and provides a policy framework

Box 5. Case study:
A flood in Bangkok shocks the car industry in Japan

The case of the 2011 floods in Bangkok and its impact on the Japanese car industry demonstrates that climate disasters in vulnerable countries impact not only the multinational manufacturing entities in these countries, but also the source countries of these entities, their societies, institutions and more [Figure 7]. It also shows that the damage to multinational companies has the highest potential to carry risks across borders.

The floods provide a clear example of transboundary climate risks in industrial global supply chains, leading to cascading risks on interdependent industries in Japan and other parts of Asia. The flood itself was caused by strong rainfall events in quick succession as a result of the strong Southern Oscillation Index (SOI) in 2011 (Gale & Saunders, 2013) – the wettest year for more than six decades. Hence, the Chao Phraya River experienced a peak river flow with an estimated return period of 10-20 years.

The estimated economic cost of the flood to the Thai economy was USD 46.5 billion – around 1.1% of national GDP (World Bank, 2012) – with insured losses estimated to be around USD 12 billion (Swiss Re, 2012). Nearly 70% of the total losses were borne by the manufacturing sector because the flood hit industries that were concentrated in the Ayuthaya and Pathum Thani areas. The Navanakorn industrial zone in Pathum Thani alone had 270 manufacturing facilities employing nearly 270 000 workers (Kate, 2011). Many of these industries produced electronic parts and components for automotive manufacturers. While the overall physical damages were fully recovered, losses related to lost production may never be recovered, with the flooding projected to have continued cascading effects in the following years.

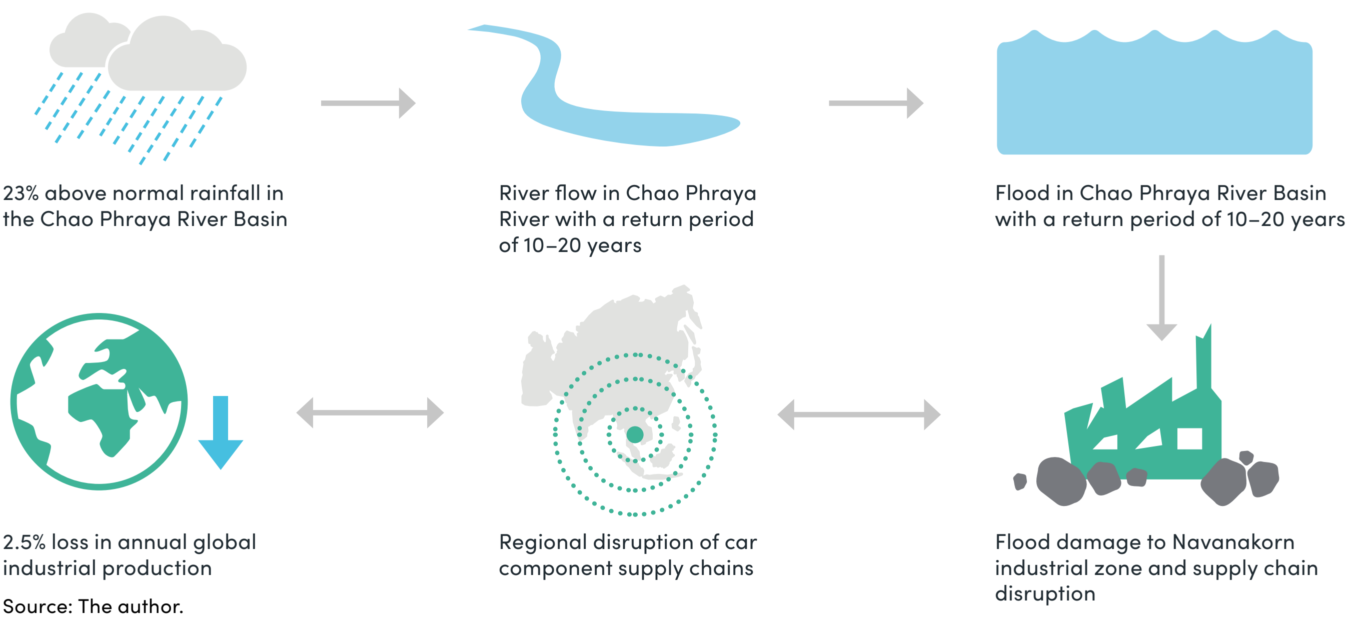
While the flooding itself took place in Thailand, the impact on Japan was significant. More than 550 Japanese affiliate firms were affected, and production facilities such as buildings and machinery were severely affected by floodwaters (Hayakawa et al., 2015). In addition to the direct effects, many Japanese firms engaged in supply chains outside the flooded areas were also affected by these floods: firms that link production facilities in Thailand with other countries in Southeast Asia.

As a result, automobile exports from Japan were severely affected, with falls in their yearly growth rates. This also coincided with the Tohoku earthquake in Japan, which had already disrupted automobile exports in 2011, with a 70% slump in exports in April of that year (Chongvilaivan, 2012). The impact of the Bangkok flood on Japan's automobile exports led to a 20% downfall in December 2011. Overall, as a result of floods, the insured losses for Japanese firms alone were estimated to be in the range of USD 10-15 billion, with a significant share of these losses borne by Thai insurance companies (Meehan, 2012).

As these firms supply factories in Indonesia, Malaysia, Viet Nam and other parts of the world, the production of these factories was also affected by the shock to the supply chains. Consequently, the floods in Bangkok also had a major impact on global industrial production, with estimates of a 2.5% loss in annual global industrial production (METI, 2012).

Such negative shocks for multinational corporations in developing countries matter if foreign investments in vulnerable and developing countries are to make any tangible difference to their economies. It is important, therefore, that the economic plans and investments by corporations in developing and vulnerable parts of the world are addressed with a multi-pronged approach that takes account of potential transboundary climate risks (Kato & Okubo, 2017).

Figure 7. The impact pathway of industrial supply chain disruption from the 2011 Bangkok floods



Source: The author.

for that expansion. However, most FDI policies are oblivious of local risks, and this can contribute to – and even drive – the transboundary climate risks related to industrial supply chains.

Despite this limitation, FDI policies have become "go-to" economic policies for developing countries wanting to attract foreign investments in manufacturing and technology (Kimura & Obashi, 2011). As a result, FDI flows doubled between 1990 and 2016, with Asia attracting the most FDI for its manufacturing, infrastructure, energy and transport sectors (Prabhakar & Shaw, 2020). This was a win-win situation for developing countries as they introduced new technologies and provided new labour markets.

Yet many FDI policies do not specify the climatic risks or inform the investors about these risks or the precautions needed – a situation often compounded by lax environmental regulations in many of these developing countries. Poor risk communication between recipient countries and investors is a key factor in the exposure of global supply chains to climate change risks. In the context of rapidly growing global investments in Asia, countries that attract global investments for manufacturing and service industries are also seen as highly vulnerable to climatic disasters and related losses (World Bank, 2012).

Regional integration processes

Regional integration processes also contribute to the globalization of local risks, such as the processes happening in Southeast Asia to promote free trade and labour market mobility. Enhanced trade and investments have been significant for regional integration in Asia and other parts of the world in recent decades (Asian Development Bank, 2017). Asia has become a producer of goods and services for the rest of the world and, as a result, investments in the region have grown significantly (World Bank, 2018). While such regional integration processes benefit countries by enabling them to tap into economic growth potential, they also lead to the expansion of growth in climate-vulnerable locations, including coastal areas that are vulnerable to flooding and sea-level rises.

Governance

The legal aspects of supply chain governance merit attention to understand their vulnerability to climate change risks. Unlike manufacturing establishments that are governed by the law of the land, other parts of the supply chains are not governed by any single entity or institution. Instead, their legal governance is often spread across several countries, laws and regulations depending on the specific element of the supply chain. This makes it challenging to manage the risk coherently. While supply chain management is largely left to individual manufacturing units, the ability of these units to fully manage supply chains is limited.

Planning is an integral part of supply chain management, with simulation and scenario-based planning helping to envisage some potential shocks. Yet, most planning focuses on production disruptions caused by machinery failure, for example, rather than the prospect of large-scale catastrophic disruptions that seem unlikely, or high-impact climate events that affect manufacturing and supply chains. Most businesses now focus on lean manufacturing processes, and while these can increase efficiency, there is little incorporation of risk management or the identification of risk elements across the full supply chain. However, businesses are increasingly aware of the risks to their supply chains, as shown in the case study.

Critical reflections on existing policy tools and their limitations

The multi-pronged approach needed to address transboundary climate risks via supply chains can be informed by existing solutions or those that are being debated. Many of these have been derived from the efforts made through the corporate disaster risk reduction initiatives by various countries and industries; climate change adaptation interventions; and the debates and experiences emerging from the Covid-19 pandemic, which caused serious disruptions to global supply chains.

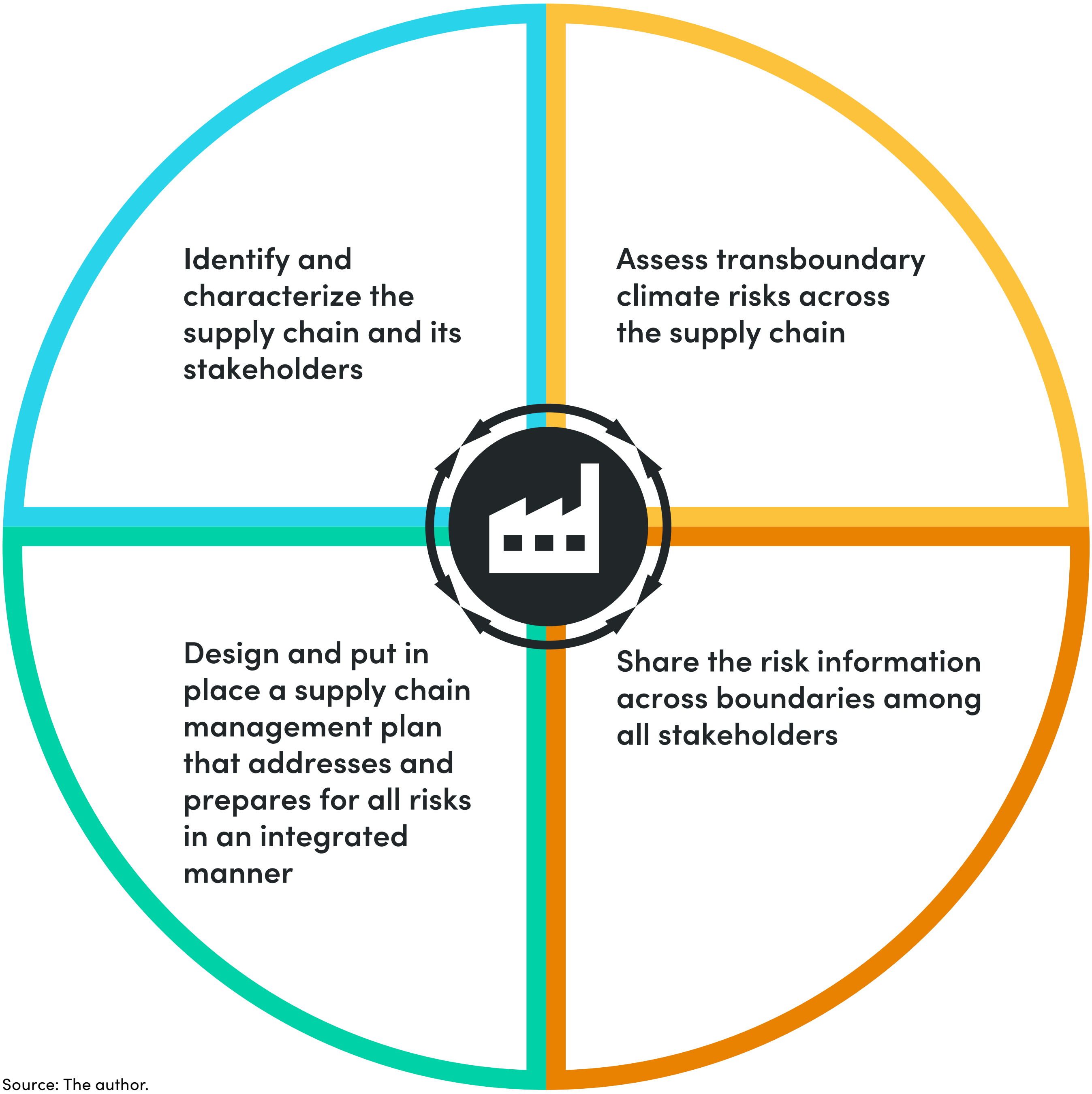
Key solutions to reduce the globalization of local risks in the face of a changing climate and non-climate drivers are:

- the identification and characterization of the supply chain and its stakeholders
- mandatory and transboundary risk assessments that go beyond financial and market risks to analyse natural and climatic hazards
- the open and transparent sharing of risk information by countries, within the supply chain across boundaries, and with potential investors, and
- the strengthening of risk management and adaptation planning across supply chains [Figure 8].

The rest of this chapter discusses aspects of these four categories of solutions for making supply chains resilient to transboundary climate risks.

First, firms often may not fully understand transboundary climate risks in their own supply chains to the extent needed. They need to understand not only the quality of products and services offered by the supply chain, but also the risks and underlying vulnerabilities for the various stakeholders within those supply chains. Building a supply chain that is resilient to transboundary climate risks starts with a deep understanding of the supply chain from the point of view of their risks and the capacities of their component actors.

Figure 8. Management and adaptation planning across supply chain



Source: The author.

Second, effective, transboundary risk assessments are crucial. Supply chain risk assessments are not new, yet most current industry risk assessments focus on the potential for mechanical failures, labour shortages, market risks, financial risks, resource production and supply and, to some extent, political risks. Natural hazards including climate changes and social risks are given less attention. However, this is changing slowly. A recent study using a localized climate change variability/vulnerability index revealed that nearly 49% of manufacturing facilities are exposed to climate variability and rapid temperature and precipitation changes in China, Taiwan and the US (Boyson et al., 2022). This analysis looks at how facilities can be affected by floods, storms, heatwaves, water scarcity and fires in a changing climate. Such assessments would help industries move away from disaster management that focuses on event-based planning towards a more long-term and integrated adaptation perspective to address climate change risks.

Third, it is vital to share information. Governments need to facilitate a mechanism where the local climate change risks are transparently communicated to investors. Likewise, the industry should communicate the supply chain risks that may adversely affect the national interests and security. Many climate risks to supply chains originate outside the industrial establishments, i.e. through damage to roads, ports and telecommunications, and many of these are under the purview of governments. Governments also play a key role in incentivizing FDI and the proliferation of industrial agglomerations and other policy instruments. Climate hazards also affect the communities that provide industries with their labour force, generating cascading effects on livelihoods and household welfare.

For all of these reasons, effective climate risk communication is critical across governments, the private sector, civil society organizations, science and technology institutions and communities for the governance of transboundary climate risks and global supply chains, alongside multi-stakeholder engagement and participation. The risk communication between national governments and investing entities should be strengthened such that the hidden risks are clearly recognized and efforts are made to reduce them. International investing entities, in particular, should be able to show that their investments don't bring global risks to the local level and that they don't act as conduits that carry local risks to the global level.

Finally, manufacturing countries need to put in place measures to adapt to the climate risks for industry in general and for their international investments. Measures include building climate-proof infrastructure, information communication and constructing a risk insurance facility for industry. National and subnational adaptation plans should focus on industry-specific risk assessments and identify where government policies can have an impact by changing the behaviour of stakeholders. Governments can, for example, make it mandatory for all industrial units to conduct their own climate change risk assessments to examine the effects on employees and societies that depend on their goods and services. A similar requirement could be imposed by the industry-originating countries on how foreign investments by domestic multinational corporations affect national stability and sustainability through feedback shocks through financial markets etc. Past experience indicates that industry can adopt stringent measures for its competitiveness and overall sustainability (e.g., environmental standards).

Continual engagement with input suppliers and original equipment manufacturers is an important and emerging area that can enable industries to address the quality of services they provide, but these engagements could also focus on understanding and addressing transboundary climate risks. Traditionally, companies have provided designs and asked the original equipment manufacturers to provide components that are subsequently tested and certified by the procuring entity. However, this is changing. More manufacturers now engage with their suppliers on a long-term basis, training them so that the original equipment manufacturers can test the components even before they arrive at the assembly line. This has advantages including avoiding last-minute surprises, reducing delays, managing demand and, importantly, improving trust with parts providers.

Such engagements have the potential to build resilient supply chains and avoid supply chain disruptions. For example, Boeing, through its quality integration strategies, has helped suppliers to design and test parts, and by closely monitoring the process, has been able to reduce delays in input supplies and reduce costs. Some companies such as Mitsubishi are going further to advise their parts manufacturers to insure against known risks including climatic disasters, thereby reducing their overall risk exposure. Supply chain insurance products are now being offered but they have very high premium costs as they are often custom-made and the market is small. As more multinational corporations encourage supply chain insurance, there is the potential for a reduction in premium prices in the near term.

Redundancy in supply chains has also received much attention in relation to supply chain management and transboundary climate risks. Redundancy refers to the identification and contracting of back-up manufacturing facilities and multiple-input procurement sources and channels, finding alternative transportation routes, and constant engagement with alternative options to understand the lurking risks. One related aspect is the need to balance procurement in terms of geographical spread. More industries are focusing on local procurement rather than depending on distant suppliers – following their experiences during the Covid-19 pandemic. This can have implications for costs and for the availability of suppliers that can meet quality and quantity requirements. Corporations can, however, address these issues by weighing the costs and benefits of building the capacity of local suppliers against the risks involved in procuring from distant locations.

In conclusion, there is a wealth of experience across various industries and the strengthening of supply chains is higher on their agendas than it has ever been. It is time for them to take a long-term perspective to address climate change risks and engage with a wider range of stakeholders than they have in the past.

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Chapter 2.5

Transboundary climate risks in the energy sector

Jinsun Lim[1,2]

If greenhouse gas emissions are not mitigated and the global temperature rises above +2°C, interconnected electricity networks are projected to experience a larger number of disruptions with cascading risks across borders, triggered by extreme weather events.

- A failure in any single part of an interconnected electricity network could generate cascading impacts, particularly if a transboundary network relies heavily on a single or limited number of energy sources.
- When disruptions to power supplies are coupled with extreme weather events, the socioeconomic damage can be massive, particularly for vulnerable people, that can exacerbate inequalities and adaptive capacities.
- The projected rise in the frequency of high-intensity tropical cyclones, wildfires and heatwaves requires countries to adapt to and prepare for future climate impacts on their energy systems, especially to address transboundary climate risks including the potential effects of adaptation decisions across borders.

Overview

This chapter discusses the transboundary climate risks for energy transmission and distribution networks. Transboundary interconnected electricity networks play a key role in improving energy access, integrating clean energy technologies and ensuring electricity security. However, interconnected electricity grids can cascade the destructive impacts of extreme weather events from one country to others, spreading electricity supply disruptions across borders and impacting local communities. Adaptation measures need to be implemented to prevent these cascading impacts of climate-driven disruptions, while recognizing that adaptation measures can also have cross-border impacts. Governments, international entities and other stakeholders all have a role to play in shaping long-term adaptation to transboundary climate risks for electricity networks.

Introduction

Electricity networks are the foundation of reliable and affordable electricity systems. They support clean energy transitions by integrating a variety of renewable sources, such as solar and wind power. They also help to enhance energy security, allowing more localized electricity usage and connecting distributed power sources.

At present, the global electricity network is around 80 million kilometres in length, and it is expected to grow substantially over the next decade across multiple countries (IEA, 2021a). The expansion of the electricity network does, however, raise concerns about its greater exposure to climate change impacts. The network is already seen as the part of the electricity value chain that is the most vulnerable to climate impacts, as its disruption is the leading cause of climate-driven outages in many countries (IEA, 2022a, forthcoming). Although interconnected networks can help to address power shortages by connecting alternative power sources, they can also transmit the impacts of climate disasters across borders.

This chapter discusses the transboundary climate risks to interconnected electricity networks. It discusses how interconnected electricity grids can provide both opportunities and trade-offs in addressing the adverse impacts of climate change, focusing on three extreme weather events – tropical cyclones, wildfires and heatwaves – that are the major concerns for electricity grids.

Characterization of the transboundary climate risk

Interconnected cross-border electricity networks could play an important role in ensuring the reliability of access to energy supply in the face of climate change. Transboundary electricity networks help to diversify and balance electricity demand and supply among countries by aggregating multiple sources of supply and loads. Extended networks pool the potential for flexible sources and bolster flexibility across the overall system.

1 International Energy Agency (IEA), Paris France.

2 This chapter was not funded by the European Commission.

In addition, interconnected electricity networks can help countries find alternatives quickly when their domestic generation is disrupted by climate disasters. The transboundary electricity network in Europe, for example, helped France's electricity transmission operator, Réseau de Transport d'Électricité (RTE), cope with increased electricity demand after heatwaves in June 2022 reduced domestic generation from the country's nuclear power plants. Electricity was imported from Spain, Italy, Germany, Belgium and the United Kingdom to fill the energy gap (Binnie & Abnett, 2022).

Interconnected networks can, however, have trade-offs that transmit destructive impacts from one country to another. For example, a forest fire in southern France in July 2021, fuelled by a heatwave and hot temperatures, caused short circuit failures and line trippings in two Baixas Gaudière transmission lines between France and Spain. The loss of these lines overloaded other transmission lines, leading to more trippings. After a series of trippings, the Iberian Peninsula was disconnected from the Continental Europe electricity network for 1-2 hours. Spain, which was importing 2 500 MW electricity from France at that time, needed to go for load shedding to relieve the pressure on its main energy sources (ENTSO-E, 2021).

Transboundary climate risks can spread along the interconnected electricity network as a result of extreme events. As noted, electricity grids are parts of the electricity value chain that are highly vulnerable to climate change. They are susceptible to extreme weather events, such as tropical cyclones, wildfires and heatwaves, which are likely to become more intense and frequent in the coming decades. If greenhouse gas emissions are not mitigated and if the global temperature rises above +2°C, more electricity networks are projected to experience a larger number of disruptions caused by extreme weather events (IPCC, 2022, forthcoming).

Tropical cyclones are a major concern for interconnected cross-border electricity networks. High-speed winds can topple trees and branches to damage transmission and distribution lines, poles and transformers. Heavy precipitation and associated floods triggered by tropical cyclones can also impair electricity networks. At present, almost one-quarter of the world's electricity networks (mainly in Central and North America, East and Southeast Asia, the Pacific Islands and Southern Africa) are exposed to the destructive impacts of tropical cyclones (IEA, 2021b). They are projected to face intense tropical cyclones more often in the future, rising by 10% in the low emissions scenario[3] and by more than 30% in the high emissions scenario (IPCC, 2021).

Wildfires can cause multiple faults across various parts of the electricity grid simultaneously through fire and

"Transboundary climate risks can spread along the interconnected electricity network as a result of extreme events."

smoke. They can damage lines, poles and substation equipment, while causing the thermal derating (operations below maximum capacity) of overhead lines (IEA, 2021c). Fire weather seasons lengthened by 18.7% worldwide between 1979 and 2013 as a result of extended droughts and warmer temperatures (Shukla et al., 2019). Climate projections indicate that these seasons will continue to extend in areas where there are major grid interconnections, such as the Mediterranean, Southern Africa, and the western part of North America (IPCC, 2022, forthcoming).

Heatwaves, which can also trigger grid failures, have become longer, more frequent and more intense across the world, and this trend is likely to continue into the future. Even in the IPCC's lowest emissions scenario, hot temperature extremes that used to occur only once in a decade in a pre-industrial climate will occur four times every decade on average and will be 1.9°C more intense (IPCC, 2021). In general, higher ambient temperatures reduce the capacity of transmission and distribution equipment and lead to higher losses. Overheated networks that are going above their operational limit can lead to power outages. Indeed, in the Netherlands, some electricity distribution network components were overheated in 2020, resulting in power cuts. The network operator had to upgrade parts of the electricity grid to increase resilience to extreme heat (IEA, 2022b).

A failure in any single part of an interconnected electricity network could transmit impacts to local communities throughout every country connected to that grid. The transmission usually occurs between locations in adjacent geographical regions, but it could have multi-regional impacts if the interconnections are linked to the power pools of other regions. The propagation of an initial impact of climate-driven disruptions in the electricity network is cascaded into system components to affect each importing country. These cascaded impacts tend to diminish when they are transmitted from one location to another, particularly when the interconnected electricity network has the flexibility and redundancy to switch loads at speed and bypass the faults. However, if a transboundary network relies heavily on a single or limited number of energy sources, the cascaded impacts may well escalate.

The cascaded impacts of a failure in a transboundary electricity network can have significant socioeconomic costs across countries. Disruptions in power supply can hinder business operations and the provision of public services in the affected countries, while increasing the

3 The low emissions scenario is known as shared socioeconomic pathway 1.9 (SSP1-1.9), indicating negative emissions by the 2050s (Henson, 2021).

use of carbon-intensive energy sources, such as diesel generators, as a back-up. When disruptions to power supplies are coupled with extreme weather events, the socioeconomic damage can be massive, particularly for vulnerable people. Power outages during heatwaves can, for example, increase mortality and hospitalization significantly as a result of heat stroke and gastrointestinal infections. A reliable power supply is essential to cope with heatwaves and maintain a healthy environment, supporting the regulation of indoor temperatures, the refrigeration of food, and the supply of good quality water.

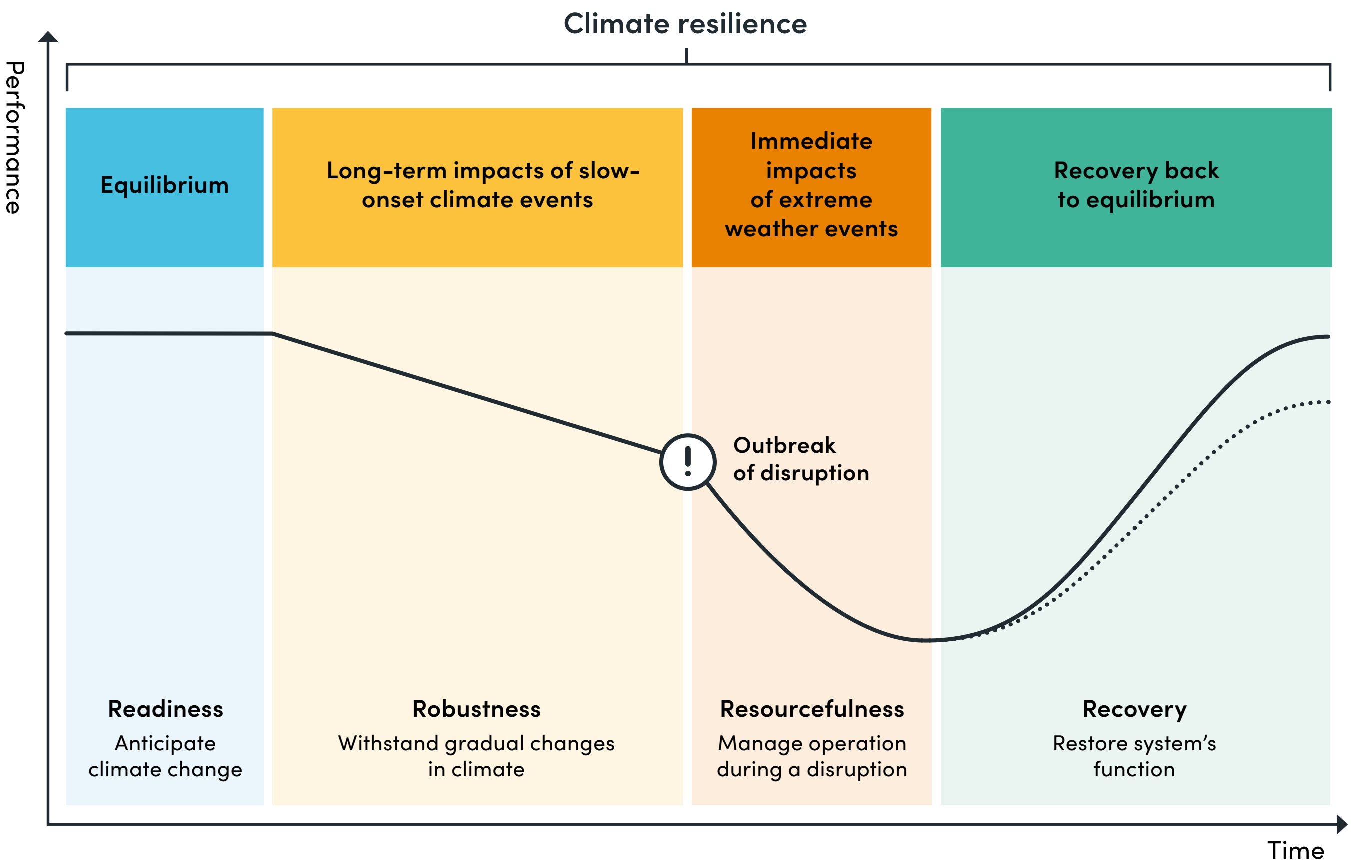
Enhancing resilience to the cascading impacts of climate-driven disruptions involves several adaptation measures at different stages of responses. The International Energy Agency (IEA) considers four categories of potential response based on each stage of climate change impacts: readiness, robustness, resourcefulness and recovery [Figure 9] (IEA, 2022a).

- Readiness is the ability to assess, anticipate and prepare for changes in climate in advance: climate risk and impact assessments of electricity networks could help operators prepare for future disruptions.
- Robustness is the ability of an energy system to withstand the gradual, long-term changes in climate patterns and continue operation, with an improved electricity network better able to reduce the cascading impacts of climate-driven disruptions.
- Resourcefulness relates to continuing operation during immediate shocks by accommodating alternative options, such as expanding the network to connect to more diverse energy sources.
- Recovery is about the restoration of the system's function after an interruption resulting from climate hazards. Electricity operators are starting to adopt smart grid technologies that can alert them to outages and help fix problems, enabling them to reroute power and prevent lengthy outages.

Critical reflections on existing policy tools and their limitations

To minimize the adverse impacts of climate change on the energy sector and cascading risks, effective policy measures have a central role to play in accelerating action by key actors. Although businesses have responsibility for and a direct interest in protecting their own assets and providing reliable services to their customers, three factors may deter some from adopting measures for climate change adaptation and disaster risk reduction in practice.

Figure 9. Climate resilience in energy networks



Source: IEA (2022a, forthcoming).

Box 6. Case study:
The impact of Tropical Cyclone Idai on interconnected cross-border electricity networks

The case of Tropical Cyclone Idai in 2019 shows how climate impacts can transmit in a cascade across interconnected electricity networks (IEA, 2020). This was one of the most severe cyclones ever to hit the east coast of Africa, striking Madagascar, Malawi, Mozambique and Zimbabwe with strong winds, severe flooding and associated landfall. Over 900 people died – the greatest loss of life in a southern hemisphere tropical cyclone in the last 100 years (WMO, 2020).

In Malawi, two major hydropower plants, Nkula and Kapichira, were damaged by flooding and excessive debris. They were forced to go offline, reducing Malawi's hydropower capacity by more than 80% and causing widespread disruptions in power supply across the country for several days (WMO, 2020). In Mozambique, 570 000 customers were affected and the cost of physical damage to the electricity infrastructure amounted to more than USD 133 million (ILO, 2019).

The adverse impacts of Tropical Cyclone Idai cascaded into other countries connected through the Southern African Power Pool. It destroyed pylons that supported the 1400-km transmission line between Mozambique and South Africa. This interrupted the electricity supply in South Africa, which relied on electricity imported from the 2 075 MW Cahora Bassa hydropower plant in Mozambique. It created a loss of 1 100 MW of power, and forced Eskom, South Africa's electricity utility, to load-shed for weeks.

At the height of the crisis, South Africans had their power interrupted 12 times in a four-day period. As a result of the interrupted electricity supply from the central grids, electricity demand patterns in South Africa changed dramatically. Demand for diesel jumped as the disruption drove more people to use back-up generators (Council on Foreign Relations, 2019).

This shows how the effects of extreme weather events can cascade into an adjacent country that has not been touched directly by those events. South Africa, which was not hit initially by Tropical Cyclone Idai, was forced to ration its power. It also signals that interconnected electricity networks need to build resilience against climate-driven disruptions and integrate long-term adaptation, while considering potential cross-border impacts of these actions.

Climate projections indicate that the number of intense tropical cyclones at the level of Idai is likely to increase in the future as warmer air and sea-surface temperatures will make more energy available for more cyclones and more rain (WMO, 2020). In 2019, 13 cyclones out of 18 reached hurricane intensity in the South Indian Ocean basin, equalling the largest number on record (IEA, 2020). The projected increase in the frequency of high-intensity tropical cyclones requires countries to adapt to and prepare for future climate impacts on their energy systems and build systems that are more resilient. Coupled with rising sea levels, the high-speed winds of tropical cyclones also present challenges, such as storm surges and inland flooding in low-lying cities. Indeed, Beira, a coastal city in Mozambique, was devastated by Tropical Cyclone Idai as a result of a storm surge of more than 4 metres (Nuki, 2019).

To prevent similar cases in the future, countries in Southern Africa have implemented measures to enhance the resilience of their electricity systems. The transmission lines from Cahora Bassa in Mozambique to South Africa were reinforced after the cyclone. The African Development Bank gave Mozambique a loan to rehabilitate damaged power lines and replace wooden posts with metallic structures on concrete bases to improve the adaptability and resilience of the network (Club of Mozambique, 2022). Thanks to these efforts, tropical cyclones in 2021 and 2022 had relatively minor impacts on the transmission lines. While there were some localized outages, there were no major disruptions to the cross-border transmission line (SA News, 2021).

First, improving adaptation and resilience generally requires high upfront costs, and the return on investments tends to become tangible only after some years or even decades. Second, electricity grid operators bear only a fraction of the entire social cost, while the impacts of disrupted electricity supply have large socioeconomic costs that are spread right across society. Third, monopolistic market conditions in some places could discourage operators from investing in resilience building (IEA, 2021a). It is, therefore, the job of policymakers to collaborate with businesses and encourage them to establish resilient power systems by adopting effective policy measures that can prevent potential "market failure".

The first step is to mainstream adaptation and resilience in national climate and energy plans. Many countries have already made progress in incorporating adaptation and resilience in their national policies, including over 75% of IEA member and association countries (IEA, 2021a). However, some countries continue to overlook energy adaptation and resilience. Incorporating adaptation aspects into national energy strategies and plans could raise awareness of the importance of climate resilience in the energy sector. Governments can then build policy frameworks that include not only planning but also implementation, monitoring and review.

In the UK, for example, a nationwide climate risk assessment, the National Adaptation Programme, is conducted every five years, the National Adaptation Committee monitors progress on implementation, and electricity grid operators are asked to report on the projected impacts of climate change and their potential management (UK government, 2020). These reporting requirements help the Government better understand the energy sector's exposure to climate change.

In addition to domestic policies, interconnected electricity networks require international cooperation to address transboundary climate risks. International entities can coordinate the actions of their member countries and help to enhance electricity security against the increasing threat of climate hazards. In Europe, for example, the European Network of Transmission System Operators for Electricity (ENTSO-E) runs the Steering Group System Resilience, providing guidance and expertise to improve the security of critical infrastructure and to develop risk preparedness plans, methodologies and procedures against natural hazards (ENTSO-E, n.d.). ENTSO-E's research and guidance also support the establishment of regulations by the European Commission, which sets policies and regulations for trans-European networks.

International organizations can also support cross-border collaboration by providing technical assessments of climate impacts on the energy system, and help governments and businesses mainstream climate consideration in their energy planning. The IEA, for example, has assessed climate change impacts on hydropower generation in Africa, and showed how interconnected networks across African sub-regions could help hydropower plants adapt to climate change impacts and enhance system resilience. According to the assessment, a projected decrease in hydropower capacity factors in North Africa and the Zambezi Basin could be compensated, to some extent, by an increase in capacity in the Nile Basin if the grid interconnection is designed properly and accessible by vulnerable people (IEA, 2020).

"In addition to domestic policies, interconnected electricity networks require international cooperation to address transboundary climate risks."

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Chapter 2.6

Transboundary climate risks and finance

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Financial risks triggered by climate change can become transboundary as a result of the global nature of investments and the complexity of economic and financial networks.

- Losses from hazards that hit a firm's productive plants in one geographic area could cascade across economic value chains and materialize in the portfolio of an investor located far away from the original disaster.
- Climate financial risk assessment is a first step to informing investment decisions on climate change mitigation and adaptation, that can help to promote financial stability, particularly given the interconnectedness and interdependencies of financial actors.
- In a context of increasing and compounding climate risks, direct foreign investment could help to build the conditions to attract long-term capital, and to create bankable adaptation projects.
- It is, however, crucial that climate risk is not transferred entirely to those least able to bear it: the most climate-vulnerable countries with no fiscal space to invest in adaptation.

Overview

The implications of climate change for finance have been analysed mostly at the country level. There is, however, a growing focus on the transboundary climate risks for financial institutions that could affect financial stability at the regional and global level. For example, losses from a climate hazard that hits a firm's productive plants and economic activities in one geographic area could cascade across value chains, and materialize in the portfolio of an investor located far away from the original disaster. Financial losses could, in turn, cascade from the portfolio of one investor to other investors through their holdings of financial contracts and securities. Such losses could be amplified through reverberation in the financial network, with potential implications on financial stability at the level of individual institutions, and for the global financial system.

This chapter presents the transmission channels of transboundary climate risks to finance. It analyses the direct, indirect and cascading impacts of transboundary climate risks to financial institutions and sovereign investors (state-owned investment funds or entities), and the finance-economy feedbacks.

Introduction

The exposure of financial actors (e.g. banks, insurance firms, pension funds, investment funds) to climate physical risks can be geographically confined and localized to a specific country or region. Consider, for example, the case of home insurance, or a regional bank that lends to local firms. However, financial risks triggered by climate change can become transboundary as a result of the global nature of investments (Carter et al., 2021) meaning that they can affect investors that are located far away from the initial point of impact of a climate hazard (Bressan et al., 2022). Transboundary climate risks could materialize, for example, for investment funds headquartered in the European Union that have invested in the sovereign bonds of a country hit by a hurricane, which affects that country's economy and gross domestic product (GDP).

Another example is the case of a bank headquartered in the United States that invests in manufacturing firms that produce automotive parts and electronics in northern Mexico – a region affected by floods and water stress. Heavy floods decrease the productive capacity of these Mexican firms, cascading to the local and regional economy, to local financial actors (e.g., Mexican banks who lent to the firms), and spreading to global value chains (e.g., firms that use the intermediary goods produced and traded by the Mexican firms). The shock would eventually reach the US bank, by reducing the value of the firms' equity shares or corporate bonds the US bank invested in. Given that US banks are highly interconnected

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to other financial actors, including at the global scale, the losses from the balance sheets of that bank could cascade to other financial actors (e.g., via the interbank network).

Characterization of the transboundary climate risk

Climate change risks are expected to have a global, yet spatially heterogeneous impact on socioeconomic development. The frequency and intensity of extreme weather events is expected to intensify in all climate scenarios (IPCC, 2021), leading to increases in both mitigation and adaptation costs, and in supply chain disruptions.

Central banks and financial supervisors (CBFS) have recognized the relevance of climate risks for macroeconomic performance and financial stability (BIS, 2021; Carney, 2015; NGFS, 2019). Over 120 CBFS have joined the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), which aims to foster climate-financial risk disclosure and financial risk assessment.

Physical climate hazards have a negative effect on the performance of firms that own plants in vulnerable areas and that do not employ adaptation measures to build resilience to such risks. These climate-related losses could have financial implications by increasing the yields of the sovereign bonds of countries affected by the shock (Beirne et al., 2021), and affecting the portfolios of investors who hold such bonds (Bressan et al., 2022). Overall, physical climate hazards entail "fundamental economic disruptions, endanger food security, and undermine public health, with ripple effects on poverty and inequality, displacement, and conflict" according to a study by the International Monetary Fund (IMF) in the Middle East and Central Asia region (Duenwald et al., 2022) [Chapter 2.3].

The importance of disclosing and assessing climate-related financial risks has been also recognized by international financial initiatives (e.g. UN NetZero Assets Owners Alliance, and the Science Based Targets Initiative), consulting firms and major data providers (e.g. Bloomberg NEF, Refinitiv Eikon, S&P Global Trucost). Growing investors' consideration of climate risks is influenced by a potential lack of insurance and hedging products, and by the lack of systematic adaptation plans and their implementation.

Poor adaptation is a common feature across all economies: emerging markets, developing economies and developed economies. Investing in adaptation is a challenge for private investors and insurers, given the long-term nature of most adaptation investments, and for governments emerging from years of economic downturns caused by the Covid-19 pandemic, and dealing with the consequences of geopolitical tensions, including high prices for food and energy commodities. Furthermore, in emerging markets and developing economies that are vulnerable to climate hazards, governments with tight budget constraints, and little and costly access to international markets, face trade-offs between investment in mitigation and adaptation. To address these barriers, development finance institutions have, however, started to expand their investment plans for adaptation (e.g. the European Investment Bank's Adaptation Plan (EIB, 2021) and the World Bank (Tall & Brandon, 2019)).

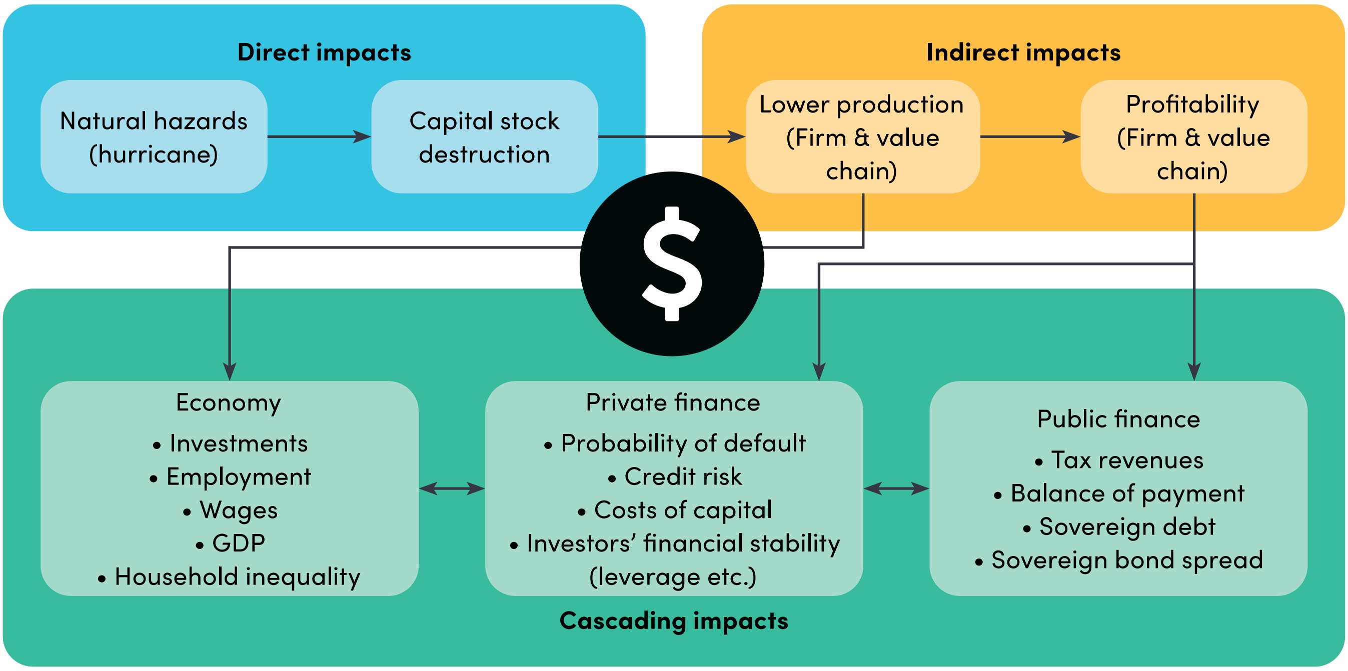
> "The importance of disclosing and assessing climate-related financial risks has been also recognized by international financial initiatives."

Transboundary climate risks could materialize in, for example, foreign direct investment (FDI) (i.e. investments associated with a resident in one economy having control or significant influence over the management of an enterprise in another economy). They could also manifest themselves through cross-border portfolio investments (i.e. the purchase of financial securities by investors from another country). According to the IMF Coordinated Direct Investment Survey and Coordinated Portfolio Investment Survey (IMF, 2018a; IMF, 2018b), the investments by the EU27 countries in both categories are highly concentrated in the North and Central American region. In 2018, this region accounted for 39% of the EU27 USD 10 trillion in FDI (mainly held in financial services, manufacturing and telecommunications sector) and 44% of the EU27 USD 9.8 trillion in portfolio investment. While the holdings of firms (e.g., machinery manufacturers) in their subsidiaries abroad account for a major share of this FDI, the EU financial sector is exposed to transboundary climate risks through its portfolio investments because the main investors in financial securities abroad are financial institutions (West et al., 2021).

Investors' exposure to transboundary climate risks is related to *the geographic location* of the productive plants belonging to the firms in which they have invested, via financial contracts and securities; *the exposure* and the *vulnerability* of such plants to climate risks; the relevance of the plants for the *revenues* of the firm; and the productive characteristics of plants and presence of *adaptation* [Chapter 2.4].

Consider, for example, a firm located in a non-European country that is vulnerable to hurricanes. To finance its activities, the firm issued bonds, which were bought by an EU financial institution (e.g. a pension fund). The firm's plants in the areas hit by a hurricane will experience capital and production losses, depending on the hurricane's strength and whether adaptation measures are in place. Depending on the importance of these plants for the firm's business, the firm owning them could face losses to such an extent that it increases the firm's probability of default.

Figure 10. Transboundary climate risk transmission channels to the economy and finance



Notes: The figure considers direct, indirect and cascading impact. It reports an example of hurricanes impacting firms that have productive plants (e.g. automotive parts, electronics) and are connected both to the economic value chain via supply of components, and to international financial markets via issuance of equity and bonds.

Source: Adapted from Gourdel et al. (2022).

An increase in the probability of default of the firm that has issued the bond is reflected in its credit rating and leads to a decrease in the expected value of its bonds, which has, in turn, a negative effect on the value of the investor's portfolio and its risk profile. If the investor is highly leveraged and interconnected with other financial institutions, losses can reverberate through the ownership chains to endanger the financial position of other investors. For example, if the investor is also an intermediary that issues securities, such as bonds and equity, or is involved in interbank loans, the original shock can propagate to other institutions and contribute to systemic risk (Battiston et al., 2012). Thus, in the financial network, losses resulting from transboundary climate risks can be amplified and impair financial stability.

Economic losses could also occur for firms in the value chain that import and transform the goods produced by the plants originally hit by the hurricane, which can suffer production blocks as a result of the shock. If these firms have issued securities or subscribed loans, a worsening of their economic performance would be reflected in a negative adjustment in the value of their securities and ability to repay the loans. The compounding of climate hazards, such as droughts followed by floods, could amplify these economic losses (Dunz et al., 2021).

Figure 10 presents the transmission channels of transboundary climate risks (acute), considering direct, indirect and cascading impacts to the economy, the sovereign and global investors.

Critical reflections on existing policy tools and their limitations

Climate financial risk assessment is crucial to inform investment decisions on climate change mitigation and adaptation, particularly given the interconnectedness and the interdependencies of global financial markets. Standardized disclosure of climate-relevant information is fundamental for risk assessment and for the effective identification of the direct and indirect impacts of transboundary climate risks on finance.

The importance of climate-related risks has been recognized by the Task Force on Climate-Related Financial Disclosures (TCFD), created by the Financial Stability Board (FSB),[2] which has developed recommendations for standardized climate-related corporate disclosure (TCFD, 2017). However, the transboundary dimension is not yet addressed, and there is continued potential for cascading risks and implications for cross-border investments and FDI.

Following the recommendations of the TCFD, several regulators have introduced guidelines on the disclosure of climate-related information for (large) companies (e.g.

2 The FSB is an international body that monitors and makes recommendations about the global financial system (https://www.fsb.org/about/). See also FSB (2020).

Box 7. Case study:
A hurricane in Mexico: a transboundary climate risk for investors and companies in Europe

The case of financial relations between European investors and companies that have physical assets (e.g. production and energy plants, mines) in Mexico illustrates the complexity of assessing transboundary climate risks. Bressan et al. (2022) analysed by how much the financial valuation of financial securities (in this case, equity) issued by firms with assets in Mexico and that are owned by financial actors (e.g. banks, investment funds, pension funds) headquartered in Europe should adjust to reflect the assets' exposure to climate hazards.

The impacts of scenarios of chronic and acute shocks are analysed at geolocalized asset level. Climate shocks on assets are translated into economic losses via damage functions. Firms' losses are then translated into indirect macroeconomic impacts at the sectoral level, in terms of adjustments in firms' revenues and the probability of default, and from here into adjustments in the financial valuation of equity contracts of the firm that owns the plants. The adjustment in the valuation of the equity price is then translated into adjustments in financial risk metrics of the investor who holds such stocks, such as the quantile-based climate value at risk that quantifies the potential losses in the tail of the distribution.

A counterfactual analysis that does not consider the shock on the individual assets of a firm but approximates it by using the locations of companies' headquarters, can lead to a relative underestimation of investor portfolio losses by up to 56.27%. This highlights the need to use firms' asset-level information to identify the relative importance of climate-related shocks for climate mitigation and adaptation projects financed by European investors but located far from Europe. An inaccurate estimation of risk caused by overlooking the asset-level nature of climate risks results in potentially incoherent investment decisions of companies and financial actors, and the misallocation of funds.

Further losses could be induced by mispricing the contract in a network of leveraged financial actors, which can be analysed with financial networks and integrated into climate stress tests (Battiston et al., 2017). A climate stress test makes it possible to analyse "how bad it can get" for an investor (e.g. banks) in terms of a given scenario combined with the initial financial characteristics of that investor (e.g. leverage or its share of risky assets). It can also explore the "whys", i.e. the risk transmission channels from firms' assets to the balance sheet of banks. Further, climate stress tests allow for assessing the conditions that enable financial institutions to absorb or amplify climate risks.

In terms of macroeconomic effects, climate hazards generally deliver a supply shock to the economy (Ranger et al., 2022). Tropical cyclones, for example, affect the economy by destroying firms' productive capital and disrupting production. This is a direct impact, because capital is an input factor for firms, and the climate shock limits their ability to serve demand. Then, since firms in the real world cannot fully substitute capital in the short run, they start to lay people off. Unemployment rises, household incomes and consumption levels go down, and real GDP falls.[3] Lower real GDP leads to lower tax revenues and increases the government's deficit and the need for more external financing (e.g. by issuing sovereign bonds). This, in turn, increases public debt (Dunz et al., 2021).

As a result, the sovereign cost of borrowing on international capital markets increases, reducing the government's fiscal space and its ability to react to future climate-related crises. Figure 11 provides a schematic representation of the cascading risks induced by climate hazards (in this case, tropical cyclones) hitting Mexico. The effects for the Mexican economy, private and public finance sectors, and European investors' portfolios are depicted.

EU,[4] UK,[5] and US[6]). Data on climate-risk disclosure by companies is, in turn, important for climate-risk disclosure by financial institutions. In January 2022, the European Banking Authority (EBA) presented its draft implementing technical standards on disclosure requirements for environmental, social and governance risks for large credit institutions whose securities trade on EU capital markets. However, regulations usually apply to large companies only, and overlook small and medium enterprises, leaving room for corporate manipulations and a shift of polluting assets and projects to smaller subsidiaries. Further, the overall quality of information available, particularly on the physical assets of companies, is poor. Many studies use proxy geolocations (e.g., the country of a company's headquarters rather than the precise locations of its assets), which leads to an underestimation of economic and financial shocks.

Nevertheless, trade-offs may emerge between climate risk assessment and access to climate finance, particularly finance that has transboundary effects. Several low-income countries that are highly vulnerable to climate risks could face increasing challenges to access international capital markets to finance climate change mitigation and adaptation investments. In these countries,

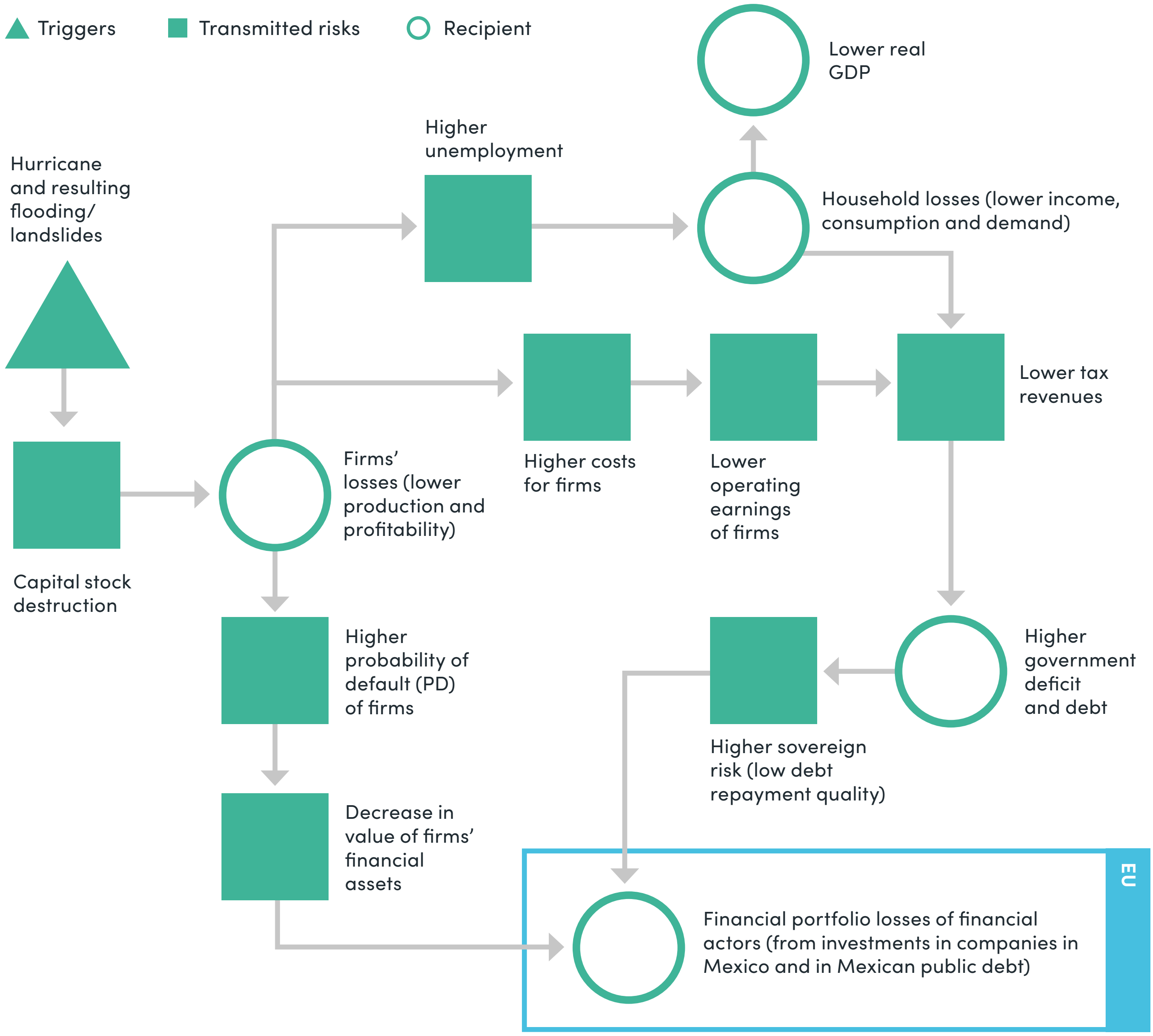
3 Note that climate hazards have different impacts for different sectors. This allows some sectors to use their unused capacity and serve the increased demand for investment.

4 https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/corporate-disclosure-climate-related-information_en

5 https://www.gov.uk/government/news/uk-to-enshrine-mandatory-climate-disclosures-for-largest-companies-in-law

6 https://www.sec.gov/news/press-release/2022-46

Figure 11. Cascading climate physical risk to the European financial system



Notes: The figure illustrates how impacts from climate hazards (in this case, hurricanes) that hit non-European countries (Mexico) can cascade to European private investors and sovereigns, via economic and financial transmission channels.

Source: Adapted from Dunz et al. (2021).

climate-related economic losses would affect the bankability of the affected firms on the one hand, and public finance and debt sustainability on the other, challenging access to international finance.

If, for example, a country is considered to be a higher risk by markets because it is exposed to climate risks, its cost of borrowing (i.e. the interest rate) will be higher and even unaffordable. Indeed, some investors may be discouraged from investing or may want to increase the cost of capital. As a result, adaptation investments may not take place in countries where there is already little or no fiscal space. However, there will always be investors who decide to increase their exposures to such countries for diversification purposes.

Blended finance, described as a "strategic use of development finance for the mobilization of additional finance towards sustainable development in developing countries",[7] is one of the most debated transboundary financial risk management mechanisms. Blended finance aims to de-risk climate projects in emerging markets and developing economies that would otherwise be seen as unbankable, and would not be financed. Nevertheless, blended finance might not always work as smoothly as expected in terms of achieving adaptation investment goals.

7 https://www.oecd.org/dac/financing-sustainable-development/blended-finance-principles/

Blending does not necessarily support the poorest countries and often focuses on the most profitable sectors in an economy, leaving behind the activities most vulnerable to climate disasters (Pereira, 2017). Only 6% of private finance mobilized by the interventions of development finance institutions between 2012 and 2018 went to the least-developed countries. In addition, private investments mobilized in these countries are concentrated in just a few revenue-generating sectors, such as banking, energy and financial services, while vulnerable yet crucial sectors, such as energy, sanitation and water services, receive less finance (OECD & UNCDF, 2020).

Even if projects are financed, blended finance could create new challenges for public finances when local governments take the risky share of the investment, and contribute indirectly to transboundary climate risks for financial systems in developed (i.e. investor) countries. Many of the least-developed countries have public finances that are already very fragile, as well as a history of sovereign defaults, and they simply do not have the fiscal space to assume additional risk.

In the context of increasing and compounding climate risks, FDI could help to build the conditions needed to attract long-term capital and create bankable adaptation project pipelines, ensuring the fair sharing of risks and benefits between governments and the private investors. In particular, it is vital that the risk is not transferred entirely to those who cannot bear it: the most climate-vulnerable and inadequately prepared countries (Blended Finance Taskforce, 2018).

De-risking instruments could complement transboundary climate risk finance in the implementation of long-term and coherent economic policies at the country level by decreasing uncertainty, and by affecting investors' expectations. This, in turn, would require an adjustment in the policies of the Group of Twenty (G20), the Intergovernmental Group of Twenty-Four (G24) and the Vulnerable Twenty Group (V20), entailing a major scale-up of both policy ambition and coherence.

"Many of the least-developed countries have public finances that are already very fragile, as well as a history of sovereign defaults, and they simply do not have the fiscal space to assume additional risk."

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Chapter 2.7

The transboundary climate risk of infectious diseases

Kristine Belesova[1]

As weather parameters shift under climate change, the geographical distribution, prevalence and emergence of infectious diseases is also changing and shifting across geographical boundaries to trigger transboundary climate risks.

- Climate change has already influenced the spread of vector-borne infectious diseases over the past decade and it seems certain to increase the health impacts of climate-sensitive diseases significantly.
- Projections show that under a scenario of 2.8°C warming, 50% of the global population will be exposed to malaria vectors by 2050. In addition, an estimated 2.7 billion people could be exposed to temperatures suitable for Zika virus transmission by 2050 in the event of high global warming.
- While many responses are implemented locally and within national boundaries, some responses aim to prevent the spread of transboundary diseases. Integrated climate-informed disease surveillance and early warning response systems can anticipate risks and trigger prompt action.
- The benefits of adaptation to the climate-induced risks of infectious diseases include health system strengthening and knowledge transfer to enhance response capacities to climate risks, as well as other emergencies.

Overview

Changes in the spread of infectious diseases are projected to be among the transboundary climate risks with the greatest impact. The main climate-sensitive infectious diseases include vector-borne malaria and dengue, food-borne salmonellosis, and water-borne Vibrio cholera. The drivers of their spread are complex and interconnected. However, climate change impacts on their spread can be fast-tracked exponentially by travel and tourism, global trade, and other changes in natural and human environments. This chapter shows how climate change impacts the spread of infectious diseases through propagation and their distribution through geographical and social patterns of impacts to constitute a transboundary climate risk. It also explores the responses (anticipatory and reactive) from national to international levels, and the opportunities for further strengthening.

Introduction

Many infectious diseases, such as malaria, dengue, Zika virus, Tick-Borne Encephalitis and salmonellosis are sensitive to climate change. Together, these five diseases caused over 290 million cases of infection worldwide in 2019 (Vos et al., 2020). Infectious diseases can be spread directly from person to person (e.g. through droplets or direct contact), through an intermediary vector organism (e.g. a mosquito or sandfly) and through environmental mediums (e.g. soil, water or food). Because vector organisms (e.g. mosquitos, sandflies or ticks) and infectious agents (e.g. viruses or bacteria) cannot control their own temperature, their survival and reproduction depend on local environmental conditions – temperature, precipitation, sunlight, wind and elevation above sea level. As weather parameters shift under climate change, the geographical distribution, prevalence and emergence of infectious diseases is also changing and shifting across geographical boundaries to trigger transboundary climate risks.

Multiple non-climate factors modify these changes to make some individuals and communities more vulnerable to climate-sensitive infectious diseases and their propagation across borders (Marmot, 2005). These include baseline health status, the coverage and quality of healthcare systems, hygiene practices, transportation, human migration and other behaviours, drug resistance, nutrition and environmental influences that affect vector and pathogen habitats and their interaction with people, such as agricultural development, deforestation, urbanization and water projects.

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Characterization of the transboundary climate risk

Current impacts

A mass of evidence demonstrates how changes in weather and climate have already influenced the spread of vector-borne infectious diseases over the past decade. Changes in temperature, relative humidity and rainfall have been linked to the spread of West Nile fever in south-eastern Europe and increases in the spread of dengue in India, Indonesia, Jordan, the Philippines, Thailand, Timor-Leste and the US, expanding its historical spread to new countries (Cissé et al., 2022).

In highland areas, such as those in Colombia and Ethiopia, malaria is shifting to higher altitudes as rising temperatures at these altitudes create more favourable conditions for its vectors. Climate change has also contributed to the spread of Lyme disease in higher latitudes and elevations in North America and Europe; Tick-Borne Encephalitis in higher latitudes and elevations in Europe; and the emergence of chikungunya virus in Latin America and the Caribbean, and its outbreaks in Italy and elsewhere in Europe (Cissé et al., 2022).

In areas that lack water, sanitation and hygiene, heavy rainfall, flooding, high temperatures and droughts are linked to an increased risk of diarrhoeal and other water-borne diseases. Yet, such risks also exist in high-income settings, including the UK, the US, Scandinavia and Canada. Food-borne diseases, e.g., Salmonella, have also been linked to higher air and water temperatures and longer summers in Australia, China, Hong Kong, New Zealand, Singapore, South Korea and the UK. In New York City, US, every 1°C increase in temperature has been correlated with a 0.70–0.96% increase in daily hospitalizations for gastro-intestinal infections (Cissé et al., 2022).

Dynamics of spread

The dynamics of climate-sensitive infectious disease spread are also influenced by El Niño – the unusual warming of surface waters in the eastern tropical Pacific Ocean. The subsequent warming of air temperatures in this area has been associated with increased dengue incidence, for example in Colombia. El Niño also triggers changes in temperatures and precipitation in other regions, for example in parts of Africa, and such changes have been linked to increased cases and outbreaks of cholera (Cissé et al., 2022).

The importation of climate-sensitive infectious diseases through travel and tourism or global trade also alters the dynamics of their spread with climate change [Chapter 2.8]. There are local malaria outbreaks every year as a result of the importation of malaria into areas where malaria has been eradicated, including Europe (Cissé et al., 2022; Semenza et al., 2016). While the risk of its re-establishment in Europe remains low, in areas with more suitable climates and weaker health systems and sanitation, (re)importation of climate-sensitive diseases can lead to new epidemics, with possible cascading effects at national and then regional scales.

"It seems certain that the health impacts of climate-sensitive diseases will increase significantly as a result of climate change."

Environmental influences that impact vector and pathogen habitats and interaction with humans, such as agricultural development, deforestation, urbanization, and water-related projects, can also alter the dynamics of climate-sensitive infectious disease spread. This facilitates outbreaks and epidemics, as well as cross-border dynamics.

Future risks

It seems certain that the health impacts of climate-sensitive diseases will increase significantly as a result of climate change (Cissé et al., 2022). Climate-sensitive infectious diseases are projected to expand their geographical range and affect more people [Figure 12]. It is projected that under 2.8°C warming by the end of this century, 50% of the global population will be exposed to malaria vectors by 2050 (Kraemer et al., 2019). There will be disparities by region, however, with an additional 76 million people facing endemic risk of malaria by the 2080s in Southern and Eastern Africa, while there will be no climate change effect in West Africa or even a small net reduction (Cissé et al., 2022).

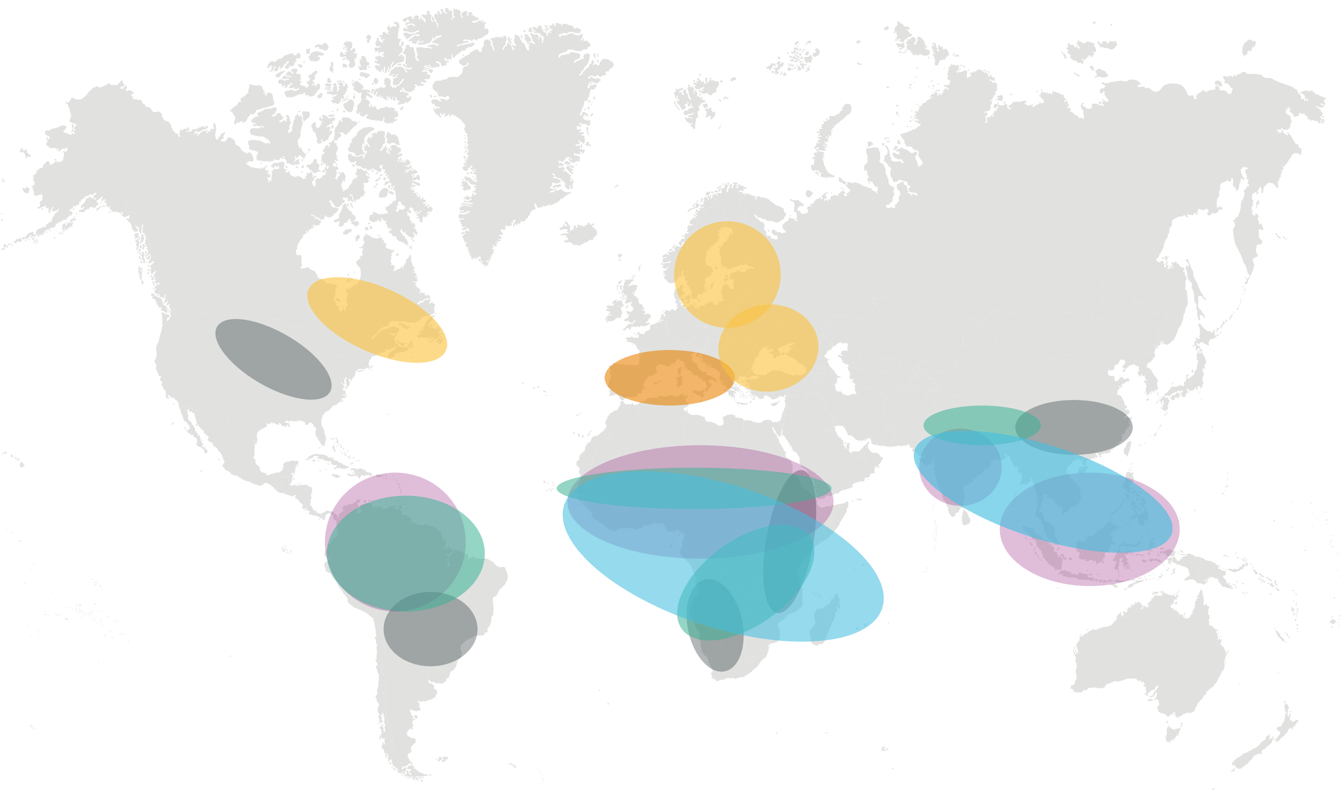
The risk of dengue is also projected to increase across all continents and cross many boundaries, for example from southern to north-central Mexico and to mid-western regions of the US (Proestos et al., 2015). In China, dengue exposure under a scenario of 4.3°C warming would increase the exposed population from 168 million people in 142 counties to 490 million people in 456 counties by the end of the 2100s (Fan & Lui, 2019).

The distribution of schistosomiasis is projected to change with climate change, with an increased risk of infection in most of Eastern Africa, except for northern and eastern Kenya, southern Sudan, and eastern Democratic Republic of Congo, where the risk is projected to decline (McCreesh et al., 2015). Yet, the risk factors for water- and food-borne diseases are highly dependent on future socioeconomic development, human activities and adaptation efforts (Cissé et al., 2022).

Responses and adaptation

The responses to the growing risk of climate-sensitive infectious diseases can be classified as reactive or anticipatory.

Figure 12. Hotspots of climate-sensitive infectious disease risk and other climate-health risks



Source: Rocklöv et al. (2021).

Reactive responses are implemented to contain or suppress a disease transmission or outbreak that is already under way. Examples include integrated case management to improve and coordinate patient care, integrated vector control management to reduce or interrupt transmission (e.g., spraying with insecticides) and the provision of insecticidal bed nets.

Anticipatory responses are implemented proactively to prevent and minimize the risk of disease. Examples include: enhanced disease surveillance; early warning systems to identify potential outbreaks with seasonal and – for some diseases – even decadal time scales; strengthening health system capacity; vaccination; and raising awareness about self-protection practices. For food-borne and water-borne diseases, anticipatory practices also include improved water, sanitation and hygiene conditions, and for food-borne diseases particularly, improved food processing and preservation as well as enhanced storage and cold chains (Cissé et al., 2022) [Chapter 2.3]. Anticipatory responses for vector-borne diseases also include housing improvements to keep vectors out, such as closing eaves and installing mosquito screens (Lindsay et al., 2003). Climate-sensitive infection control strategies often include both anticipatory and reactive response strategies implemented sequentially in a complementary manner.

While many responses are implemented locally and within national boundaries, some responses aim to prevent cross-border disease spread. After its elimination of malaria in 2021, China developed a strategy in collaboration with neighbouring countries to prevent re-importation of malaria (Xu et al., 2021). This focused on the 2.5 km (the distance that can be travelled by the malaria-bearing mosquito species) internal perimeter of China's border to provide intensive vector surveillance, pathogen detection and reactive responses to detected cases. China, Laos, Myanmar and Viet Nam also agreed to strengthen their vector control, which helped to achieve low incidence of malaria in northern Laos and Viet Nam (Xu et al., 2021).

Another example of cross-border response is the development of the European Environment and Epidemiology (E3) Network by the European Centre for Disease Prevention

Box 8. Case study:
Zika virus and transboundary climate risks

Zika is an emerging mosquito-borne virus that tends to be symptomatic in only 20% of infected people. In most cases, the symptoms are mild: a rash, fever and joint stiffness. However, the infection of women at certain stages of pregnancy can lead to microcephaly – a neurological condition where a baby's head is much smaller than expected. This is often caused by abnormal brain development and has high social and human costs (Caminade et al., 2017).

Zika virus was first discovered in monkeys in Zika forest, Uganda, in 1947 and later identified in local mosquitos (Gubler et al., 2017). It was first identified in humans in 1954 in Nigeria, with symptomatic infections historically limited to sporadic cases or small clusters (Gubler et al., 2017). The first major outbreak occurred in 2007 in the Federal States of Micronesia followed by French Polynesia, Cook Islands, Easter Island, New Caledonia, and, most recently, in the Americas with importations into Europe (Plourde & Bloch, 2016). Since 2013, Zika has spread to >49 countries and territories (Ryan et al., 2021). Its largest outbreak in the Americas in 2015/16 resulted in up to 1.3 million infections and 4180 cases of microcephaly in Brazil by the end of 2015 alone (Bogoch et al., 2016; Teixeira et al., 2016).

Zika is thought to have been introduced into the Americas through air travel from French Polynesia to Brazil and vectored by the local Aedes mosquito (Baker et al., 2022). The outbreaks in the Pacific in 2007 and South America in 2015/16 followed record high temperatures and severe droughts (Cissé et al., 2022). Research found that the warm temperatures caused by the combination of the El Niño and continuous global warming enhanced the transmission of Zika virus in South America in 2015 by increasing the rates of mosquito bites, lowering mosquito mortality rates, and shortening the incubation period (Caminade et al., 2017).

Extreme El Niño events are projected to increase even under a 1.5°C of warming (Rao et al., 2019). Estimates suggest that 2.7 billion people worldwide are likely to be exposed to temperatures suitable for Zika virus transmission by 2050 in the worst-case scenario of high warming combined with continued changes in population trajectories (Ryan et al., 2021).

As the 2015/16 Zika outbreak evolved, a range of transboundary responses were mounted. The World Health Organization (WHO) and the Pan American Health Organization (PAHO) issued regular reports, guidelines and recommendations on managing the outbreak locally, regionally and internationally (Chang et al., 2016). Brazil and its neighbours urged women of childbearing age to delay pregnancy until the outbreak was under control (Chang et al., 2016). Unaffected countries issued travel alerts advising pregnant women against travelling to the affected countries (Saiz et al., 2017). WHO advised the unaffected countries with vectors that could spread the disease to disinfect airplanes (Saiz et al., 2017).

On 1 February 2016, WHO declared Zika virus a Public Health Emergency of International Concern (Chang et al., 2016). International and regional health authorities such as WHO and PAHO worked with the governments of the affected countries to develop response strategies, and deliver critical support (WHO, 2016). WHO also coordinated global and regional responses (WHO, 2016). Assistance was also provided by inter-governmental initiatives, and by NGOs (Lucey, 2016). In all, over 60 partners were engaged in the global response, and the UN Secretary-General established the UN Zika Response MultiPartner Trust Fund (WHO, 2022).

The transboundary global, regional and national response was recognized, yet many opportunities throughout the response were missed leaving a sizeable negative impact as a result of the emergency. The long-term adaptation measures that are urgently needed in the face of climate change and the likelihood of more outbreaks, such as early warning systems and vaccines for Zika virus, are still under development.

and Control (ECDC). This network monitors environmental conditions related to infectious disease threats and analyses the risks in Europe and beyond, such as environmental suitability for malaria in Greece and Vibrio species worldwide (Suk et al., 2014).

Critical reflections on existing policy tools and their limitations

Climate-sensitive disease risks can be managed reactively at the point of impact and through a range of anticipatory strategies that include surveillance and early warning systems. Many of these responses require collective and coordinated action, such as raising funds and sharing technical expertise to support outbreak response in countries with limited response capacity. Research collaboration and open sharing of information are essential, particularly when new diseases emerge, to develop effective response strategies, medications and vaccines.

Actors at the national level, such as the US Centres for Disease Control and Prevention (CDC), monitor disease cases and issue relevant policies, develop programmes, and advise the public and relevant stakeholders within national boundaries. Regional disease risks trigger responses by regional actors, such as PAHO and ECDC, which coordinate responses at regional level and assist the most affected countries. Where the risk reaches international level, actors such as WHO, further assist with international coordination of the response, expertise and capacity strengthening in the countries that require support. The success of such adaptation responses are often influenced by adaptation responses to other climate change impacts, such as migration and underlying health status.

Such international coordination falls under the International Health Regulations (IHR) of 2005 – a legally binding agreement of 196 countries to build the capability to detect and report potential public health emergencies worldwide (WHO, 2016). The IHR require that all countries have the ability to detect, assess, report and respond to public health events (WHO, 2016). However, only one-third of countries currently have these capacities – a major barrier to compliance with the regulations (CDC, 2022). Therefore, agencies such as WHO, PAHO, CDC, and international NGOs are providing assistance.

In some cases, new inter-state collaborations aim to address gaps in cross-border cooperation. The Middle East Consortium for Infectious Disease Surveillance (MECIDS) was formed in response to the IHR to improve laboratory capacity and infectious disease control across Israel, Jordan and the Palestinian National Authority. This helped to address the limited opportunity for a dialogue among these countries through WHO, as Israel fell into WHO's European Region while the other two were in its Eastern Mediterranean region (Torjesen, 2020). MECIDS created a new channel for communication, surveillance and rapid response to infectious disease risks, including the establishment of surveillance systems for food- and vector-borne diseases, capacity building and networking for epidemiologists and laboratory experts. The Connecting Organisations for Regional Disease Surveillance (an NGO aiming to stop pandemics) enabled the replication of the MECIDS model in other regions with political tensions and conflict, including Africa, Asia and the Balkans. Similar initiatives include the World Bank-sponsored African Centre for Disease Control and Prevention, which could be replicated in the Middle East and North Africa (Torjesen, 2020).

While climate change poses an additional threat to infectious disease spread and outbreaks, there are specialized responses that can be developed and implemented. For example, integrated climate-informed disease surveillance and early warning response systems can anticipate risks and trigger measures to avoid or reduce impact and prepare an effective response. Such systems can

Climate change can shift the spread of infectious diseases across borders, calling for more cooperation on adaptation in the health sector.

help build adaptive capacity and climate-resilient health systems. The early warning lead time ranges from 1-10 days where predictions are based on short-term weather forecasts, 1-6 months when based on seasonal forecasts, to multi-decadal based on climate change projections and the frequency of El Niño events (Morin et al., 2018).

One example of an operational integrated disease early warning system is the Vibrio Map Viewer developed by the ECDC. This uses real-time data on sea surface temperature and the salinity of coastal waters to forecast the growth of pathogenic Vibrio species around the world with a five-day lead time (Morin et al., 2018). The forecasts are published in ECDC's *Communicable Disease Threat Reports* and shared with public health decision makers in Europe, who then have options for an appropriate response, including temporary restrictions to public beach access, safety alerts, and the notification of healthcare providers and at-risk populations (Morin et al., 2018).

Similar integrated early warning systems are being developed for other climate-sensitive infectious diseases including dengue, malaria, Zika, chikungunya, yellow fever and others (Hussain-Alkhateeb et al., 2021). In many cases, however, they are not yet operationalized or integrated in disease surveillance systems. Better understanding of the links between infectious diseases and climate parameters can also benefit decision making on the best long-term adaptation measures, including vaccine development and distribution, and funding to improve water, sanitation, hygiene, and food processing and preservation, as well as storage and cold chains.

The Global Framework on Climate Services (GFCS) provides advice on how to integrate climate information into health-sector activities at national level (GFCS, 2022). Similar frameworks should be established at the regional and international levels to address transboundary climate-sensitive disease risks. There is also a need for international scientific collaboration to fill research gaps on the links between climate change and infectious disease dynamics (particularly their transboundary dimensions), and to harmonize climate and health data across countries and regions (Hess et al., 2020) .

Increased funding is needed for research on international climate change and health, the application of a transdisciplinary and transboundary lens for the development of appropriate adaptation solutions, international cooperation to build capacity in data management and integrated surveillance, international leadership and appropriate transboundary decision making, and communication tools. All of these are essential to increase resilience and global capacity to adapt to climate-sensitive infectious disease risks (Hess et al., 2020).

Adaptation under all socioeconomic scenarios would have a significant impact on the global warming threshold at which health risks accelerate. An adaptation scenario that emphasizes international cooperation has the greatest potential to lower the risks under every scenario, with the exception of the highest level of global warming (Ebi et al., 2021) .

It is important, however, to assess any trade-offs and possible unintended consequences when designing climate change adaptation actions. Certain actions that help to adapt to some risks can exacerbate others. For example, increased household water storage in containers in response to a drought can attract mosquitoes, create new breeding sites and increase the risk of mosquito-borne diseases, while dam building in malaria-endemic areas can increase local malaria incidence (Cissé et al., 2022). Other negative consequences of responses to climate-sensitive disease risk may include the negative economic consequences of travel restrictions, and inequitable access to new vaccines and medication across countries. Yet, adaptation to these risks can also have wider co-benefits within and across national boundaries, including health system strengthening and knowledge transfer that would enhance the capacity to respond not only to climate risks but also other emergencies.

Finally, the examples used in this chapter also illustrate that timely climate change mitigation is part of the prevention of transboundary climate risks to human health. It will help to minimize future increases in infectious disease and other health risks, and, therefore, the induced cascading effects across borders. This adds to the urgent need for global cooperation on climate action.

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Chapter 2.8

Transboundary climate risk and human mobility

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Severe climate risks – such as the effects on access to resources (including on biodiversity) and on livelihoods (climate-sensitive activities), and in areas of conflict – are key emerging issues in the context of human mobility across borders, given global warming projections.

- Human mobility, especially across borders, is an important area of research to understand human pathways of transboundary climate risks. Climate and non-climate drivers interact and compound to influence and modify migration decisions, with impacts for both countries of origin and destination.
- The indirect cross-border effects of seasonal and temporary labour migration under a changing climate include cascading impacts on remittance flows, a financial pathway of transboundary climate risks.
- Understanding the dynamics of international labour migration under a changing climate is critical to identify the recipients of aggregated transboundary climate risks and to design appropriate policy and governance solutions. In particular, migrant workers and their families who participate in and rely on international labour markets and associated remittances are highly vulnerable because of the volatile impact of climate change on seasonal sectors and associated labour needs, and the decisions made by authorities at different scales about borders and labour migration rules.
- Policies and governance arrangements on seasonal migration and guest worker arrangements are integral to climate justice as part of transformative adaptation to climate change.

Overview

Human mobility has historic and traditional roots in how groups of people, such as nomads and pastoralists, live, or societies endure, and cope with changing environmental and socioeconomic conditions. Today, climate change is an increasingly powerful driver of mobility, combined with non-climatic factors (economic, social, political and demographic) (IPCC, 2022). There are several modes of human mobility, such as migration, displacement, relocation, tourism, education and study, and they all merit more research on the effects, both direct and indirect, that occur across borders as a result of a changing climate and adaptation decisions (Loiseleur et al., 2021).

This chapter focuses on migration via international labour markets and on temporary, seasonal or guest worker arrangements at the nexus of development and climate change adaptation. Specifically, it explores transboundary climate risks – the direct and indirect effects across borders from the regional to global scale – related to this type of human mobility. These cross-border effects include the impact on remittances, climate justice, the transfer of skills and knowledge, community social capital, loss and damage and more. The chapter addresses some of these risks in origin and recipient countries by drawing on analyses of temporary labour migration and guest worker programmes in different regions.

Introduction

There is growing awareness of the current and projected impacts of climate change on human mobility, including migration, forced displacement and relocation (IPCC, 2022). Extreme weather events (tropical storms, flooding) and slow-onset processes (higher temperatures, land and forest degradation, loss of biodiversity, sea-level rise and ocean warming) can be threat multipliers that exacerbate poor development and socioeconomic conditions, and ultimately influence mobility (Andreola Serraglio et al., 2021). Different types of climate events can shape mobility decisions over time, and the use of scenarios requires the consideration of various push and pull factors, such as physical exposure, opportunities, constraints and capacities (Cissé et al., 2022).

Social, economic and political as just some of the non-climate variables can have a major influence on or

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modify migration trends – including by undermining the ability of trapped populations to move. Yet severe climate risks, such as the effects on access to resources (including on biodiversity) and on livelihoods (climate-sensitive activities), and in areas of conflict, are key emerging issues in the context of human mobility across borders, given global warming projections (Birkmann et al., 2022; Detges et al., 2022).

The costs of mobility, both social and economic, have been falling and this has opened up internal and international migration flows for different reasons, such as temporary work. It is clear, therefore, that climate and non-climate drivers can interact and compound to influence the needs or desires of population groups to move – including across borders – with consequences for both their countries of origin and destination.

Temporary labour migration, for example guest worker programmes or seasonal work arrangements, is an important segment of the international labour market and occurs in a number of regions, with Europe, North America, Australia and New Zealand all employing guest workers in their primary industries. In 2013, many of the world's estimated 150 million international labour migrants (accounting for 65% of international migrants) were concentrated in Europe (33%) and North America (25%), with most of the rest found across Asia (Costa & Martin, 2018; ILO, 2017).

Climate hazards across these locations can impact temporary labour migration and have cascading consequences in origin and recipient countries. Seasonal work in recipient countries is often clustered within a few specific sectors worldwide, such as agriculture, forestry, industrial processes (meat packaging), fisheries and tourism. Of all the migrant workers in 2017, 27% worked in agriculture, 23% in industry, and 51% worked in services, including domestic work (ILO, 2017). Many of these activities are exposed and vulnerable to climate variability.

Migrant workers and their families who participate in and rely on international labour markets are highly vulnerable because of the volatile impact of climate change on these seasonal sectors and associated labour needs, and the decisions made by authorities at different scales about borders and labour migration rules.

Temporary mobility has long been seen as a way to diversify livelihoods and earn higher wages abroad. For example, in the higher Himalayan areas such as Humul, Nepal, seasonal migration is a livelihood diversification strategy for subsistence farming communities that face the impacts of climate change on their agriculture yields [see Chapter 2.1] (Gautam, 2017). Farmers migrate off season during the winter to neighbouring India to earn money.

The impacts of climate change on climate-sensitive subsistence practices and resources that support traditional livelihoods can modify temporary migration patterns for labour [see Chapter 2.9]. This, in turn, has cascading effects on communities and their wellbeing [Chapter 2.10] as well as on economies, including negative risks such as maladaptation, and potentially positive impacts such as contributions to local economies and financial adaptive capacity.

"Temporary mobility has long been seen as a way to diversify livelihoods and earn higher wages abroad."

The indirect effects of transboundary climate risks and temporary labour migration include cascading impacts on remittances, which are part of the global economy – particularly in climate-vulnerable developing and emerging countries. This can affect communities and economies that are highly dependent on remittances from abroad, especially where alternative work options are limited. Some segments of the population are particularly vulnerable to changes in remittance flows, such as women, elderly and people with disabilities in low-income countries. Across the Pacific Islands, for example, remittances are an important source of additional household financing that supports overall welfare (Brown & Connell, 2006).

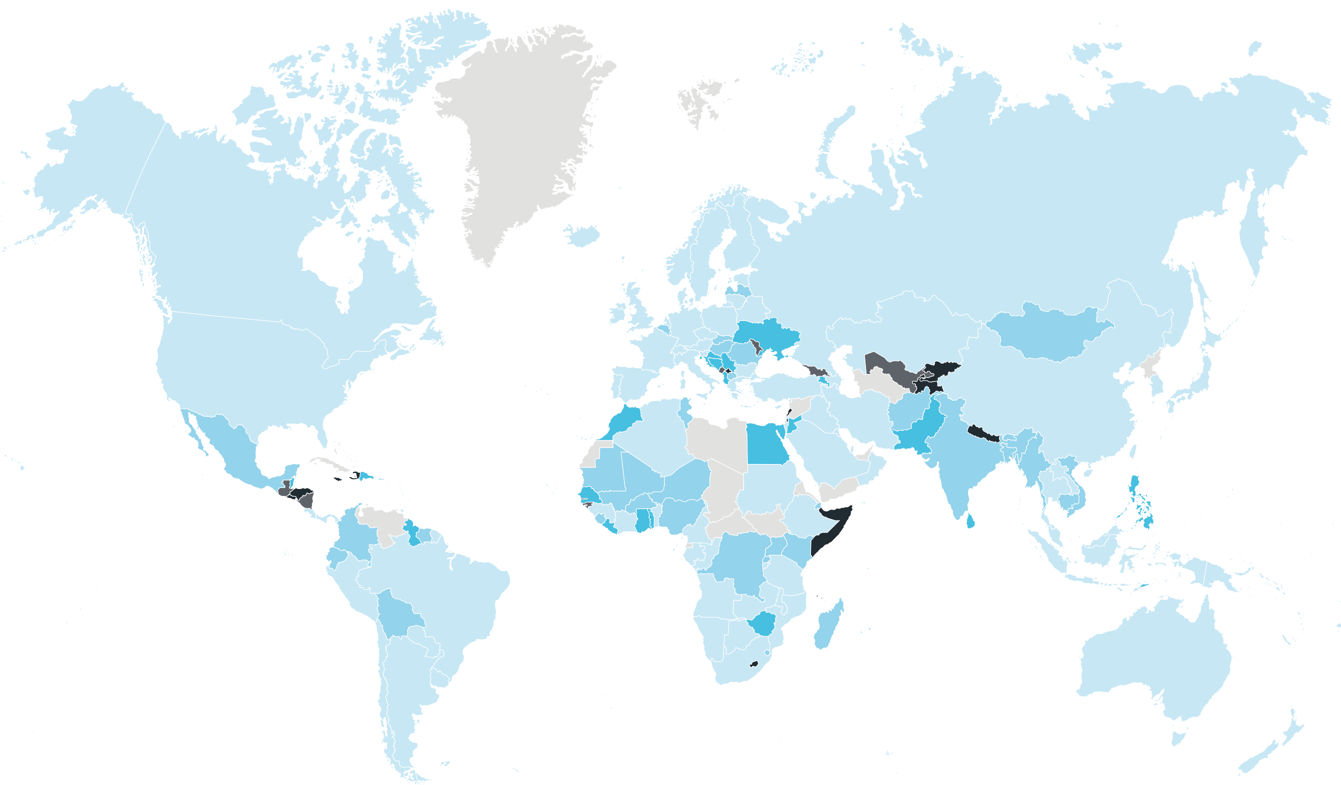
Some migrant workers come from developing countries that are highly vulnerable to climate change, and many come from middle-income and emerging economies (Costa & Martin, 2018). Indeed, the origin countries of temporary migrant workers are often the most climate-vulnerable as a result of structural poverty and other precarious development conditions (e.g. political and institutional). Climate change threatens resources and the livelihoods dependent on them in these countries, and exacerbates conflict (Andreola Serraglio et al., 2021; Birkmann et al., 2022), creating further demand for accessible international labour markets and increasing the significance of remittances as a financial resource.

This has cascading impacts on development conditions and potentially adaptive capacity. It threatens the resources and capacities that are available to enable people to leave their countries of origin, resulting in trapped populations who cannot move as these types of additional financial resources are uncertain and unstable under global warming and severe climate risk projections.

Characterization of the transboundary climate risk

Climate change impacts in origin and destination areas for temporary and seasonal labour migration – such as in the agriculture sector – can influence mobility, with the potential to propagate risks all the way along the entire human pathway. For example, extreme weather

Figure 13. Personal remittances, received (% of GDP)



Source: World Bank (2022).

can reduce crop yields, leaving migrant workers unemployed. Further, a combination of climate and non-climate variables, such as labour laws and border policies, can also influence access to international labour markets, with regional and global consequences.

Livelihoods often depend on resources that are threatened directly by climate change impacts, such as the effects of ocean warming and acidification on geographical shifts in fishing stocks, combined with coastal infrastructure that faces sea-level rise and flooding in small island developing states [Chapter 2.2]. In this case, cross-border temporary or permanent labour migration and the resulting remittances from abroad are essential coping mechanisms.

Together, these drivers can generate indirect and cascading effects on the capital flow of remittances – propagating transboundary risks through finance pathways (Benzie et al., 2016). Remittances from abroad play an important role in some economies[2] [see Figure 13] and can even contribute to the climate risk-management strategies of individual households. Poverty and vulnerability are interrelated, therefore finance can contribute to strengthening capacities to cope and adapt (Erikson & O'Brien, 2007). Remittances can be a source of complementary adaptation finance in climate-vulnerable developing countries, and are expected to increase at a higher rate than overseas development assistance and other international climate funding (Bendandi & Pauw, 2016; Musah-Surugu et al., 2017).

In some contexts, overseas remittance flows are important financial resources, particularly in rural and small-island communities, providing a means to conserve community networks, traditional livelihoods and cultures, as well as investments for local adaptation projects. In the Solomon Islands, remittances from migrant workers participating in seasonal work programmes in Australia and New Zealand contribute to development outcomes and, potentially, to climate change adaptation through investment in household and community climate-resilient infrastructure (Dun et al., 2020).

Indirect feedback effects from transboundary climate risks on remittances show how the risks propagate along the chain of impact (i.e. across the human and financial pathway) with potentially severe local consequences in the form of aggregated risks for remittance recipients. While remittances accessed through international labour markets can provide additional resources to support households and extra coping capacities in the face of environmental risks, studies also point to the risk of these resources contributing to increased risks and overall

2 The top 10 countries that depend on remittances based on percentage of GDP in 2020 are: Tonga (39%), Kyrgyz Republic (31.1%), Tajikistan (26.9%), Lebanon (25.6%), Samoa (25.3%), Somalia (24.9%), Nepal (24.3%), El Salvador (24.1%), Haiti (23.8%), Honduras (23.5%). Source: World Bank (2022).

maladaptation in origin countries over the long term (Davis & Lopez-Carr, 2014).

Remittances tend to be used in reaction to events (whether climate- or non-climate-related). They have also been shown to increase land purchases and construction in high-risk areas, leading to higher overall vulnerability and exposure to climate impacts. For example, remittances in some countries across Latin American and the Caribbean contribute to land desertification and degradation as a result of the expansion of land for production (agriculture and cultivation), which intensifies deforestation and increases climate risks (Andreola Serraglio et al., 2021).

In addition to transboundary climate risks for economies as a result of cross-border labour migration and remittances, social risks are another important aspect of seasonal migration and guest worker programmes. A wave of migration abroad for work, particularly from climate-vulnerable countries, can result in the loss of ties to land and traditional practices that are rooted in an understanding of the local environment and risks. This understanding has been important for perceptions about risks and preparedness and has been integral to community adaptation efforts. The social capital needed for adaptive capacity is also affected by strains on family relations and wellbeing when migrants are far away for a long time, further eroding the family units, community ties and social networks that are essential for community resilience [see Chapter 2.10].

In many cases, men migrate for seasonal work, which puts pressure on women in the household and exacerbates gender inequalities. These issues further exacerbate the non-climate drivers of vulnerability in developing settings that are already climate vulnerable.

Box 9. Case study:
Seasonal migration and guest worker schemes in the Pacific region

Mobility has been a part of life in the Pacific Islands region, through shipping and fishing that dates back to pre-colonial times. Seasonal or temporary migration to other countries for work has played a role in local economic development and is seen increasingly as a component of climate change policy (Davila et al., 2022; Farbotko et al., 2022). The physical characteristics of the Pacific region's small islands, with their limited land mass and exposure to climate risks, combined with vulnerabilities linked to development trends and difficulties in diversifying economic activities beyond fishing and tourism, mean that access to labour markets in other countries has been a key way to access financial opportunities, depending on the situation of each individual.

Australia and New Zealand established seasonal worker programmes more than 15 years ago. The Australian Seasonal Worker Programme (SWP), the Pacific Labour Scheme (PLS) and the New Zealand Recognized Seasonal Employer (RSE) invite Pacific islanders to fill labour gaps in key sectors, including agriculture, meat processing, tourism and care for the elderly. The duration of these programmes varies from shorter seasonal periods to up to three years. The Pacific countries involved include Fiji, Kiribati, Nauru, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

Such schemes are increasingly seen as part of the development of climate mobility policy at national and regional scales including the transboundary effects on remittances as part of these economies and their adaptive capacities (ILO, 2022). In Kiribati and Tuvalu, for example, national labour migration policies have been revised in the context of climate change to consider the role of international labour migration. The underlying policy approach aims to ensure a rights-based framework on climate change and human mobility that empowers migrant workers and supports skills transfer and development processes in their countries of origin.

In Tuvalu, for example, policies are in place to assist safe and secure employment opportunities abroad for shorter and longer terms, led by the principle "migrate with dignity" (Farbotko et al., 2022). At the regional scale several initiatives aim to bring together the different aspirations of islands in relation to seasonal work programmes to contribute to climate change adaptation at home. Joint projects have been initiated to support national policy design (see Enhancing the Capacity of Pacific Island Countries to Manage the Impacts of Climate Change on Migration) (ILO, 2012). Further, the International Organization for Migration (IOM) has launched the "Enhancing Protection and Empowerment of Migrants and Communities Affected by Climate Change and Disasters in the Pacific Region" programme to address regional rights related to human mobility (Farbotko et al., 2022).

These initiatives aim to support mobility at the nexus of climate change and development by evaluating how seasonal work programmes and guest worker arrangements can be opportunities for Pacific islanders in terms of both economic and social benefits. International remittances as transboundary dynamics resulting from human mobility provide a means to contribute to building climate-resilient community infrastructure and adaptation projects back home. At the same time, stays abroad allow the transfer of new skills and knowledge that can support development processes, such as the introduction of new technologies, that contribute to adaptive capacity, long-term adaptation options and the overall building of resilience to climate change (Davila et al., 2022).

Remittance flows from seasonal migration can increase economic development in countries of origin as a result of the higher salaries that can be earned in destination areas, and provide an opportunity for the transfer of knowledge and skills. However, a reliance on external labour markets can have cascading effects on the building of community resilience in the face of climate change and challenge the future aspirations of communities in terms of their identity and culture. This could, in turn, contribute to overall loss and damage in highly climate-vulnerable countries of origin where many people engage in seasonal work programmes.

It is vital to assess these issues in cross-border seasonal migration to gauge the direct and indirect impacts of transboundary climate risks, especially vulnerable groups of society that are highly dependent on remittance flows from abroad. More research is now needed on transboundary climate impacts and climate-migration to help identify the cascading effects. This research should include insights on the positive implications of adaptive capacity for local social networks in countries of origin, such as preserving traditions, cultural heritage and, more broadly, a diaspora community.

Critical reflections on existing policy tools and their limitations

Understanding the dynamics of international labour migration – whether temporary or permanent – under a changing climate, and the indirect effects on remittances in different contexts, is critical to better identify the recipients of aggregated transboundary climate risks. It is also crucial for the design of appropriate policy and governance solutions. Such policies need to look at how human mobility patterns will be influenced by a changing climate directly (impacts) and indirectly, combined with policies and governance around development, labour, human rights and migration (Birkmann et al., 2022).

Some research is considering how human mobility could be posited as an adaptive response if properly prepared for with policies and governance arrangements that ensure people's fundamental human rights and security (Loiseleur et al., 2021). Enhanced cooperation can, for example, support orderly and safe mobility across borders, and can include cross-sectoral adaptive capacity building within labour migration arrangements as part of sustainable climate development. Such cooperation and coordination of policies and governance arrangements would need to account for different scales of transboundary climate risks (local, regional and international).

The exploration of mobility as a choice and adaptive option is emerging in climate policy in some regions, such as the Pacific, through the advancement of coordinated governance arrangements across actors at different scales (national, regional, international) and policy areas (human rights, labour markets, nationality, identity and culture) [see Box 9]. Temporary labour schemes can provide insights into alternative options such as transitions to long-term or permanent relocation, and into how policies can support just and equitable decisions around migration across different socio-environmental and cultural contexts. Further considerations about mobility and international labour markets should also address indirect effects, such as the role of remittances in developing contexts.

International conventions and international law are scattered across a fragmented landscape where mobility is yet to be integrated into climate change policy and sustainable development. In addition, the issue of taxonomies and the characterization of different types of mobility is crucial, given the tensions around emerging concepts of "climate refugee" and "climate migration" more generally, which are often portrayed as a national security issue to be met with protectionist discourse and border closures.

Major global actors in mobility governance include the IOM and the United Nations High Commissioner for Refugees, particularly in relation to displacement. In the context of labour, the International Labour Organization has an overarching role in setting out policies and rules about the rights of workers and movement schemes, while the World Trade Organization sets some rules about the global operations of multinational companies and employment arrangements.

Bilateral and regional arrangements are in place, including guest worker programmes in the Pacific region between small islands and Australia and New Zealand [see Box 9]. Other examples include Malaysia and Singapore, which share a labour market. In the US, some seasonal farmworkers who live in Mexico fall under the special H-2A visa programme.

National governments are the primary actors in setting visa rules, border conditions, sectoral policies and the way in which human mobility is addressed in national climate change adaptation strategies. They also determine to what extent transboundary climate impacts are integrated.

More broadly, policies and governance arrangements on seasonal migration and guest workers are integral to climate justice as part of transformative adaptation to climate change. Care is needed, as such arrangements can increase structural inequalities rooted in the marginalized impacts of climate change (Guatam, 2017), with migrants from highly climate-vulnerable areas forced to explore external labour markets as a result of the precarious conditions (poor development and socio-economic context) in their country of origin. While the destination countries for migration (developed and industrial economies) have, historically, far greater responsibility for climate change, it is the migrant who ends up owning the climate risks (Farbotko et al., 2022).

More research is needed on the opportunities around transboundary climate effects at the crossroads between human mobility, seasonal work arrangements and climate change adaptation in sustainable development pathways. Complementary policies developing around loss and damage (the loss of livelihoods, ecosystems, etc.) and the Warsaw Mechanism under the United Nations Framework Convention on Climate Change may offer useful insights.

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Chapter 2.9

Transboundary climate risks and livelihoods

Sarah Opitz-Stapleton[1]

Transboundary climate risks to livelihoods are transmitted through the direct impacts of climate hazards on natural resource assets over large scales, and indirectly through interconnected and interdependent systems such as supply chains, trade relations or economic instability.

- Transboundary climate risks to livelihoods affect the assets, capabilities and activities people need to make a living and contribute to economies.
- Cross-border and cascading climate risks to livelihoods may particularly threaten the most vulnerable groups of people - those who are marginalized socioeconomically, politically and culturally – or areas with weak or contested governance. Such individuals are often forced to make "adaptation" choices about their livelihoods with little or no formal assistance, which can lead to ripple effects across borders (e.g. human mobility) and be maladaptive in the long term.
- Those with livelihoods in poverty and high-vulnerability hotspots struggle to adapt. They face disproportionate risks when these hotspots overlap with regions where climate change shifts in temperature and/or precipitation make some livelihoods untenable, such as agriculture or pastoralism.

Overview

Livelihoods are the capabilities, assets and activities that enable people to make a living and meet their own daily needs. Collectively, livelihoods build economies, from the subnational to the global scale. However, livelihoods in the primary sector (involving the exploitation and extraction of natural resources, e.g. agriculture, fishing, or mining) or in the secondary sector (involving the processing of these resources, e.g. processed foods or manufacturing)[2] face climate risks that span the local to international scales. In addition, various kinds of livelihoods, from traditional to modern, are now deeply embedded in local to global socioeconomic development systems.

Transboundary climate risks to livelihoods are transmitted through the direct impacts of climate hazards on natural assets, like forests or rangelands, over large scales, and indirectly through interconnected and interdependent systems such as supply chains, trade relations or economic instability. The direct and indirect impacts (both positive and negative) on local to global systems spill over into livelihoods, and the effects of this cascade back upwards through local to global systems. Adapting livelihoods to climate change impacts at different scales means addressing embedded inequalities in the world's economic, political and social systems and ensuring coherence with – and the implementation of – international frameworks like the 2030 Agenda for Sustainable Development (UN, 2015) and the 2030 Agenda for Sustainable Development (UN, 2015), the Sendai Framework for Disaster Risk Reduction and the Paris Agreement (UNFCCC, 2015) within subnational, national and regional policy and practice.

Introduction

Transboundary climate risks to livelihoods manifest both directly and indirectly on the assets, capabilities and activities people need to make a living and contribute to their economies. The direct livelihood impacts are the damage to or loss of assets or activities as a result of a climate hazard that interacts with the underlying, non-climate vulnerabilities of an individual (e.g. no savings or access to credit) and a system (e.g. overfishing and ocean pollution). Marine heatwaves, for example, have triggered coral bleaching in the Caribbean region and caused declines in already stressed reef fish populations and aquaculture, while triggering other fish species to move to deeper, cooler waters (Monnereau et al., 2015) [Chapter 2.2]. Reductions in fish catches during marine heatwaves affect small-scale fishers and fish processing livelihoods, with potential knock-on impacts on household food security and income.

Indirect transboundary climate risks relate to the cascading impacts of a climate hazard that damages and

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2 Livelihoods may be further organized as primary, secondary, tertiary and quaternary sectors in economies (Kenessey, 1987).

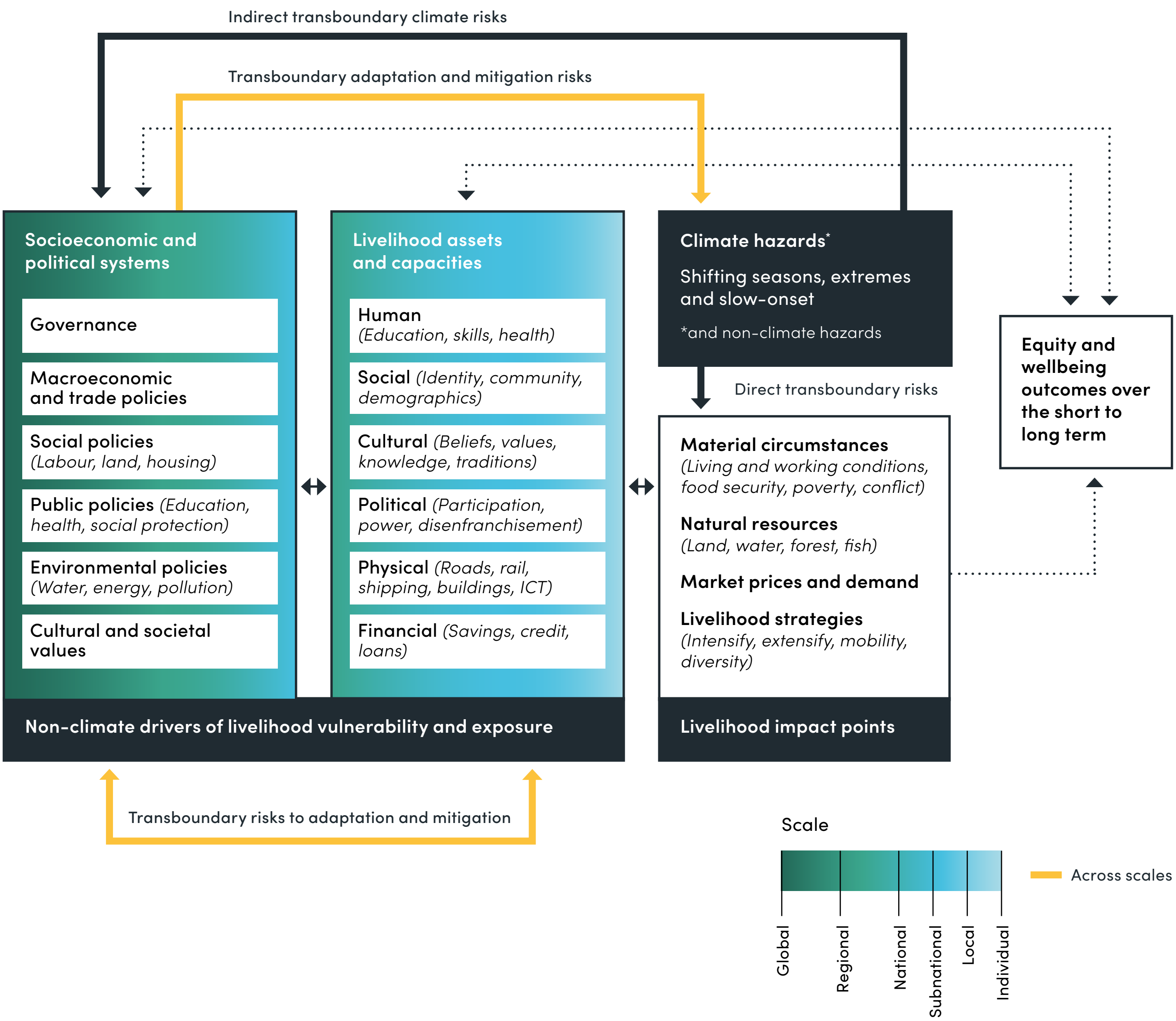
disrupts the vital inputs and outputs of livelihoods along trade, finance, sociocultural and infrastructure pathways. These indirect transboundary climate risks are less researched, with many studies focusing on the macroeconomic risks to a particular sector, such as construction or manufacturing. Finally, national and regional adaptation actions can have cascading and inequitable impacts on the assets and capacities of various livelihood groups.

This chapter explores transboundary climate risks that impact on livelihoods, with the caveat that the likelihood and magnitude of certain risks to certain livelihoods are better researched than others.

Characterization of the transboundary climate risk

At present, climate-livelihood impacts, their severity and transboundary extent are propagated extensively through non-climate factors (e.g. market prices or cultural beliefs) and systems (e.g. finance, trade or social policies) [see Figure 14]. This sometimes makes it difficult to untangle the impact of climate on livelihoods in, for example, agriculture, livestock and other food systems (Bezner Kerr et al., 2022). Complex and dynamic non-climate vulnerabilities and exposures influence capabilities, assets and

Figure 14. The interactions of non-climate factors that influence livelihoods in the face of climate hazards



Notes: Transboundary climate risks to livelihoods are propagated through non-climate factors at different scales. Individual- to local-level livelihood assets, capacities and activities are embedded within local, subnational, national, regional and global socioeconomic and political systems. Climate change hazards, adaptation and mitigation policies and actions can generate transboundary risks that impact livelihood assets, capacities and activities directly or indirectly by affecting the systems upon which they depend. Impacts to livelihood assets, capacities and activities at individual to subnational scales can accumulate and create transboundary risks that propagate upwards to systems.

Source: Adapted from Solar & Irwin (2010) and Sseguya et al. (2009).

activities at an individual livelihood and at a collective economic level (Chambers & Conway, 1991). Meanwhile, multidimensional poverty and vulnerability are evolving at several scales, but have their roots in historical inequalities. These inequalities are perpetuated in today's socio-economic development trends (Opitz-Stapleton et al., 2019) and local to larger-scale conditions and contexts.

The non-climate factors that influence livelihood vulnerability and exposure – and that create overall sensitivity to a climate hazard and allow transboundary climate risks to propagate – relate to the capacities, assets and activities needed to sustain livelihoods at an individual level, as embedded within subnational to global socio-economic and political systems (Sseguya et al., 2009).

Capacities at the individual to subnational scales include the quality of and access to healthcare and education; indigenous knowledge of local ecosystems and services; and whether a person faces additional inequalities on the basis of their age, health, gender, religious or ethnic identity. Individuals practicing livelihoods that rely on transnational mobility such as traders, migrant farm or construction workers, fishers or pastoral livestock owners, might face discrimination and lack access to services like medical care when practicing their livelihood in locations where they are not formally recognized (Piper & Withers, 2018).

The critical assets at a variety of scales needed to maintain livelihoods include the quality of and access to services like finances, credit or fertilizer for farming or veterinary drugs for livestock; the connectedness, robustness and location of infrastructure like roads, electricity networks or the Internet for connectivity to regional and global markets; and the extent to which regional land and water resources have been degraded by the mismanagement of resources. Demand for products, market prices, policies and the strength of local to regional governance are some other more macro-level non-climate factors.

Livelihood activities are the formal or informal job(s) that individuals have in order to earn a living and support themselves and any dependents, or contribute to household wellbeing. These activities include fishing (primary sector) and the processing of fish (secondary sector); logging and harvesting of forest products (primary sector) and the conversion into finished building materials, paper or other wood-based products (secondary sector); and livestock rearing (primary sector) and the selling of dairy products or meat products (secondary sector), for example. The full range of livelihood activities is too extensive to cover in this chapter.

The combination of all of these non-climate factors influences the success of livelihoods and whether an individual can intensify, diversify or change their livelihood activities entirely in response to shocks, stresses, trends and individual aspiration. And as a result, some individual livelihoods, as well as clusters of livelihoods in some regions, are much more vulnerable to negative impacts when local

"Complex and dynamic non-climate vulnerabilities and exposures influence capabilities, assets and activities at an individual livelihood and at a collective economic level."

to transboundary climate hazards occur. As Birkmann et al. (2022, p. 1174) note:

> Areas of high human vulnerability . . . high levels of poverty, a significant number of people without access to basic services, such as water and sanitation, and wealth and gender inequalities, as well as governance challenges . . . are characterized by larger transboundary regional clusters (*high confidence*).

The Intergovernmental Panel on Climate Change (IPCC) identifies the regional clusters as East, Central and West Africa, South Asia, Micronesia and Melanesia, and Central America as having high vulnerability. Economies within these regional clusters have a large percentage of livelihood activities in the primary (e.g. farming, fishing, logging or livestock rearing) and secondary sectors that involve the processing of the outputs of primary sector livelihoods (World Bank, 2022).

Direct and indirect transboundary climate risks and their impacts on livelihoods are propagated through extreme and slow-onset climate hazards over a large area, typically spanning the borders of two or more countries. Propagation depends on the underlying non-climate sensitivities in the trade, transport, financial, governance and natural resource systems that shape individual livelihood capacities, assets and activities.

Direct impacts on livelihoods affect the quantity, quality and functioning of terrestrial, ocean and coastal multi-country shared natural resources and ecosystem services (natural assets) that support livelihoods in the primary and secondary sectors [Chapter 2.1 and Chapter 2.2]. They also manifest through impacts on other livelihood assets and outputs. Extreme events such as floods, drought, heat waves or hail storms damage or destroy assets, including farming equipment, fishing gear or livestock fodder, as well as livelihood outputs like crops, livestock, fish catches or forest products. This leads to lost incomes, food insecurity and indebtedness.

Warmer temperatures and extremes have already reduced crop harvest stability, livestock productivity and sustainable yields of wild fishing and aquaculture in many regions (Bezner Kerr et al., 2022), with variable impacts on local livelihoods. These local impacts aggregate to national and regional economic damages (Burke & Tanutama, 2019). Repeated climate extremes, coupled with slow-onset changes to an area's rainfall or temperature during different seasons, contribute to the constant erosion of financial or input assets as people have to replace livestock, crops or fishing gear multiple times (Risk to Resilience Study Team, 2009). This can tip people who have escaped poverty back into it, or trap them in it (Shepherd et al., 2019), with the damages and losses to individual livelihood activities accumulating into subnational to regional economic disruption (Dellink et al., 2019).

By 2100, it is likely that 8% of current agriculture and livestock production areas could be unsuitable for livelihoods under an emission scenario in line with the Paris Agreement; a percentage that rises to over 30% under a high emission scenario. It is estimated that every 1°C increase will lead to a 5% decline in marine fisheries and aquaculture productivity, with knock-on impacts for fishing-related industries. Heat stress will decrease the labour productivity of outdoor livelihood activities (e.g. construction, farming, livestock, forestry, fisheries), with

Box 10. Case study:
Pastoralism livelihoods and transboundary impacts in the Sahel region

There is research and policy recognition of the transboundary climate impacts and risks to farming, fisheries and forestry livelihoods, but awareness of transboundary climate risks to livestock-based livelihoods is relatively limited (Trisos et al., 2022), with a few exceptions (Godde et al., 2021). Livestock-based livelihoods span a wide range of activities, from keeping small ruminants in pens to mobile pastoralism, and from the processing of livestock products like dairy, meat and leather to the trade of such products within and across national borders.

Pastoral livelihoods are often, by their very nature, transboundary, either through the seasonal movement of herds (transhumance) or permanent mobility (nomadism) across borders in search of fodder and rains. In Africa, pastoralism contributes to between 5% and 30% of GDP; in West Africa, it accounts for around 40% of agricultural GDP (de Haan, 2016) . This transboundary movement exposes pastoral livelihoods directly to a range of climate hazards – drought, heat waves and more variable rainy seasons. Climate extremes and slow-onset hazards in one country or across a multi-country region can trigger impacts that spread regionally through livestock economies to impact the livestock-based livelihoods of millions.

Linked biophysical and trade transboundary climate risks to pastoral livelihoods are the most visible. Should a mean global warming of 2°C be reached, it is projected that the duration of meteorological droughts may double from two to four months across the western Sahel and that the frequency and magnitude of precipitation and temperature extremes will increase (Godde et al., 2021) . This can lead to the widespread death of livestock during multi-country droughts as water becomes scarce, as seen in 2022 across the Horn of Africa where an unprecedented four-season drought has contributed to the death of more than 3 million livestock across Somalia, north and eastern Kenya, and parts of Ethiopia (FEWS NET, 2022). There are threats to rangeland productivity and fodder availability, with agreement that West Africa rangeland productivity could decrease by up to 40% above a mean global warming of 2°C, while northern and southern Africa would see decreases of 32% and 37% respectively if there is warming of 2.4°C by 2050 (Godde et al., 2021).

Shifts in temperatures, rainfall patterns and humidity facilitate the spread of existing or novel livestock (and human) diseases across national borders. Multi-country zoonotic disease outbreaks, for example, are associated with heavy rainfall and flooding and have impacted livestock production, livelihoods and trade. Large-scale Rift Valley Fever outbreaks in livestock in Kenya, Tanzania and Somalia in 1997/98, and in Sudan in 2007 and 2010, for example, led to Saudi Arabia banning imports of livestock and livestock products from East Africa on many occasions. This has had severe impacts on livestock-based livelihoods and economies in multiple East African countries (Peyre et al., 2015).

The regional interconnectedness of livestock markets and shared rangeland ecosystems requires coordinated transboundary climate risk management across countries and scales. Land tenure security and the protection of cross-border rangelands are integral components of adaptation planning to address transboundary climate risks for local pastoral livelihoods. Land tenure security for grazing and livestock migration routes, and usage rights for water and vegetation need better protection by enforcing existing legal mechanisms, reviewing and updating land laws from earlier eras that favoured settled farming over pastoral mobility, and working with the grain of traditional systems of land and resource governance.

It should be noted that even subnational barriers to pastoral mobility and rangeland resources can have multi-country impacts. Regional livestock disease surveillance and management systems need to be built where they are lacking, and strengthened where they exist. Greater local, subnational and multi-country cooperation is needed to address the transboundary aspects of pastoralism and other livelihoods connected to livestock, from the processing of livestock products to produce butter or leather to trade, to the monitoring and management of the health of both livestock and humans.

a 3°C increase in warming compared to 1986-2005, reducing labour capacity by 30-50% in Southeast Asia and sub-Saharan Africa (Birkmann et al., 2022). It would also reduce the capacities of outdoor workers through negative health impacts [Chapter 2.7], disrupting household incomes through the heat-related illness or death of one or more earners.

Indirect transboundary climate risks cascade through interconnected non-biophysical pathways (e.g. trade, sociocultural knowledge, finances) to disrupt livelihood inputs and outputs. However, there is little quantification of such transboundary climate risks at livelihood scales; the severity and likelihood of impacts tend to be researched at the macroeconomic scale (Birkmann et al., 2022).

Indirect impacts affect the agricultural, livestock, fisheries and forest-based livelihoods that use goods and services produced in other locations as inputs. Damage at ports like Shanghai or New York as a result of, for example, rising sea levels or severe storms, can suspend the livelihoods of port workers while disrupting regional and global supply chains (Becker et al., 2018) [Chapter 2.4].

Regional mechanisms to manage transboundary climate risks are emerging in the Sahel where they threaten pastoralism/transhumance activities.

These risks propagate across livelihoods in different regions: supply chain disruptions to concrete, steel, semiconductors or wood impact the livelihoods of construction and manufacturing workers, including those employed in developing renewables like wind energy (Lundie et al., 2019). Disruptions due to a climate extreme at a major exporter of fertilizer can lead to global supply reductions and price increases for importers that are passed down to farmers (Cordell et al., 2021) [Chapter 2.3].

An additional route for transboundary climate risks, explored in Box 10, is the potential for crop or livestock disease outbreaks related to a climate hazard, with the prospects of importing countries imposing bans on such livelihood outputs, leading to lost incomes. Further research is now needed on the magnitude, likelihood and timing of indirect transboundary climate risks and their implications for livelihoods not only in the absence of adaptation, but also in a context of adaptation measures at supplying and importing locations.

Critical reflections on existing policy tools and their limitations

The abilities of local livelihoods and asset bases to cope with and recover from hazards and diversify into new livelihoods are often shaped by community, national and regional political, cultural, socioeconomic and infrastructure systems (Birkmann et al., 2022). Capacities and assets are enabled and constrained to a variable degree by the type of government plans and policies at various sub-national to regional scales and the abilities to implement and enforce them.

Governance priorities for livelihoods, fiscal and environmental management, and socioeconomic development trajectories are often set at the national level through short-term (e.g. economic stimulus packages and budgets) and medium-term economic plans (five-year), as well as long-term economic visions (5 to 10+ years). Sector-specific and sub-national plans outline the "rules of the game" that influence livelihoods, whether or not individual people are aware of them. They include agriculture, energy and urban planning, policies that dictate priorities for healthcare, mobility or the treatment of disadvantaged groups, and regional cooperation agreements. Cultural and social norms also interact with governance to shape livelihoods.

These non-climate systems are not fair, and they create high poverty, livelihood vulnerability and exposure to local to transboundary climate hazards. Certain groups of people are marginalized socioeconomically, politically and culturally, while in other areas with weak or contested governance, individuals make "adaptation" choices with little formal assistance (Birkmann et al., 2022). As a result of these interconnected non-climate factors, some livelihoods are more impacted than others, resulting in poverty, hunger, disproportionate environmental degradation and poor wellbeing (Birkmann et al., 2022) [Chapter 2.10]. And these "adaptation" choices may prove maladaptive.

Those with livelihoods in poverty and high vulnerability "hotspots" may be far less able to adapt. They may face disproportionate risks when these hotspots overlap with regions where climate change shifts in temperature and/or precipitation make certain livelihoods untenable, such as agriculture or livestock-rearing and processing. Livelihood adaptations, whether incremental through the purchase of more drought-tolerant seed or more transformative in terms of diversification or mobility [Chapter 2.8], might not be possible for some in the absence of transformative shifts in broader economic or political systems at multiple scales (Birkmann et al., 2022).

Current policy tools and frameworks for the transition to sustainable, adaptive livelihoods[3] reflect diverse scales of governance. At the international level, frameworks such as the 2030 Agenda for Sustainable Development (UN, 2015), the 2015 Paris Agreement (UNFCCC, 2015) and the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) offer goals and visions that impact livelihoods and that could lead to climate-resilient development. However, with the exception of the Paris Agreement, many international frameworks are not legally binding and create no political obligation to act. Policy approaches and implementation remain siloed, and the goals and targets of international frameworks can only be met if they are integrated into and implemented through subnational to national policies (Opitz-Stapleton et al., 2019). The latest report of Working Group II of the IPCC states that even if 1.5°C emission targets are reached, certain groups and livelihoods will not be able to adapt as long as poverty and inequality remain high, and some countries will not be able to manage the severe risks to their socioeconomic development (IPCC, 2022).

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3 Sustainable livelihoods entail productive employment and decent work for all women and men, including young people and persons with disabilities, that also enable individuals and households to cope with and recover from stresses and shocks, and maintain or enhance wellbeing and assets both now and in the future, without undermining natural resource bases (adapted from FAO, n.d.; SDG 8.2 in United Nations, 2015; IPCC, 2022).

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Chapter 2.10

Transboundary climate risks and wellbeing

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Transboundary climate risks pose a grave threat to people's physical and mental wellbeing by impacting their livelihoods and natural environments; their access to land, food and water; and their country's socio-economic development more broadly. Many of the transboundary climate risks illustrated in the preceding chapters of this report will ultimately impact on people's wellbeing. Wellbeing is, therefore, a cross-cutting dimension of transboundary climate risk.

- The current adaptation architecture does not adequately support or enhance wellbeing. New concepts of societal progress must guide our adaptation efforts and define our measures of success in building resilience to climate risks, including those that cascade across borders. Managing transboundary climate risk is about recognizing the value and integrity of life in all parts of the world, that our wellbeing is founded upon the deep connections between all people and places.
- Placing wellbeing as the guiding objective for adaptation paves the way towards more ambitious and transformative adaptation policies at every level, from the local to the global. Such an approach could also strengthen the management of transboundary climate risk. We can no longer govern adaptation in ways that assume domestic policies alone can serve the national interest. In an interconnected world, working in the national interest demands collaboration with others to strengthen our systemic and collective resilience.

Overview

The direct impacts of climate change on human wellbeing have long been recognized, even though they are far from being sufficiently addressed. The Intergovernmental Panel on Climate Change (IPCC) notes that "the cumulative scientific evidence is unequivocal: climate change is a threat to human wellbeing and planetary health (very high confidence)" (IPCC, 2022, p. 33). However, there is far less recognition of the transboundary climate risks that also threaten human wellbeing: how local climate impacts and adaptation in one place can have far-reaching repercussions on one's wellbeing in another. These risks to wellbeing remain poorly identified and understood. This chapter argues that recognizing the interconnections between our societies, economies and environments opens up space for a more comprehensive exploration of the role of – and importance of – wellbeing as a guiding objective for global adaptation.

Introduction

The cross-border and cascading effects of climate change generate and amplify risk to the physical and mental wellbeing of people thousands of kilometres from the original point of the impact of a climate hazard. They reduce access to safe lands, exacerbate food and water insecurity [Chapter 2.3], limit livelihoods and economic activities [Chapter 2.9], and disrupt a range of services [Chapter 2.5]. These risks can occur when climate change catalyses knock-on effects in shared ecosystems and natural resource flows (such as river basins) [Chapter 2.1 and Chapter 2.2], in human mobility patterns and tourism [Chapter 2.8], in foreign direct investments [Chapter 2.6] and remittances, and in global markets when they spark price fluctuations or disrupt supply chains [Chapter 2.4].

It is also important to factor in the transboundary implications of adaptation action, which can also create cascading risks to wellbeing and equity. Planning adaptation to climate change must, therefore, identify, assess and address its transboundary effects on both the physical and mental wellbeing of people.

At the same time, we need to expand our concept of wellbeing and position it as the ultimate purpose of adaptation efforts. This means bringing in more varied perspectives and harnessing more diverse views to inform adaptation efforts and outcomes.

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Our definition and understanding of wellbeing can vary significantly, depending on our culture or worldview. Some see it as being linked to an individual's health and their development surroundings. Others see it more fundamentally as emerging from the connection between people and nature. The implication is that it is difficult or impossible to achieve "wellbeing" in a world that is damaged by climate change.

In addition, the degree to which we understand wellbeing as being connected to economic growth can frame adaptation decisions. For some, wellbeing can be improved by increasing material standards of living through more or "smarter" growth. For others, such a limited view of wellbeing will lead to maladaptive outcomes if the underlying root causes of vulnerability are not addressed or if the cascading consequences for people beyond the original group targeted for support are not considered.

Characterization of the transboundary climate risk

Accelerating climate impacts affect individual health and wellbeing – even across borders

The direct impacts on human health from climate-related injury, trauma and disease are well documented, particularly during and after extreme weather events. We are also learning more about the psychological consequences of climate change on individual and community health and wellbeing (Berry et al., 2010; Manning and Clayton, 2018; Persaud et al., 2018).

More coverage and consumption of news footage of frequent and extreme weather-related crises around the world are increasingly causing distress and anxiety, not only in communities nearby, but also in seemingly unconnected communities that are far away from the immediate climate hazard. Climate change threatens wellbeing where its impacts are felt most directly, but also further afield, simply as a result of the connection that people feel to one another. And young people, in particular, often feel this most acutely.

The changing climate affects the flows of remittances and other finance with transboundary implications for wellbeing, equity and climate justice

Climate change affects labour, particularly seasonal work and, therefore, the livelihoods of international migrant workers, whose jobs are often the most insecure in the market.

This, in turn, affects the flow of cross-border remittances to dependent households. Remittance flows often support the most vulnerable people and communities in low-income countries (with limited social security nets), including women, the elderly (for whom a remittance may function in place of a pension), those with disabilities and others. Many communities – for example in southern Africa – are highly dependent on such remittances and often lack alternative means to generate incomes (other than through subsistence farming) or access basic services. Similarly, people from the Pacific Islands are making greater use of guest worker programmes with New Zealand and Australia, given the growing importance of remittances to support community resilience building back home: an example of the nexus of development and climate change adaptation [Chapter 2.9].

> "It is also important to factor in the transboundary implications of adaptation action, which can also create cascading risks to wellbeing and equity."

For true climate justice, however, international labour markets and remittances more broadly must be built on principles of choice, empowerment and equity for migrant workers and their families. This is important, as the world cannot continue to place the responsibility for adaptation to climate change on the shoulders of those who have contributed the least to it, yet are being forced from their homes and communities to work in industrial economies.

A changing climate affects the global provision of goods and international supply chains, with transboundary implications for food and commodity security worldwide

The slow-onset changes and extreme weather events triggered by climate change have significant implications for the production, processing and distribution of food and other commodities, with cascading consequences across international markets [Chapter 2.3]. This creates supply and price shocks that have dire consequences for peoples' lives and livelihoods. Urban systems are particularly vulnerable because of the typically high influx of goods to cities that rely on natural systems outside their borders, often from abroad [Chapter 2.4].

Cascading climate impacts across sectors and borders affect social cohesion, exacerbate mental health challenges and social inequities, and undermine wellbeing for many

The cumulative impacts of climate change hazards that affect some of the most essential aspects of life, including water, food and financial security, are likely to exacerbate inequality in societies that are already unequal and that face many other challenges. Many communities are struggling with the lingering effects of the Covid-19 pandemic, combined with the cascading impacts of war, a global food crisis and inflation that have resulted in a cost-of-living crisis and creaking social cohesion in countries at all levels of development.

The implications for equity and justice

Transboundary climate risks have the most acute impact on the most vulnerable people in society, with severe risks for their wellbeing. This matters for equity and justice. For the first time, the latest IPCC (2022) report on adaptation highlights justice as a core quality of climate adaptation (alongside effectiveness and feasibility). The prominence it receives – mentioned no less than 16 times in the report's summary for policymakers – reflects its critical position at the very heart of adaptation. When we consider the interaction between climate change, wellbeing and equity, four key factors must be considered – all of them with a transboundary dimension.

Historic inequity

Those who have the least resources and wealth globally have contributed the least to the climate crisis and yet bear the brunt of its impact. The countries that are most resilient to direct climate impacts have benefited most clearly – and for the longest time – from the exploitation of natural resources as economic inputs to the production of their food, health, energy and infrastructure systems.

Compounding inequity

The economic and industrial drivers of today's climate crisis create transboundary and cascading risks to human wellbeing that have inequitable consequences and that exacerbate the underlying drivers of vulnerability to that crisis. Even "solutions" to the climate crisis, such as accelerated transitions to biofuels, can undermine the food security and livelihoods of vulnerable people in marginalized communities around the world, such as those that feel the negative effects of large-scale palm oil production.

Inequity and vulnerability

The risks catalysed by climate change have differentiated impacts on human wellbeing, with the most marginalized people particularly vulnerable (directly, indirectly and across sectors). They include children and the elderly, women, the homeless, low-income groups, those living in some coastal communities, people in poor health, people with poor social networks, ethnic minorities, Indigenous people, immigrants and people with low political capabilities (Araos, 2021). According to the latest IPCC (2022) report, increased poverty as well as migration and forced displacement are the two core drivers of risk to wellbeing in the context of climate change.

Unjust adaptation

The benefits of adaptation are also distributed unevenly, with the same groups of people least likely to be included in and able to harness the benefits from climate change adaptation measures (Breil et al., 2021). Just as climate risk can exacerbate existing inequalities, adaptation also creates winners and losers across scales: what strengthens the resilience of some people might also increase the vulnerability of others. Jonathan Ensor argues that of the three dimensions of adaptation justice in adaptation – distributive justice (who benefits), procedural justice (who participates) and recognition justice (respect for and engagement with diverse cultures and perspectives) – recognition justice receives the least attention (in Harris et al., 2022): recognition injustices . . . are particularly insidious forms of exclusion that leave some groups marginalized from defining when adaptation is necessary and what forms of adaptation are desirable.

The risk of transboundary maladaptation to wellbeing

Adaptation can create and even accelerate existing inequalities and vulnerabilities. For example, building dam infrastructure to support irrigation and hydropower and reduce the risk of floods and droughts can be a major regional adaptation project (Lager et al., 2021). However, the risks should not be downplayed. These include the risks of reduced access to water for communities downstream and risks for the sustainability of the entire river basin, which could generate tensions between riparian communities that could escalate to become national security concerns.

As awareness of transboundary and cascading climate risk increases, so too will responses to such risks that may not be benign for everyone. In a worst-case scenario, governments and private-sector corporations respond to these risks in a nationalist and protectionist manner by implementing closed-door migration policies, siphoning off shared resources, abandoning risky production and manufacturing regions, or invoking trade restrictions such as export bans. Such policy responses could deepen already precarious conditions for the most vulnerable people, add to instability in key global systems and undermine wellbeing for large segments of the world's population, while hampering global capacities to meet their needs.

The term "maladaptation" has been coined to reflect adaptation actions that shift vulnerability to other sectors, locations or communities. In many cases, the consequences may be unintended and are the result of a narrow understanding of the interdependencies of systems. In some cases, however, the consequences may be more deliberate as certain actors try to take advantage of the adaptation agenda, exploiting the sense of urgency for their own economic gain or to elicit power at others' expense.

Box 11. Case study:
Wellbeing and equity inform just transitions in the Brazilian coffee supply chain

Coffee is one of the most traded commodities on international markets – representing 72% of total production worldwide and employing nearly 60 million people in its supply chain (ICO, 2019). Predominantly grown in the "coffee belt" in the tropics, coffee production is highly vulnerable to climate change. The changing climate is a growing threat to the availability of suitable land for cultivation, resulting in declining yields and cascading effects on local livelihoods and global supply chains. Brazil is the largest coffee producer in the world, representing 30% of total exports (Barros, 2019). This means that the impact of climate change on Brazilian coffee growers have far-reaching consequences – from local farmers to roasters and retailers in the US and Europe, and to coffee producers, traders and consumers in countries all around the world (Adams et al., 2021; Dzebo et al., 2022).

Smallholder farmers, often using an area of 5 hectares or less, comprise nearly 80% of coffee bean farmers in Brazil (Beuchelt & Zeller, 2011). They are particularly vulnerable to climate change because of their limited access to resources to cope with climate events and to alternative agricultural inputs. In addition, actions taken across the global supply chain by coffee traders, roasters and retailers (including risk management and adaptation measures) can have indirect impacts on the wellbeing of smallholder farmers. Contracts, for example, could be cancelled or assets sold to reduce companies' exposure to climate risk. This, in turn, could lead to the loss of local community livelihoods, further threatening physical wellbeing through the loss of financial resources and welfare, as well as mental wellbeing.

Given the interconnectedness of local coffee bean farmers to global supply chains, a "just adaptation" approach is necessary in the face of climate change if adaptation actions in one part of the supply chain are to not undermine the resilience and wellbeing of actors in another. Just adaptation includes a collaborative approach, with multi-stakeholder engagement, to identify and account for cascading effects on equity and wellbeing in adaptation decision making (Lager et al., 2021). Shared risks could offer opportunities for adaptation measures and sustainable development to build wider collective resilience.

A just adaptation approach for Brazil could include:

- integrating adaptation into low-carbon agriculture in collaboration with communities – as is underway (led by the Government of Brazil)
- mobilizing resources to support farmers to develop climate-resilient practices that strengthen their capacity to cope with climate events
- leveraging the skills and capacities of the private sector to provide technical and financial support to producers in ways that increase their resilience; and revisiting sustainability certification schemes
- expanding the sustainability standards of traders and roasters – the largest actors in the supply chain – to include climate risk assessments and the promotion of adaptation action
- the repeal of tax for certified coffees by countries like Germany that are large consumers to increase demand for sustainably produced coffee
- the provision of tax incentives by Brazil or any of its trading partners to private companies that invest in the resilience of their partners abroad to encourage foreign direct investments in sustainability, and
- the incorporation of climate risk assessments in the sustainability chapters of free trade agreements and of mechanisms for climate action support in accompanying investment agreements.

Managing transboundary climate risks in the coffee sector provides an example of opportunities for multilateral cooperation on adaptation, as for many other critical commodities that connect people and productive processes across the world.

Critical reflections on existing policy tools and their limitations

Current adaptation governance does not sufficiently support or enhance wellbeing and equity. We need an approach to adaptation at the global level that centres explicitly on human wellbeing, equity and justice if we are to enhance rather than undermine them.

The first step in applying these principles to our understanding of climate risks is to recognize climate change impacts as transboundary, as systemic, and as the product of our interconnections with other people, economies, environments and societies. This requires new ways to measure societal progress that go beyond gross domestic product (GDP), as well as new ways to assess and track climate risk and the outcomes of adaptation.

In today's world, where multilateral cooperation is threatened by nationalism and populism, how can countries join forces to identify and manage shared climate risks, rather than exacerbate existing tensions? As inequality widens and people all over the world feel increasingly left behind, how can we reduce climate risk and vulnerability for all, instead of redistributing it from one country to another? And finally, if wellbeing is seen as the ultimate outcome of adaptation, how might the adaptation of tomorrow differ from the adaptation of today?

Adaptation interventions must try to address the root causes of vulnerability to climate change, and the power relations and associated inequalities that define levels of climate risk and resilience. While it is crucial to avoid maladaptation, evidence and practice suggest that this is not enough: adaptation responses that do not consider systemic inequities have been found to result in the further marginalization of those who are already vulnerable. If it is to enhance wellbeing, adaptation must tackle the inequities that drive vulnerability to climate risk. Indeed, effective adaptation is not possible unless it is just adaptation.

Adaptation actions must be better coordinated and advanced in cooperation and solidarity. It is not only climate risks that cascade across borders: adaptation can also generate a ripple effect of benefits. Harnessing these benefits means working together, transitioning from "reactive" to "transformative" adaptation and recognizing climate change resilience as a global public good.

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Conclusion

Madison Cilk[1]

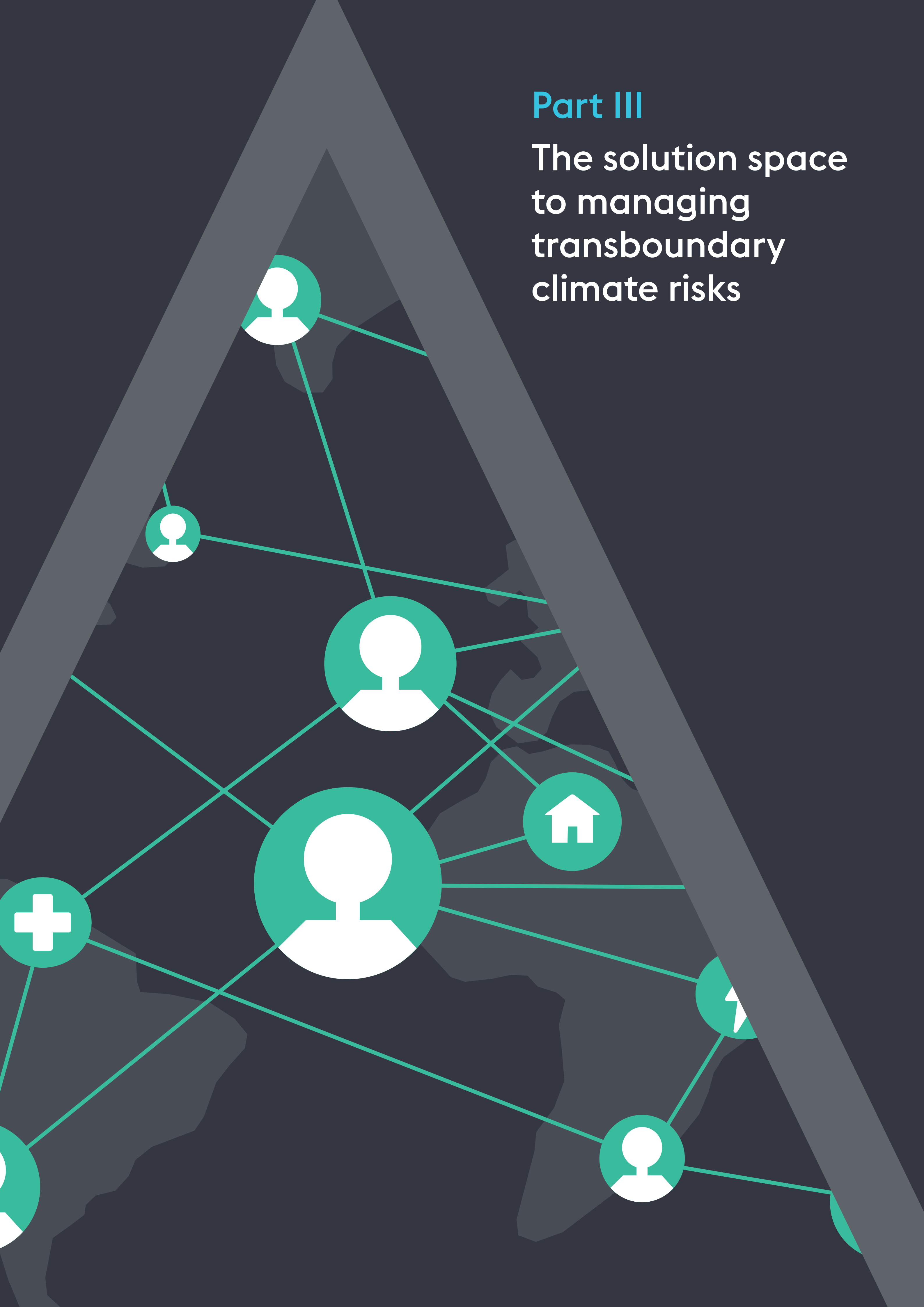
These 10 thematic chapters assess transboundary climate risks and provide insights into policy processes and governance arrangements, illustrating the successes and challenges of managing these risks. No region is untouched by these risks; cascading impacts of climate change can transmit across systems and scales (from local, regional and global scales). Local communities, particularly in climate-vulnerable developing countries, are uniquely threatened by both local and transboundary climate risks. Social justice and threats to wellbeing therefore arise as major themes throughout the 10 chapters in Part II of this report.

Efforts to adapt to the effects of climate change can similarly have transboundary impacts, as decisions taken at international and national scales have direct impacts on local livelihoods and wellbeing. It is therefore essential that stakeholders across scales recognize and aim to mitigate cross-border and cascading climate impacts, and create adaptation strategies which factor in potentially far-reaching implications. The following sections in Part III of this report highlights the role that policy can play in reducing transboundary climate risks.

1 Sciences Po University, France

Part III

The solution space to managing transboundary climate risks



Introduction

Part III explores policy and governance opportunities to address transboundary climate risks at different scales: from global and multilateral to regional, national and subnational. The analyses and case studies in Part II have demonstrated some opportunities but also gaps in policy at every scale to address and prepare for these risks. Indeed, Part II tells us that the concept of transboundary climate risks across sectors, jurisdictions and population groups – both within and across borders – has close connections with two other concepts emerging in climate change adaptation policy: cascading climate risks (i.e. domino effects) and compounding risks (i.e. cumulative interactions between several risks and/or risk drivers). Together, transboundary climate risks, cascading risks and compounding risks describe *systemic risks*, and will influence the magnitude, lifespan, rate of emergence and spatial propagation of individual climate risks across systems (O'Neill et al., 2022).

In this context, there is growing recognition that adaptation policies must look beyond the classical 'one-risk-in-one-context approach' (e.g. drought in one local area or country) and prepare to deal with systemic risks. This preparation should include the consideration of cross-border risks induced by adaptation-related responses to the climate crisis. However, while the evidence base is building on transboundary climate risks, it raises multiple governance challenges in practice, and requires the development of new assessment approaches and analyses to inform policy options to adapt to these risks, which is covered in the following sections. Importantly, there is also a critical need to enhance awareness in all layers of the society, from decision-makers to adaptation practitioners and the public, about the reality of transboundary climate risks and the need to tackle them collectively.

Transboundary climate risks call for more global cooperation on adaptation, with international policy fora as key drivers.

3.1 Policies and governance to manage transboundary climate risks

Richard J.T. Klein

Parts I and II of this report have shown us that the impacts of climate change are not confined by national borders. Likewise, actions to adapt to climate change can have impacts far beyond the area or country where they are implemented. These insights challenge the current framing in climate policy: that climate change adaptation is local, while mitigation is global.

One key insight is that adequate and effective adaptation requires knowledge of how climate risks connect with and affect other parts of the world – whether through trade and supply chains, capital flows, human mobility or the sharing of natural resources among countries.

Sir David Attenborough captured those interconnections during the Covid-19 pandemic when he said:

> Perhaps the most significant lesson brought by these last twelve months has been that we are no longer separate nations, each best served by looking after its own needs and security. We are a single, truly global species, whose greatest threats are shared and whose security must ultimately come from acting together, in the interests of us all. (BBC News, 2021)

The pandemic has revealed just how difficult it is to manage global, systemic and compounding crises. And while the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC, 2015) recognizes adaptation as a global challenge faced by all, it continues to be treated as a local-to-national responsibility. What then are the opportunities – at the global, regional and national level – to strengthen international policies and governance for the management of transboundary climate risks?

The *Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC), and in particular the contribution by Working Group II on impacts, adaptation and vulnerability, finds that adaptation progress has been uneven and too slow (IPCC, 2022). The report reveals an adaptation gap between what is being done and what is needed. This is confirmed by the *Adaptation Gap Report* (UNEP, 2022), which shows that the gap – in terms of planning, implementation and finance – is widening. Both reports stress the urgent need to raise our collective adaptation ambition in response to increasingly severe climate risks and to avoid reaching adaptation limits.

Equally disconcerting is the IPCC finding that climate risks are becoming increasingly complex and more difficult to manage. Compound, cascading and transboundary climate risks were all but overlooked in previous IPCC reports, but the 2022 report devotes considerable attention to the issue across several chapters, providing evidence of the cascading and transboundary nature of climate risk as a cross-cutting adaptation challenge. However, the IPCC could not assess how best to manage these risks and who should be involved because research on these issues is still in its infancy.

"It is clear . . . that the management of transboundary climate risks requires action and initiatives at multiple levels of governance, from global to regional and national."

It is clear, however, that the management of transboundary climate risks requires action and initiatives at multiple levels of governance, from global to regional and national – and enhanced coordination and cooperation across actors operating at these levels. This part of the report will highlight opportunities at each of these levels. First, it discusses two global processes established by the Paris Agreement: the Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation and the global stocktake. And second, it explores regional governance arrangements and national adaptation planning.

3.1.1 Transboundary climate risks under the UNFCCC

Richard J.T. Klein

As well as recognizing adaptation as a global challenge, the 2015 Paris Agreement established the global goal on adaptation as one of three long-term goals (the other two being mitigation and support):

> enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2. (UNFCCC, 2015, Article 7.1)

A global stocktake will be held every five years to assess collective progress towards the achievement of the long-term goals set out in the Paris Agreement, with the first scheduled for completion in 2023. However, it has been difficult to translate the imprecisely worded global goal on adaptation into operational practice, or to agree on how to assess progress towards its achievement. Attempts to do so over the past six years have revealed "methodological, empirical, conceptual and political challenges", which the two-year Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation, established in 2021, aims to address (UNFCCC, 2021, Decision 7/CMA.3).

The Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation

The Glasgow–Sharm el-Sheikh work programme is an opportunity to consider (and reconsider) what it takes to plan, implement, support, strengthen and track adaptation action to reduce climate risk around the world. The work programme itself consists of eight workshops during 2022 and 2023,[1] which aim to result in a convergence of views on how to interpret and assess the global goal on adaptation – including as part of the second global stocktake in 2028 – and how it can be pursued.

One year into the work programme, the Parties to the Paris Agreement decided to initiate the development of a framework to guide the achievement of the global goal on adaptation. They also decided to review the framework prior to the second global stocktake, due in 2028. This suggests that the framework is intended to be operational beyond the two-year lifetime of the work programme itself. The scope and reach of the framework will be discussed and decided during 2023.

The Glasgow–Sharm el-Sheikh work programme was established at the 2021 United Nations Climate Change Conference (COP26), a few months before the release of the Contribution of Working Group II to the *Sixth Assessment Report* (IPCC, 2022). It could not, therefore, benefit from the latest scientific insights on climate risks, including the finding on their increasing complexity and more difficult management. This finding applies in particular to transboundary climate risks and the growing need for cross-border collaboration, which the IPCC mentions no fewer than four times in its summary for policymakers.

While transboundary climate risks are not specifically mentioned in the decision that established the Glasgow–Sharm el-Sheikh work programme, they are getting more attention from policymakers. Several countries or groups of countries[2] have mentioned these risks when submitting their views on the work programme and in the workshops. And at each workshop to date, representatives of developing and developed countries and observer organizations have made relevant comments, showing growing awareness of and support for this issue.

But far more is needed. The work programme must update the adaptation narrative. Rather than reflecting a predominant local-to-national focus on single hazards, it should recognize adaptation as a global challenge faced by all with local, subnational, national, regional and international dimensions, in line with the Paris Agreement. Part of this global challenge involves addressing complex climate risks that are compound, cascading and cross-border. The work programme should also redefine adaptation ambition in response to the complexity of climate risk, and set out what – and who – should be involved in raising this ambition.

This report provides inputs for the work programme and any more permanent successor. It also aims to inform the broader process of enhancing countries' collective understanding of complex and transboundary climate risks and the global nature of the adaptation challenge.

The global stocktake

Without focusing on individual countries or groups of countries, the global stocktake is intended to inform and stimulate the periodic ramping up of collective ambition on climate action and support. Each five-year global stocktake cycle allows countries to build on their previous results when formulating and submitting updated or new nationally determined contributions (NDCs). The global stocktake for adaptation is mandated (UNFCCC, 2015, Article 7.14):

- to recognize the adaptation efforts of developing countries
- to enhance the implementation of adaptation action
- to review the adequacy and effectiveness of adaptation action and support, and
- to review the overall progress made in achieving the global goal on adaptation.

The global stocktake on adaptation will be informed by the Glasgow–Sharm el-Sheikh work programme. In addition, it will be based on a wide range of materials, such as the IPCC Sixth Assessment Report and a synthesis report on the state of adaptation efforts, experience and priorities (to be prepared by the UNFCCC Secretariat). Other possible sources of input include submissions from non-Party stakeholders and observer organizations (UNFCCC, 2018), including this report. The thematic assessment chapters and illustrative case studies presented in Part II offer unique insights into the challenges involved in assessing and managing a diverse set of transboundary climate risks that can be included in the technical assessment of the global stocktake.

Metrics provide another example of how the global stocktake could incorporate transboundary climate risks. As outlined by Möhner (2018), adaptation metrics have evolved under the UNFCCC and its Paris Agreement.

1 Four workshops per year; the workshops held in 2022 addressed the following topics: "Enhancing understanding of the global goal on adaptation and reviewing progress towards it", "Enhancing adaptation action and support", "Methodologies, indicators, data and metrics, monitoring and evaluation" and "Communicating and reporting on adaptation priorities". The first workshop in 2023 was on "Transformational adaptation and indigenous peoples' wisdom, values and knowledge".

2 These include: AOSIS (Alliance of Small Island States), Australia, Argentina, Colombia, AILAC (Independent Alliance of Latin America and the Caribbean), ABU (Argentina, Brazil and Uruguay) and the Republic of Maldives.

The author distinguishes:

- metrics to identify and prioritize adaptation needs
- metrics to monitor and evaluate adaptation progress and actions, and
- metrics to evaluate effectiveness, adequacy and collective progress.

The third type of metrics is of most relevance to the global stocktake, but also the least developed. And none of the metrics considered refer – as yet – to transboundary climate risk. Assessment frameworks are progressively emerging [see Section 3.2], but no concrete outcomes are expected to be ready for the first global stocktake.

3.1.2 Regional perspectives on transboundary climate risks and governance arrangements

Ariadna Anisimov, Magnus Benzie, Madison Cilk

Regional adaptation governance mechanisms to identify and manage transboundary climate risks are not yet well-defined (Dzebo et al., 2023). Two neighbouring countries may characterize sets of risks differently, depending on their socioeconomic and development priorities, as well as their cultural values. Indeed, what one country sees as a risk may be seen as an opportunity by another country in the same region. For example, transboundary shared water resources such as river corridors and basins can host one country's hydropower dams for net-zero transitions and water security, yet create potential cascading risks for its neighbours downstream.

The regional geopolitics of countries sharing borders or economic groupings will also influence institutional arrangements and possibilities for the governance of transboundary climate risks. Geopolitical navigation is particularly crucial around those risks related to shared natural resources, mobility or trade and commodity markets. As an example, the various regional economic communities within West Africa that are united by trade and sometimes political and military cooperation have developed regional frameworks to enhance the mobility of people and livestock across borders. Yet, few member countries have signed – or are willing to implement – such freedom-of-movement protocols.

Several regions around the world share transboundary climate risks while having different governance arrangements and policy solutions. In this section, we illustrate this with three examples in the African continent, the Hindu Kush Himalaya and the Caribbean.

Insights from Africa

Africa is highly exposed to climate change and to transboundary climate risks from countries far away because of its connections to global food supply chains (e.g. rice imports from Asia) as well as risks originating within the continent. In the Sahel region, for example, the cascading impacts of climate change on livelihoods, agriculture and pastoralism are spilling over to interact with pre-existing challenges to human and community security as well as natural resource management. Regional risks are also highlighted by the challenges posed by climate change to traditional livelihoods and shared natural resources that cut across borders.

These risks are recognized in Africa's *Climate Change and Resilient Development Strategy and Action Plan (2022–2032)*, which sets out a priority area for intervention to: "strengthen coordination among the African Union and its structures, as well as key regional partners, in supporting Member States to achieve climate action"(AUC, 2022, p. 32). It underlines a regional approach based on coordination between economic communities and member states to address transboundary and cascading climate risks.

Coordinated adaptation activities to address these regional risks are now being developed. For example, regional water management and governance arrangements are shifting to address transboundary climate risks in relation to climate-sensitive shared ecosystems and livelihoods, especially water resources such as river basins and pastoralist cultures.

In West Africa, a Regional Water Observatory has been established, led by the Economic Community of West African States (ECOWAS) (Harris et al., 2022a). The programme aims to develop knowledge about cross-border climate change impacts and support the mainstreaming of adaptation into Integrated Water Resource Management plans for transboundary river basins in the region. Other observatories led by ECOWAS include those on marine and biodiversity issues, which can also contribute to capacity building for the planning of adaptation to cross-border climate risks on coasts and other ecosystems.

Elsewhere in Africa, neighbouring countries are developing regional member state agreements to address cross-border and cascading climate risks. In Africa's southern region, up to eight countries share three main transboundary river basins: the Limpopo, Okavango and Zambezi

"Climate change has increased covariate risks across the Caribbean, with specific ramifications for the region's ambitions for shared economies, the pooling of risks, and other multi-level resilience-building measures."

Basins. Transboundary climate risk adaptation must, therefore, address water accessibility and energy needs from hydropower across these shared river basins. Measures to increase water and energy resilience across such shared resources include setting up agreements on transboundary water basins that consider climate change and future socioeconomic development, and developing joint or compatible frameworks for adaptation.

Insights from the Hindu Kush Himalaya

Stretching across eight countries – Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan – the Hindu Kush Himalaya region is arguably the world's most important "water tower". It is the source of 10 of Asia's largest rivers as well as the largest volume of ice and snow outside the Arctic and Antarctica. Several regional initiatives are being led by countries and organizations in this region to bolster cross-border cooperation for sustainable mountain development and long-term adaptation.

The Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI), for example, promotes transboundary cooperation for the conservation of ecosystems, biodiversity, and ways of life across China, India and Nepal (ICIMOD, 2022). The sharing of knowledge, evidence and practices is a key part of this initiative and other regional frameworks in the region that recognize the need to tackle cross-border and cascading risks as critical for the achievement of national adaptation goals that are tightly linked and dependent on neighbouring countries.

Insights from the Caribbean

Climate change has increased covariate risks across the Caribbean, with specific ramifications for the region's ambitions for shared economies, the pooling of risks and other multi-level resilience-building measures. For example, while substantial progress has been made on poverty reduction across the region, transboundary climate risks are threatening to reverse those achievements. Given that most Caribbean countries are small islands with high exposure to climate risks and limited resources to respond to them, transboundary adaptation solutions can significantly reduce climate-induced shocks at multiple levels.

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) was created in 2007 and is the first multi-country "risk pool" in the world. The CCRIF shows how regional cooperation can be leveraged to tackle transboundary climate risks, as its core policies are supported by both traditional and capital markets. Climate protection instruments such as CCRIF can reduce the use of coping mechanisms that deplete the reserves of those whose livelihoods are weather-dependent.

The Caribbean region is also particularly vulnerable to cross-border climate risks that compound with other global events, such as pandemics and conflicts. Many of its small islands are highly dependent on imports, given their limited agricultural productivity and landmass, which exposes them to risks in global food supply chains.

Small-island states in the Caribbean (but also countries in Latin America) are highly dependent on cereal imports from the US, for example. Maize, wheat and soy imported into the Caribbean are critical for livestock production and food security, resulting in high vulnerability to transboundary climate risks (Adams et al., 2021). Jamaica consumes roughly 320 000 tons of maize each year for its domestic meat and poultry production and the local ethanol market; 87% of that maize is imported from the US, which is projected to suffer yield declines of 45.5% by the end of the century (Davis & Hocquet, 2021). Jamaican consumers are, therefore, highly exposed to climate change impacts on farming in US states like Iowa: a characteristic shared by many of its neighbouring islands.

Jamaica itself has little capacity to influence the international maize market. However, it can act with its Caribbean neighbours to enhance the prospects of collective regional resilience. This can be achieved through regional insurance, strategic grain storage, easing intra-Caribbean and Latin American trade and even acting together in international and global trade and other negotiations – all of which can work in combination to offer a new and previously untapped adaptation pathway for tackling transboundary climate risk.

The examples of regional adaptation governance and policy from Africa, Hindu Kush Himalaya and the Caribbean show that this is about more than recognizing climate risks around shared ecosystems and natural resources. It is also about understanding exposure to transboundary climate risks connected to distant places via trade, supply routes and financial pathways.

In the African agricultural sector, trade agreements have the potential to help offset transboundary climate risks by reducing import dependence and protecting domestic markets. This potential is limited, however, by weak institutional mechanisms to enforce these ambitious goals.

The question of building regional resilience in the Hindu Kush Himalaya to transboundary climate risks that originate outside the region, for example via threats to remittance flows or food trade, have not yet featured in discussions about regional governance of transboundary risks. Instead, these discussions tend to focus on more familiar transboundary impacts, such as the downstream effects of landslides and flooding, for example.

The experience of the Caribbean region demonstrates that regional adaptation frameworks should include economic and trade policy to address shared exposure to transboundary climate risks. This offers a way forward for cooperation and regional integration that does not leave any neighbouring country behind.

3.1.3 National adaptation plans to identify and assess transboundary climate risks

Sarah Opitz-Stapleton

National governments increasingly acknowledge transboundary climate risks impacting them, but struggle to identify these risks in their national adaptation instruments, including the effects of their own adaptation measures on other countries.

Governments can, however, set adaptation standards, promote a culture of risk awareness, and shape investments that have a direct impact on the livelihoods of people outside of their jurisdiction. They can address transboundary climate risks by coordinating with neighbouring and distant countries to assess the impacts of national adaptation policies. The further development of assessment methods [see Section 3.2] can support the integration of these risks into adaptation plans by highlighting key areas of cooperation (e.g., the most prominent transboundary climate risks at a given regional level) and helping to set up shared adaptation objectives.

At the national scale, the UNFCCC National Adaptation Plan process was established under the Cancun Adaptation Framework to assist national governments in the governance of climate risks, including medium- to long-term climate adaptation planning and the definition of institutional mandates and implementation needs. The process is designed to be flexible, iterative and country-specific, enabling countries to assess priority climate risks and integrate adaptation measures into their national socioeconomic plans, policies and programmes.

While the 2012 *Technical Guidelines for the National Adaptation Plan Process* promotes the identification of regional climate risks and regional adaptation planning and implementation, progress toward regional and international transboundary climate risk governance remains a recognized gap and need (Least Developed Countries Expert Group, 2012; UNFCCC, 2020). At present, adaptation plans are defined and developed at the local to national scale and often in isolation from one another, with a danger that they will create their own cascading effects by redistributing – rather than reducing – vulnerabilities and risks. With a growing focus on transboundary climate risks, subnational and National Adaptation Plans could help to identify and assess the exposure to these risks from abroad. They could also improve our understanding of how a country's direct exposure to climate risk can create vulnerabilities for others, and where its adaptation actions enhance the resilience of others and contribute to make climate adaptation a global public good. There are therefore opportunities for enhanced coordination and cooperation between regional bodies (such as the regional economic communities in Africa) and individual countries in addressing and managing transboundary and cascading climate risks [see Section 3.1.2].

> "National governments increasingly acknowledge transboundary climate risks impacting them, but struggle to identify these risks in their national adaptation instruments."

The transboundary climate risks that are recognized explicitly in policies and the way in which they are characterized in terms of vulnerability and exposure factors both reflect the kinds of adaptation options and actions prioritized by a country. Subnational plans, national adaptation instruments (e.g. legislation, policies) and national socioeconomic development visions and sectoral policies are beginning to mention transboundary climate risks. However, similar to the challenges raised above for the global level, important questions remain open at the national level on how transboundary climate risks should be managed and by which government ministries, as well as which metrics and funding mechanisms should be used.

For example, legal frameworks and sectoral mandates for livestock, agriculture, energy, land, water and mineral resource management and mobility of people are most often led by different government ministries that act in silos. Subnational and national sectoral policies within a single country may therefore be in conflict or contradictory. These factors undermine coherence in climate adaptation planning to address cascading impacts across sectors, including transboundary climate risk governance.

At the local and subnational levels, municipal and subnational governments often lack the legal and financial capacities needed to address climate change risks and rely, therefore, on national and international policies to address them. Local governments can, however, address this by, for example, engaging in public-private partnerships to benefit from private funding and expert knowledge for adaptation efforts. In addition, joining city networks that advocate transboundary climate risk reduction and promote knowledge sharing is one way to better engage local stakeholders.

3.2 Knowledge for better governance: the assessment and tracking of transboundary climate risks

Alexandre K. Magnan, Magnus Benzie

Meeting the governance challenges of transboundary climate risks and seizing opportunities for their management demands a more structured understanding of these risks now and into the future. This report is innovative as it draws together an evidence base of transboundary climate risks by providing groundwork on 10 globally significant examples across a range of sectors and systems [Table 1 in Part I, and Part II]. However, there are still gaps in the methods to assess and characterize these risks that are crucial for the design of transnational policy responses and coordinated governance arrangements. This section sets out key steps for research to inform different scales of climate policies – from the global to the regional and national – to better address transboundary climate risks in climate change adaptation as a contributor to systemic risks. It outlines four potential areas for progress:

- opportunities for innovative research on transboundary climate risk
- the design of indicators to track transboundary climate risks
- research on the future of transboundary climate risks based on scenarios and foresight exercises, and
- the use of foresight and scenario exercises also to characterize policy pathways to address transboundary climate risks.

3.2.1 Opportunities for innovative research on transboundary climate risks

Angela Hawke

There has been little in-depth scientific research to date on the nature of transboundary climate risks, their timescales, their transmission modes and related adaptation policy responses. Similarly, there have been few – if any – robust assessments of both transboundary risks and the potential cascading, cross-border effects of adaptation decisions (particularly at the national level); or the relevant governance arenas and mechanisms.

Harris et al. (2022b) argue for more innovation in adaptation research to better reflect the complexities and interdependencies that characterize today's world. As shown in Figure 15, they have proposed a seven-step research protocol, which builds on principles for the management of complex risk and frameworks for the assessment of transboundary climate risk and multi-level risk ownership. The protocol is designed to enable case-study research on identifying, assessing and appraising transboundary climate risks, and to enquire into appropriate risk owners and adaptation options across scales.

The complexity of multiple interacting variables and the transmission of effects related to transboundary climate risks across diverse jurisdictions calls for innovative approaches to climate risk assessment and adaptation planning. If we continue to apply a highly quantitative, standardized and national-level approach to climate risk assessment, we may well underestimate levels of risk exposure, fail to identify actors who may be vulnerable

"There has been little in-depth scientific research to date on the nature of transboundary climate risks, their timescales, their transmission modes and related adaptation policy responses."

to climate risk, and neglect to motivate the necessary investments in (and cooperation on) adaptation at national, regional and international scales. New kinds of climate risk assessments are therefore needed that account for both systemic complexity and future uncertainties – such as the use of foresight and scenarios [see Section 3.2.4] to determine the dynamics of different kinds of transboundary climate risks beyond the available real-world case studies.

We know that the degree to which such risks are, or could be, managed by regional and global governance systems and processes varies from sector to sector. Evaluating the propagation of impacts and responses across the network – as well the effect of adaptation activities or other initiatives that aim to build resilience – is, therefore, critical for a better understanding of the dynamics of transboundary climate risks, how they are transmitted and who they ultimately affect.

3.2.2 Designing indicators to track transboundary climate risks

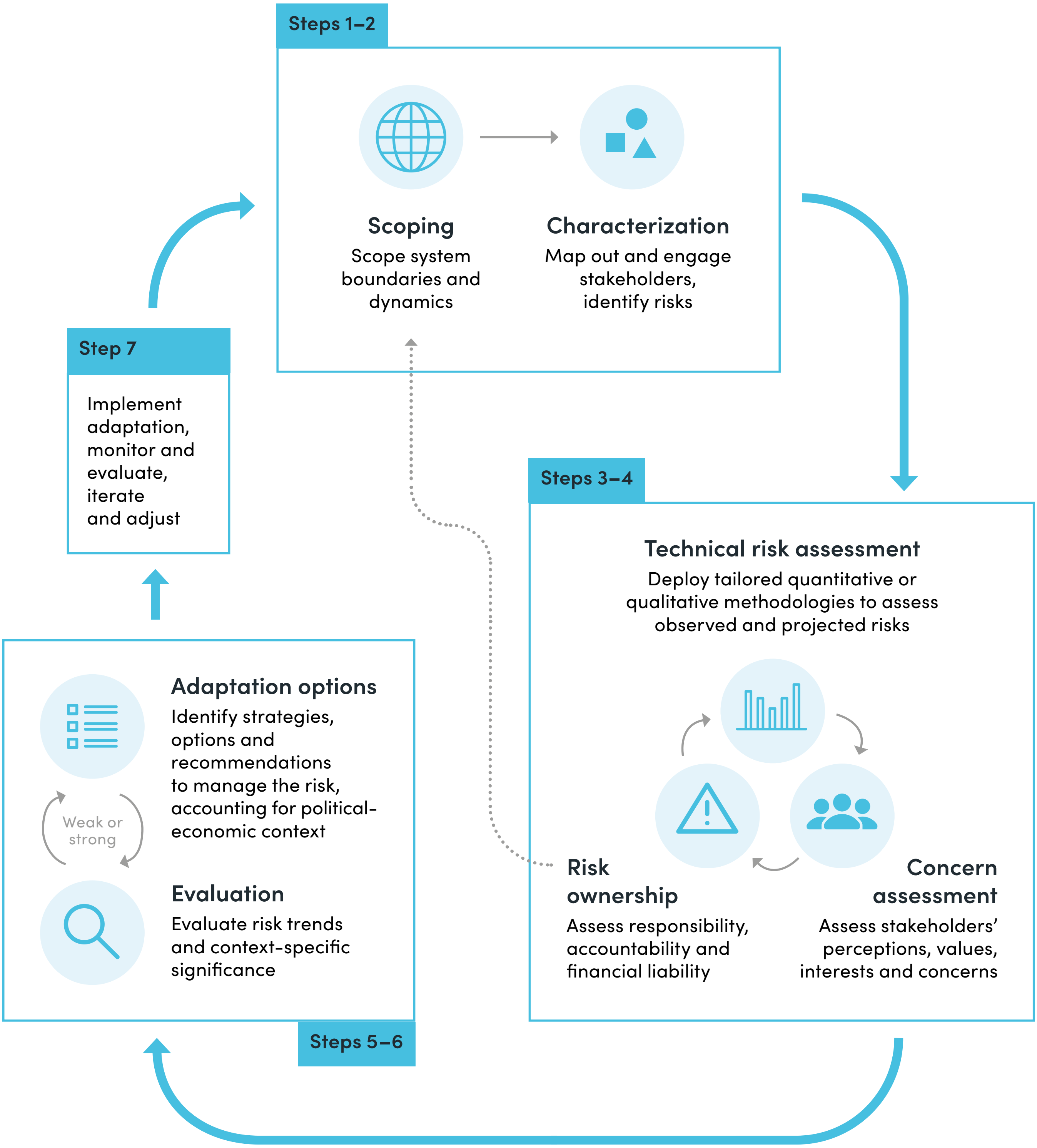
Magnus Benzie

The tracking of transboundary climate risks is a new scientific challenge, and studies to either scope or address these risks are only beginning to emerge. However, the literature on tracking adaptation progress at the global level is more established and explores some approaches, such as the Global Adaptation Progress Tracker (GAP-Track) methodology, that hold some promise for the tracking of transboundary climate risk.

Magnan et al. (2021a) propose options for the upscaling of their methodology for the conduct of a global assessment, some of which have potential for the incorporation of transboundary climate risk, for example large regions, socio-geographical systems, sectors and hybrid approaches. Representative adaptation challenges can then be identified – including ones that incorporate transboundary climate risk (e.g. in the global food system, or large transboundary ecosystems). The GAP-Track methodology can be followed to derive an expert-led assessment of adaptation progress.

Indicators to track transboundary climate risk face conceptual and quantification challenges as indicators for

Figure 15. A proposed seven-step research protocol for the analysis of transboundary climate risks



Source: Harris et al. (2022b). © American Meteorological Society. Used with permission.

adaptation at other scales. Given the higher degree of complexity associated with cross-border systems and flows, it is even harder, in most cases, to attribute a material risk to a specific climate trigger. It is even more difficult to classify an outcome as being the result of a climate risk rather than a compound series of drivers, with climate change just one driver among several.

The collection of data that describe cross-border flows in complex systems is also a daunting challenge. Traditional trade statistics, for example, are compiled by various organizations such as the UN Comtrade Database, but tend to describe bilateral trade flows only. That is not sufficient for the assessment of supply chain risks where multiple tiers of trade are involved. There are various modelling approaches and sector-, product- or regional-specific databases that can provide that information, but this fragments and complicates the task of global aggregation, integration and comparability that is necessary for the development of robust and useful indicators.

There is a pressing need – and clear potential – to develop transboundary climate risk indicators. Given the multi-scale dynamics of transboundary climate risks, *indicators to track these risks could be developed at two different and complementary scales: national and system level.*

At the national level, indicators could be developed to assess a country's changing exposure to transboundary climate risk and to track the progress of national adaptation efforts to reduce or manage these risks. Indicators could also be developed to identify and track the cross-border consequences of national adaptation measures (e.g., where a National Adaptation Plan has positive or negative implications for neighbouring countries or trade partners: a key dimension of transboundary climate risk). National indicators would be based predominantly on national-level statistics and data.

At the system level, indicators could be developed to track the changing level of climate-related risk in transboundary systems such as commodity markets, human mobility flows or health. These would be based predominantly on global data on cross-border flows [see Box 12]. Suites of national- and system-level indicators could combine to create a picture of transboundary climate risk at the global scale.

Indicators at the national and system level could also be applied to assess adaptation processes and outcomes. These refer to:

- process indicators to assess the coverage of transboundary climate risk in national adaptation documents, such as National Adaptation Plans and Adaptation Communications, and
- outcome indicators to assess changes in risk or loss and damage resulting from transboundary climate risk. In theory, these could be developed at any scale.

It is also important, both scientifically and politically, to track opportunities (i.e. positive outcomes) as well as solely tracking risk (i.e. negative outcomes). This could be vital where adaptation investments and interventions are shown to have "systemic benefits", or boost resilience in places (including other countries) other than the area targeted by the initial investment. Where indicators can demonstrate this pattern of transmission of risks and opportunities, it may help to build the political and business case for greater ambitions on adaptation finance, including finance that is designed and allocated to build "just resilience" with system-wide benefits.

The development of suites of indicators to track transboundary climate risk would fill an important gap in the current evidence base for consideration in the UNFCCC global stocktake cycles. Without the development of specific transboundary climate risk indicators, such exercises cannot be expected to do much more than aggregate initiatives at national scale, leaving a potentially large

Box 12. System-level indicators in agricultural commodities markets

It should be possible to develop a set of system-level indicators to track changes in climate risks for global commodity markets. This would provide a valuable assessment of the status of the adaptation challenge at an international scale. Options might include:

- the inclusion of simple global commodity price indices combined with extreme weather event indices, to illustrate a proxy on the relationship between climate impacts and food insecurity
- the compilation of national data from all countries to provide an overview of system-level changes in the sensitivity of the global food system to shocks. This would provide proxy insights into the status of global resilience. It would reveal, therefore, whether the world is progressing towards or regressing further from the global goal on adaptation. Examples of such indicators include the following (Kummu et al., 2020):
    - food production diversity (the range of food types produced domestically)
    - food supply diversity (the range of food types available domestically from both independence from food imports and the share of each food type that is produced domestically rather than imported), and
    - import connections (number of significant food-import relationships).
- an assessment of resilience in the global food system, as modelled by Seekell et al. (2017). This is also built on national indicators, but provides a system-level overview. The three indicator groups in that study are:
    - socioeconomic access to food (income of the poorest quintile relative to food prices)
    - biophysical capacity to intensify or extend food production, and
    - the magnitude of and diversity of current domestic food production.

Options for developing this kind of approach – for a full range of transboundary climate risks – should be examined in more detail, for example via a Technical Report by the UNFCCC Adaptation Committee, or via partnerships between civil society, the scientific research community and market analysts from the private sector.

shadow of un-assessed transboundary climate risks and adaptation responses. Not only would this render the global stocktake an incomplete assessment of global progress, it would also send an inaccurate message to business and political leaders.

It is essential, therefore, to measure the positive as well as negative contribution of investments in climate resilience to international systems, rather than only measuring their effects at local scale. Shining a light on how adaptation is helping to reduce climate risk in cross-border flows and systems should encourage greater action on adaptation.

The first global stocktake and relevant technical dialogues are already underway for 2023. Current discussions around adaptation progress tracking, such as under the Glasgow–Sharm el-Sheikh work programme on the global goal on adaptation show that there is also country interest in filling the gap on tracking progress on transboundary climate risks. The acknowledgment of the need for indicators on transboundary climate risks is, therefore, a critical component in addressing overall adaptation progress. It is an opportunity to integrate cross-border cascading risks in future cycles of the global stocktake (in 2028 and beyond).

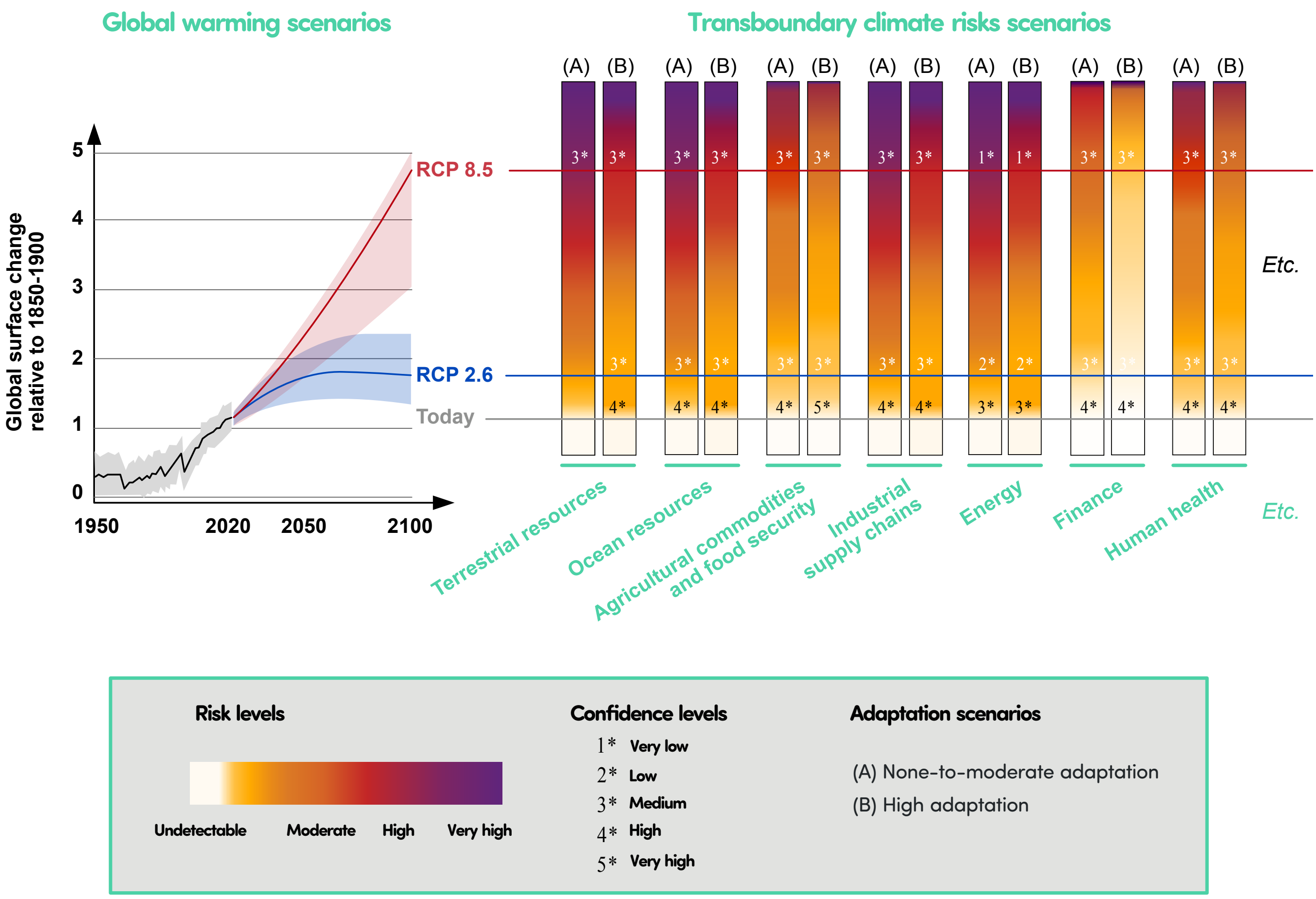
3.2.3 Exploring the future of transboundary climate risks

Alexandre K. Magnan

There is some knowledge on specific topics that are relevant for transboundary climate risks, such as water management, trade and commodities, finance, and human mobility (see chapters 2.1, 2.3, 2.6 and 2.9, respectively). However, we still lack a comprehensive and global-scale understanding of the level of transboundary climate risks we face today, and those we could expect in the future under various climate scenarios [see Figure 16]. Assessing such a "big picture under climate change" raises important methodological challenges, especially in identifying comparable indicators, metrics and other information across diverse transboundary climate risks and in considering future climate and non-climate trends together. In such a context, approaches based on expert judgement exercises could add value.

Expert judgement approaches have a long history and have shown multiple benefits. They have, for example, helped to assess climate risks against temperature changes in the framework of the IPCC and describe potentially

Figure 16. A potential outcome from an expert judgement assessment of transboundary climate risk levels



Source: The global warming panel (left) builds on the *IPCC Special Report on the Ocean and Cryosphere* (Oppenheimer et al., 2019). This visualizes a potential outcome of an expert judgement assessment of a series of risk levels under contrasting climate change and adaptation scenarios.

dangerous anthropogenic interference with the climate system (Zommers et al., 2020).

Most notably, expert judgement assessment methods can *support the generation of scientifically based knowledge when information does not exist or is scattered*, which is the case with transboundary climate risks that are not well documented in the literature or by existing databases. As shown in Part II of this report, there is a lack of scientifically established knowledge on multiple aspects of transboundary climate risks, including both robust and comparable data on risk dimensions across diverse contexts; on the cross-border nature of climate risks and associated responses; and on the changes to be expected in the future.

Expert judgement approaches also *provide a unique opportunity to explore the potential effects of various stages of adaptation response on levels of transboundary risk*. There are key knowledge gaps on the extent to which adaptation can really reduce climate risk today and in the future. Building on recent examples under the *IPCC Special Reports* on the ocean and cryosphere and on land (Magnan et al., 2021b; Oppenheimer et al., 2019), it would make sense to contrast adaptation scenarios that cover the range of responses required to tackle transboundary climate risks.

Two contrasting scenarios could refer to a "None-to-moderate adaptation" scenario – assuming no major additional adaptation efforts – versus a "High adaptation" scenario based on ambitious and effective action (e.g., through the implementation of the policy pathway described in Section 3.2.4) and assuming minimal financial, social and political barriers to the implementation of adaptation measures. Contrasting climate risk levels under various adaptation scenarios is critical to identify the room for manoeuvre in terms of transboundary climate risks reduction, but also the residual risks to be expected.

The use of scoring systems is foundational to an expert judgement process, creating a common language across diverse topics, indicators, sources of information and experts with different backgrounds. The systematic application of scoring systems makes it possible to compare and aggregate risks of a different nature, providing

Table 2. A potential outcome from an expert judgement assessment of transboundary climate risk levels

1. Importance of the affected system or dimension of the system	As described in Table 1 in Part I and Part II of this report.
2. Magnitude of adverse consequences	Magnitude measures the degree to which particular dimensions of a system are affected, should the risk materialize. Magnitude can be approached by assessing: • the pervasiveness of the consequences across the system (geographically or in terms of affected population) • the degree of consequences, i.e. the degree of change in these measures induced by climate change, accounting for the interaction with exposure and vulnerability • the irreversibility of consequences, with their irreversibility over long timescales considered a higher risk than those that are temporary • the potential for impact thresholds or tipping points, with higher risks described through the potential for exceeding a threshold beyond which the magnitude or rate of an impact increases substantially, and • the potential length of the cascade of impacts, with some correlation between higher risks and long impact chains to other ecosystems, sectors or population groups.
3. Likelihood of adverse consequences	A higher probability of high-magnitude consequences poses a larger risk, whatever the scale considered. This probability may not be quantifiable, and it may be conditional on assumptions about the hazard, exposure or vulnerability associated with the risk.
4. Timing of the risk	Transboundary consequences occurring sooner, or that increase more rapidly over time, present greater challenges to interconnected systems. A persistent risk (i.e. long-lasting consequences) may also pose a higher threat than a temporary risk.
5. Ability to respond to the risk	Having only limited ability to address transboundary climate risk favours severe climate risks. This depends on the ability of the system (from where the risk is triggered, to where the impact cascades happen) to reduce hazards (e.g., through ecosystem management), to reduce exposure or vulnerability (e.g., through social policies or economic diversification), or to cope with observed impacts.

Source: O'Neill et al. (2022).

new information on analyses that are specific to transboundary climate risk and that draw on dedicated indicators [see Section 3.2.2]. Scores on the influence of risk drivers could be developed, as well as scores on the potential benefits of a range of adaptation responses, as shown, for example, in the *IPCC Special Reports* mentioned earlier that used either adaptation-specific metrics (to address sea-level rise risks) or contrasted shared socioeconomic pathways.

The development of transboundary climate risk indicators could also benefit from the framing used in the recent IPCC Working Group II report to assess representative key risks and, therefore, thus characterize the "dangerous interference with the climate system" raised within the UNFCCC (O'Neill et al., 2022) [see Table 2].

When developing assessment methods for transboundary climate risks, such as the expert judgement approach, it is important to ensure that the assessment feeds into policy-relevant discussions and is not too theoretical. Past experiences under the IPCC (Oppenheimer et al., 2019) or more individual initiatives (e.g. Duvat et al., 2021; Haasnoot et al., 2019) provide insights on how to move beyond the lack of systematic, consistent and global-scale data. In particular, these studies show that it helps to draw on real-world local or regional examples for two reasons: first, to identify relevant and ground-rooted information, and second, to inject a regional-to-local perspective into global analyses. This helps to capture the reality on the ground and to integrate context-specific considerations.

This approach could be applied not only to the 10 transboundary climate risks framed in Part II of this report, but also to additional themes and case studies. Multiple examples may indeed help to identify commonalities across contexts as well as heterogeneities from one context to another and, therefore, highlight the potential for lessons to be learnt across transboundary climate risks.

The analysis and case studies in this report suggest that three main methodological steps are needed to lay the foundations for future assessments of transboundary climate risks based on expert judgements, as follows:

- First, define a robust methodological protocol, including the metrics to be considered across the transboundary climate risks; the scoring system to be used (range of scores and precise description of each); and the characteristics of the experts and expert groups. The recent approaches under the IPCC or by more specific research groups provide the basis for the consideration of these methodological aspects for the assessment of transboundary climate risk in a more structured, semi-quantitative way.
- Second, identify the warming scenarios to be considered: either two that contrast (e.g. +2°C and +4°C by the end of this century), or also intermediate ones.

"The 'adaptation pathway' approach that has emerged over the last two decades offers a practical way to think about how to organize actions through time and, therefore, drive robust adaptation policy."

- Third, consider contrasting (e.g.) socioeconomic scenarios to illustrate various exposure and vulnerability conditions in the future, as well as various contexts for the operationalization of adaptation scenarios (see next bullet). As for an example, the IPCC relies on a set of five Shared Socioeconomic Pathways (SSP) that are based on societal conditions related to trends in demographics, economics, governance, etc.
- Fourth, characterize in more detail the adaptation scenarios to be considered as well as relevant metrics. While contrasting "None-to-moderate adaptation" and "High adaptation" is one option, another research option could be to consider different scales of adaptation and, therefore, the different potential for the inclusion of transboundary climate risks (Benzie et al., 2018). For example, distinguishing between "narrow or territorial adaptation" and "coordinated adaptation" could help to contrast risk scenarios that view adaptation as primarily local and that neglect potential cross-border maladaptations, versus risk scenarios where investments and efforts consider the effects across entire systems. This research approach could confirm that adaptation that is globally coordinated is better, in qualitative terms, than isolated adaptation measures that are nationally (and privately) led.

3.2.4 The use of foresight and scenario exercises to design policy pathways to address transboundary climate risks

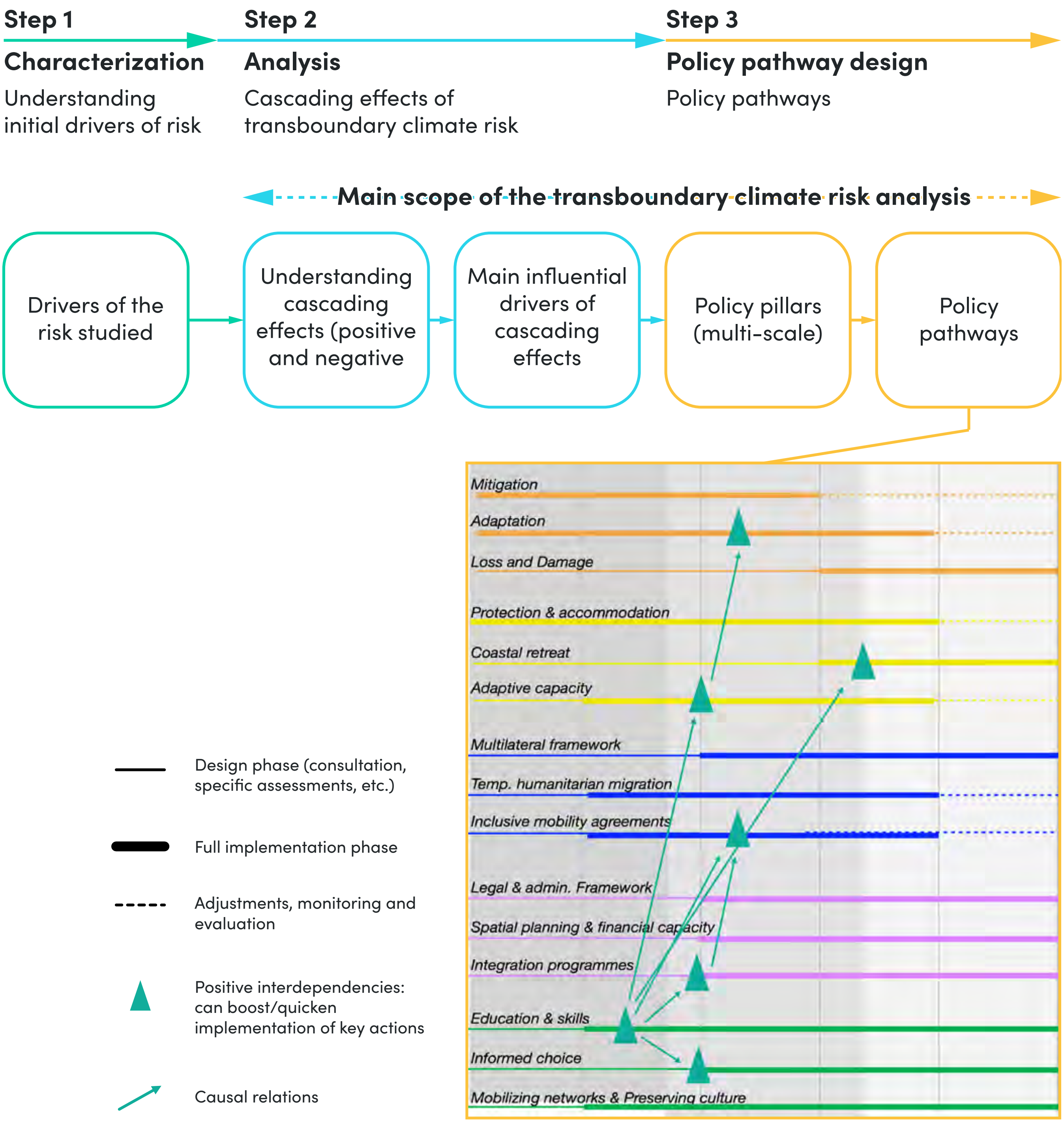
Alexandre K. Magnan

Recent literature highlights the trade-offs between adaptation measures, meaning that their effectiveness in reducing current and future risks is highly dependent on their combination over time, as well as the magnitude and timing of climate changes. The "adaptation pathway" approach that has emerged over the last two decades offers a practical way to think about how to organize actions through time and, therefore, drive robust adaptation policy.

Adaptation pathways describe long-term adaptation strategies based upon decision cycles that, over time, explore and sequence a set of possible actions based on alternative, external and uncertain developments (Haasnoot et al., 2021). The approach is based on the rationale that providing decision makers with diverse paths is critical to enable them to deal with uncertainty. In this approach it is possible to shift from one path to another connected path when a tipping point is reached or an adaptation turning point arises.

In 2021, Adaptation Without Borders developed an exploratory approach to design policy pathways for trans-boundary climate risks, using the example of the cross-border effects triggered by coastal migration induced by sea-level rise (Loiseleur et al., 2021) and considering both positive and negative consequences. This pilot study relied on the identification of major influential factors

Figure 17. Methodological approach to design policy pathways for transboundary climate risks (example of cascading effects of coastal migration across borders)



Source: Loiseleur et al. (2022) and authors' own elaboration.

that could trigger cascading effects, and identified key policy pillars at multiple scales to facilitate adaptation and resilience – whether through local adaptation strategies or adaptive migration when it is the best option available for communities and individuals.

One important aspect was to be able to move from the identification of the main drivers of transboundary climate risks to organized policy pathways, aiming to inform decision making at multiple scales. Figure 17 sets out the potential scope for effective research into transboundary climate risk, based on three main steps: characterization, analysis and the design of policy pathways.

First, the drivers and patterns of climate-related coastal migration were identified (Part II of this report provides examples of such knowledge for a wider set of transboundary climate risks). Second, the work focused on understanding the multiple cascading effects of coastal-induced migration across borders to identify more generic, high-level influential factors. Building on discussions with external experts and insights from the literature, the study highlighted five main drivers that mixed different scales of action:

- unmanageable climate change (global scale)
- increased unmanaged coastal risk and vulnerability (in the areas of origin of the migrants)
- hindered (inter)national mobility
- inadequate hosting conditions in the areas of destination, and
- the negative impacts of migration for migrant communities and individuals.

Third, the team identified 15 main policy pillars to tackle these five key drivers, as shown at the bottom right of Figure 17, as well as their respective timeframes of development (including their design, implementation and follow-up phases) between now and 2050.

For each pillar, preparation and follow-up phases (in Figure 17, plain and dotted thin lines respectively) are needed to lay the foundations of the full implementation phase (thick lines) and ensure positive outcomes over time. These policy pillars are connected, with progress made on one pillar crucial for the development of another pillar, as shown by the green triangles and arrows. For example, scaling up the climate awareness and educational profile of populations (green line) is key for the timely implementation of adaptation measures (orange line). It is also a background condition for inclusive national-level migration agreements that will, in turn, facilitate coastal retreat interventions. Such cascading interdependencies, which can also be negative (i.e. impeding or delaying the implementation of other policy pillars) justify the sequencing of actions and policies and, therefore, the “pathway” approach.

This laid the foundations for the design of a generic policy pathway describing a high ambition, multi-scale policy scenario (see the bottom panel of Figure 17). This scenario enhances our understanding of the positive and negative interdependencies across the 15 policy pillars, highlighting examples of both positive and negative influences (see green triangles and arrows in Figure 17).

Three main methodological steps – and challenges – emerge from our analysis:

- First, identify the main drivers of transboundary climate risks – the challenge being to find the right balance to ensure that these are generic and high-level enough to inform policy, rather than exhaustive.
- Second, identify the most relevant policy pillars, at multiple scales, to address these drivers. Here again, it is critical to strike a balance between being generic and exhaustiveness.
- Third, develop the method for a group of experts to move from policy pillars to policy pathways, which means defining the timeframes for analysis, as well as the warming and socioeconomic scenarios to consider.

Such an integrated perspective illustrates scientific works that could allow policy processes across scales that can anticipate and tackle transboundary climate risks. For example, the 2021 pilot study by Loiseleur et al. confirms that the extent and nature of the potential cascading impacts (negative or positive) depends, critically, on two aspects. First, the design of policies and governance arrangements to coordinate across scales (international, regional and national-to-local communities) to tackle the drivers of transboundary climate risks. And second, the ability to design a forward-looking approach to ensure robust decision making and cooperation over time. The study suggests that the future of any given transboundary climate risk will depend upon how the main drivers of cascading risks are managed at different scales and over time, and upon the related policy pillars and adaptation pathways.

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Conclusions

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As we brace ourselves for accelerated climate change, our interconnected societies must prepare for more cross-border and cascading climate risks.

The insights emerging from this report challenge a narrative that has long been embraced in climate policy: that adaptation is a local challenge, while mitigation is a global concern. The report increases our understanding of the transboundary climate risks caused by the cascading effects of both climate hazards and adaptation responses. It also highlights the need for adjustments in climate policy and adaptation approaches – both regionally and globally – to address these complex risks. In particular, its analyses show that national adaptation instruments must go beyond a domestic focus, to consider shared threats and opportunities in the face of climate change. Three major insights emerge from the report.

- **Climate impacts have far-reaching consequences across multiple borders** via shared natural resources, international trade and finance, global industrial supply chains and human mobility.
- **Emergency responses to climate-related disasters, and even long-term adaptation plans, can lead to transboundary maladaptation** by shifting vulnerability and risk to other places and people across borders.
- **A wide range of cross-border and cascading risks combine to shape the impact of single risks** across economies, societies and natural systems. We now face climate risks to lives, the environment and infrastructure that are likely to be more severe, more frequent and occur at larger scales. They will, therefore, become even more complex to anticipate and manage.

This report explores the multifaceted characteristics of transboundary climate risks through a series of thematic assessments. These analyse how many variables influence transboundary climate risks: exposure to climate hazards; interconnections across ecosystems, economies and critical sectors in global networks; development conditions; and the interaction of all of these factors with non-climate variables, from poverty to conflict. Yet, these are just "the tip of the iceberg" based on a first identification of 10 types of transboundary climate risks.

More assessments are needed to understand cross-border and cascading risk dynamics, such as the magnitude of transmitted risks across borders and the duration of their potential impacts. More examples of lessons learned and potential solutions are needed to identify the social, economic and political conditions for coordinated responses between countries and across scales. Current examples include regional initiatives in the Hindu Kush Himalaya, as well as those steered by the European Union and African Union. The knowledge gaps outlined in this report raise important questions on the nature of transboundary climate risks that need urgent answers.

- **What is the geographical reach of different kinds of transboundary climate risks (their start and end point)?** What factors influence their spread and acceleration? What feedback loops perpetuate these risks?
- **How will climate change influence transboundary climate risks under different global warming and socioeconomic scenarios?** What do these different scenarios mean for living conditions and wellbeing across the globe?
- **How do transboundary climate risks interact and compound with non-climate drivers** such as conflicts, health crises and economic shocks? Is there an amplification effect?

This report also begins to explore the space for solutions. The case studies assessed in this report demonstrate a common lack of preparedness to non-domestic climate risks. Yet these risks cross multiple jurisdictions and sectors, calling for new forms of governance, ownership frameworks and coordination mechanisms across scales. Key questions emerge from the report for the design of policy solutions and governance arrangements.

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4 World Adaptation Science Programme

- **What are the priorities for collective action to better prepare for and manage transboundary climate risks?** As risks cascade through networks globally, where are the critical points for action?
- **What are the opportunities and limitations of existing solutions to enhance cooperative adaptation to these types of risks?** Which kinds of regional and international responses still need to be invented; and what kinds of policies can enhance cooperation at the regional and international level?
- **What types of ownership frameworks are needed** to better define and allocate responsibilities and resources?
- **What processes lead to maladaptation across borders?** What types of governance solutions can help to mitigate or manage the risks of maladaptation in ways that account for political sensitivities, and support adaptation solutions that offer shared benefits and build transboundary resilience?
- **As climate change interacts with and compounds other global crises, how can systemic resilience be strengthened?** What new governmental and intergovernmental mandates are required to build greater resilience in a way that overcomes institutional silos?
- **How can regional organizations and the global climate policy community secure more equitable adaptation solutions to cross-border and cascading climate risks?** As no country is immune to transboundary climate risks, and the greatest impacts are felt by the most vulnerable people in any society, how can multilateral processes drive more just adaptation as part of building collective resilience, ensuring that no one is left behind?

The report presents ways forward to address these complex risks: in knowledge and research, the design of policies and ownership frameworks, and in implementation. It argues for a reframing of approaches to climate risk to better account for their cross-border dynamics, and the need for the full integration of these risks in adaptation policies at multiple scales. It begins to explore new ways to enhance cooperation on adaptation from the regional to global level, with transboundary climate risks confirming that adaptation is a truly global and shared responsibility.

Adaptation Without Borders

adaptationwithoutborders.org

Adaptation Without Borders is a global partnership working to strengthen systemic resilience to the cross-border impacts of climate change. We identify and assess transboundary climate risks, appraise the options to better manage those risks and support policymakers, planners and the private sector to develop climate-resilient and inclusive solutions. We catalyse new alliances and forms of cooperation on adaptation that pave the way towards a more sustainable and resilient world.

This report is produced by IDDRI on behalf of the Adaptation Without Borders partnership

Adaptation Without Borders is directed and managed by three founding members – SEI, ODI and IDDRI – and supported by the contributions of a growing number of partners. For further details on the partnership, visit adaptationwithoutborders.org.

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