Rising to a New Challenge: A Protocol for Case-Study Research on Transboundary Climate Risk

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ABSTRACT: Recent research has highlighted that adaptation tends to focus exclusively on the local and direct impacts of climate change and misses the crucial dimension of *transboundary* climate risk, which all countries are likely to face, irrespective of their level of development. This paper aims to improve the coverage of transboundary climate risk in case-study research for adaptation. It proposes a protocol to help researchers identify how their case studies can incorporate an analysis of transboundary climate risk, thereby supporting more holistic, effective, and just approaches to adaptation. Existing climate risk assessment frameworks and supporting guidelines have significant strengths but also various challenges when applied to the novel context of transboundary climate risk. This is illustrated with reference to the impact chain framework. Its opportunities pertain to both its flexible form and systems-first focus while its constraints include an analytic emphasis on linear cause–effect relationships (that bely the complexity and uncertainty of systemic risk) and its limited applicability to fragmented governance landscapes (in the absence of an effective consideration of risk ownership). After critically examining the suitability of the impact chain framework, a new protocol is introduced, which builds on principles for managing complex risk and frameworks for assessing risk ownership. The protocol is designed to enable case-study researchers to better identify, assess, and appraise transboundary climate risks, as well as enquire into appropriate risk owners and adaptation options across scales. The paper argues for more innovation in adaptation research to better reflect the complexity and interdependency that characterize today's world.

SIGNIFICANCE STATEMENT: This work aims to demonstrate why the transboundary nature of climate risk requires a distinct analytical approach and proposes a seven-step guide that aims to facilitate the exploration of transboundary climate risk through case-study-based research for adaptation. Domestic climate risks continue to dominate the field of climate change research, translating into a significant blind spot in adaptation planning and action. Without the provision of practical guidance—to equip researchers with approaches and tools specifically designed to analyze the transboundary and systemic nature of climate risk—adaptation action will fail to offer sufficient protection against the full range of risks climate change presents. This article begins to address this void and ultimately—through greater recognition and understanding of transboundary climate risk—promote approaches to adaptation that are reflective of the interdependency of our world today and our shared and common future.

KEYWORDS: Adaptation; Climate services; Planning; Policy; Risk assessment

1. Introduction

Despite the degree of global integration that defines our societies and economies today, a false assumption appears to underpin many of our approaches to climate risk assessment and adaptation planning, namely, that "the vulnerability of rich (and poor) countries can be understood independently of their connections and interdependencies with other countries" (Benzie et al. 2016, p. 32). This central tenet of adaptation praxis has had far-reaching consequences (Benzie and Persson 2019); dismantling this false assumption opens up space to redefine our understanding of climate risk and to ultimately improve the way we assess vulnerability, govern adaptation responses, and promote inclusive and sustainable development.

This paper aims to fill an important gap in the current literature with regard to how we explore the existence and significance of *transboundary* climate risks in case-study research. Ultimately the protocol is intended to support decision-makers to better harness opportunities from transboundary climate impacts, while managing their adverse consequences in effective, equitable, and enduring ways.

Transboundary climate risk is defined as 1) the adverse effects of climate change impacts that cross borders[1] and 2) the adverse effects of adaptation measures that cross

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[1] Conceived of as an administrative line separating two decision-making spheres.

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borders (Adaptation Without Borders 2021). In our globalized world, climate impacts in one place can be transmitted to another via flows of trade, finance, people, or shared biophysical resources (Hedlund et al. 2018). And while adaptation responses at any scale can reduce climate risk, they can also redistribute it to other groups or places (Atteridge and Remling 2017) or even amplify risk within complex systems such as international markets (Carter et al. 2021).

We argue that the cross-border nature of climate risk has been overlooked in existing risk assessment frameworks and underexplored in adaptation case studies—resulting in what Moser and Hart (2018) term a "blind spot" in research for adaptation.[2] This creates a "vicious cycle" where fewer attempts are made to analyze these types of risk, leading to a further dearth in understanding of their scale or significance. Society is thus left exposed to, and underprepared for, the full range of threats that climate change poses. This paper aims to provide an initial contribution to break this cycle—to support researchers to strengthen the coverage of transboundary climate risk in case-study research and in so doing reveal options that drive more holistic, effective, and just approaches to adaptation.

The paper begins with a short synopsis of the state of knowledge on transboundary climate risk to illustrate why a distinct analytical approach to case-study research is required. Drawing on the behavior model involving capability, opportunity, and motivation (COM-B) framework of Michie et al. [which is utilized by Langer et al. (2016) to analyze the determinants of research uptake in decision-making and thus relevant here], the paper appraises the extent to which case-study researchers (and wider stakeholders) could hold the *capability* and *motivation* to assess transboundary climate risk as well as the *opportunities* and incentives policy makers and planners have to utilize their findings. The review substantiates the theoretical, methodological, and policy context in which the following case-study protocol is proposed.

The paper goes on to assess the strengths and challenges of adopting existing climate risk assessment frameworks as a basis for case-study research into the novel and challenging context of transboundary climate risk. The impact chain framework and the broader Vulnerability Sourcebook guidelines within which it is housed (Fritzsche et al. 2014)—which were then updated in the 2017 Risk Supplement (Zebisch et al. 2017, 2021) and applied via the 2018 Climate Risk Assessment for Ecosystem-based Adaptation (Hagenlocher et al. 2018)—form the basis of an illustrative case study in this regard. When we refer to the "impact chain framework" as our object of analysis throughout the paper we refer to the framework proposed in each of these three texts as well as the wider supporting guidelines for effective vulnerability and risk assessments they present. The impact chain framework—and its conceptualization of the interaction between hazard, exposure, vulnerability, and risk—is illustrated in Fig. 1.

A novel case-study protocol for the exploration of transboundary climate risks is then introduced. The protocol has its conceptual roots in systems theory and builds on the impact chain framework, the Florin and Bürkler (2017) risk governance framework and the Young et al. (2015) Risk Ownership framework. The paper concludes by arguing for more innovation in adaptation research in order to better reflect the connections and interdependencies that characterize today's world.

2. Transboundary climate risk: The state of knowledge

Transboundary climate risks are distinct in many respects from the direct climate risks that usually form the focus of case-study research for adaptation. These characteristics affect the *capability*, *motivation*, and *opportunity* of stakeholders—including case-study researchers—to identify them, understand and assess their drivers, and appraise options for their effective management through adaptation plans and actions. The paper considers each in turn.

a. Capability

The capability of stakeholders to assess and address transboundary climate risk can be intimated by what the literature reveals in two respects: our theoretical understanding of such risks and how they propagate, and the availability and accessibility of relevant instruments and capacities to practically appraise and account for them. The literature reveals a fast-evolving field. But in both respects, transboundary climate risks present a challenge to case-study researchers of a different order of magnitude than direct climate risks, which have been the subject of many years of analytical attention.

In terms of the capability to theoretically understand these risks, recent studies propose ways to better define transboundary climate risk—with a focus on the risks that cross national borders (as opposed to other administrative scales) and offer broad conceptualizations of the types of events that can catalyze them (encompassing not only climate hazards but also adaptation responses; see Adaptation Without Borders 2021) and in some cases mitigation measures (Wei and Chase 2018).

At least three distinct approaches to conceptualizing transboundary climate risks can be identified: (i) by the nature of the risk, such as the two categories proposed by the Task Force on Climate-Related Financial Disclosures and adopted, for example, by Wei and Chase (2018); (ii) by the mode of transmission, such as the seven categories put forward by Carter et al. (2021), four mechanisms outlined by Challinor et al. (2018), four pathways conceptualized by Benzie et al. (2016), six classifications presented by Hildén et al. (2016), and eight teleconnections proposed by Moser and Hart (2015); and (iii) by what one might term the "public policy impact domain," such as PwC's (2013) five themes. Recent frameworks have further conceptualized transboundary climate risk by identifying the events and processes that trigger them, the scale and characteristics of the systems via which impacts are transmitted, and the targets and dynamics of available responses (Carter et al. 2021; Adaptation Without Borders 2021). Taylor (2013) and Atteridge and Remling (2017), among others, have added to the field with their concept of relational vulnerability and analysis of the cross-border consequences of adaptation interventions, respectively.

[2] For further explanation of why this blind spot has occurred, see Benzie and Persson (2019).

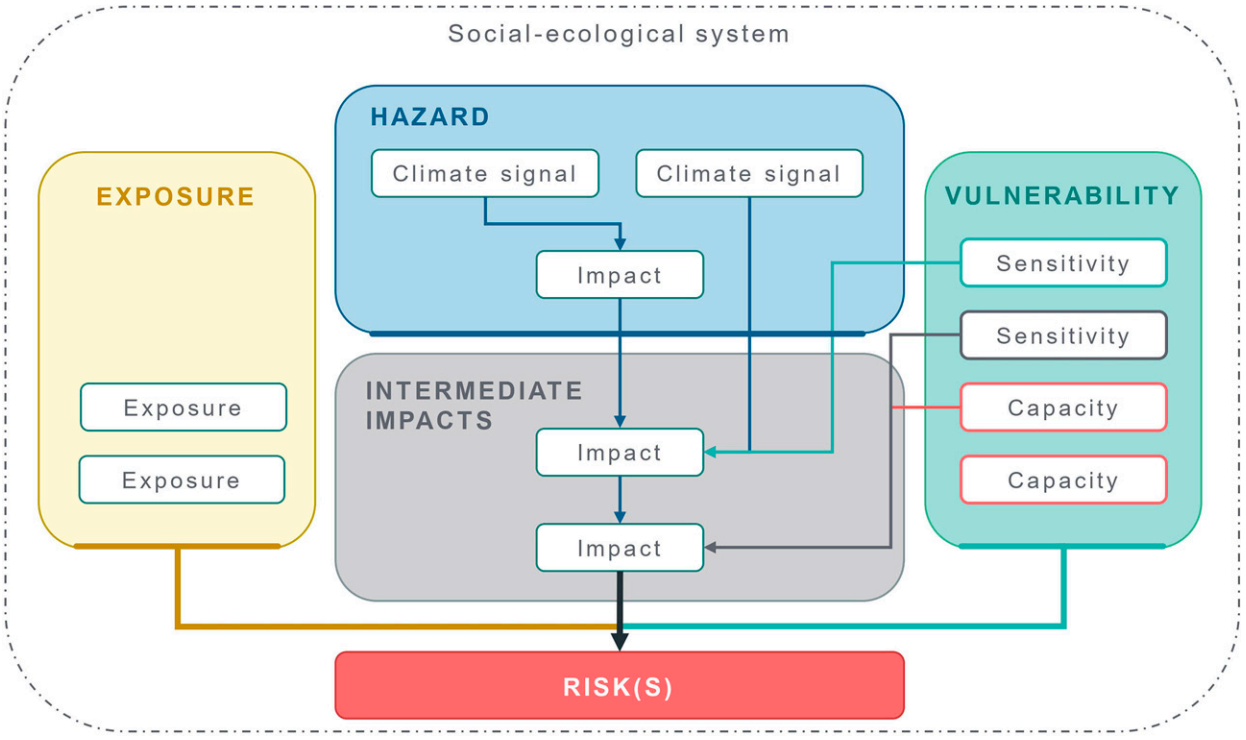

FIG. 1. The impact chain framework, structure, components, and elements (source: Zebisch et al.2017).

Various indicators, metrics, and methodologies have been proposed to either quantitatively or qualitatively assess transboundary climate risk. Some of these have evolved from analytical efforts to appraise exposure to these sorts of risks at the country level, such as the transnational climate impacts index (Benzie et al. 2016; Hedlund et al. 2018). Others have been formulated through a growing number of national assessments[3] (and handful of subnational assessments; see, e.g., Gotangco et al. 2017) focusing either exclusively or in part on transboundary climate risk (Benzie et al. 2018). These include the expert-based qualitative review pioneered by PwC (2013) for the United Kingdom, or the macroeconomic modeling of transboundary risk advanced by Peter et al. (2019, 2020) for Germany. Yet other methods have evolved for practical purposes, such as vulnerability assessments of private-sector supply chains (Wei and Chase 2018).

However, conceptual and empirical research in the field of transboundary climate risk is complicated by a lack of a common terminology[4] and high levels of complexity, ambiguity and uncertainty (as defined by Florin and Bürkler 2017), which characterize these types of risks. Their cross-border and cascading nature can manifest in numerous analytical challenges, including their potential to develop into systemic risks, defined by "high levels of connectivity, major uncertainties and ambiguities, and non-linear cause-effect relationships" (Florin and Bürkler 2017, p. 5). This undermines both the capability of researchers to assess them (i.e., to define risk drivers, acquire relevant and reliable data, deploy familiar assessment methods) and of policy makers and planners to effectively manage them [given the plurality of interests to which they could be subject and lack of "routine" legislative or regulatory measures and policy instruments with which to govern them (Florin and Bürkler 2017)].

In part as a consequence of this complexity, analytical frameworks and methodologies to understand and assess transboundary climate risks are at an early conceptual stage—often presented as innovations to spur discussion rather than advanced assessments on which to base robust risk assessments and credible adaptation plans (see Benzie et al. 2016). They have yet to be adopted by a wide enough number of stakeholders to create a "tipping point" in their uptake or cross a threshold in the likely acceptance of their results. Moreover, the variety of concepts and approaches is itself a barrier to the capability of stakeholders to assess these risks: knowledge is dispersed across a wide field and in a variety of languages, making it difficult to identify and harness best practices. This perhaps accounts for the dearth of implementable strategies or plans that outline adaptation responses to reduce transboundary climate risks—which are, to our knowledge, negligible.

[3] Canada, China, Finland, Kenya, Nauru, Norway, Sweden, the United Kingdom, and the United States, for example (Benzie and Persson 2019).

[4] A diversity of terms is used to describe these sorts of risk ("transnational," "telecoupled," "teleconnected," "cross border," "cascading," "indirect," and "international"); in this paper we use "transboundary climate risk" exclusively, recognizing that other framings might resonate more strongly with certain audiences (Benzie et al. 2016).

More research into these global risks is therefore needed (National Academies of Sciences, Engineering, and Medicine 2021).

The complexity of transboundary climate risk and lack of well-established assessment frameworks clearly inhibits the capability of case-study researchers to study these risks and may even provide a disincentive to do so. However, it is these traits that arguably make case-study research all the more necessary. A context-specific case-study approach facilitates the trialing of bespoke methodological approaches and also has the benefit of generating results of immediate relevance to stakeholders with a specific territorial or sectoral remit. There has been a concentration of case studies on transboundary water resources (see Munia et al. 2020, for example) and studies exploring other aspects of transboundary climate risk are growing in number, from "conduits" such as supply chains (Haraguchi and Lall 2015; Promchote et al. 2016) to "impact areas" such as power markets (Hildén et al. 2018) and food security (Janssens et al. 2020; Zhou et al. 2020). Nevertheless, research for adaptation is still overwhelmingly dominated by a focus on domestic risk and domestic capabilities (Benzie and Persson 2019).

b. *Motivation and opportunity*

The motivation for researchers to initiate case studies on transboundary climate risk, and for decision-makers, planners, and implementers to draw on their findings, are very different to those driving research into direct climate risks.

Literature reveals strong "theoretical" motivations to better understand transboundary climate risk, through the application of this knowledge to develop more comprehensive risk assessments and thus more rigorous and robust adaptation responses. A transboundary lens has the potential to reveal hitherto unknown or underestimated risks that could serve to significantly increase vulnerability to climate change (Benzie et al. 2018). In this context, Benzie and Persson (2019, p. 373) argue "a territorial framing, with nationally or locally scaled adaptation, may even be futile or harmful and serve to 'inadvertently increase systemic risk'."

The literature also reveals a potentially wide array of stakeholders in whose interests it is to better understand these risks: early research indicates that all countries will be exposed to some level of transboundary climate risk, including those who may have previously considered themselves relatively immune to direct climate change impacts (Benzie et al. 2016; Hedlund et al. 2018). Peter at al. (2021) found that the economic consequences of transboundary climate risk via trade alone are estimated to match or exceed those of domestic climate risk in Germany (noting similar findings for Austria and Switzerland). PwC (2013, p. 1) also inferred that international threats may be of an "order of magnitude greater than threats from domestic climate impacts" for the United Kingdom. Acknowledging the transboundary nature of climate risk could create opportunities for countries to extend their contributions to adaptation—and adaptation financing—to build regional and even global resilience (Benzie et al. 2018) and, given high levels of global interdependence, reemphasize the collective incentive to do so (Davis et al. 2016).

However, while there is a clear motivation for adaptation planners and implementers to understand the direct climate risks that originate in their jurisdictions (i.e., their mandate is clear, responsibility and accountability relatively straightforward to assign, and they are likely to have better sight of the climate hazards that trigger such risks), this is markedly different in the context of transboundary climate risks, which originate (by definition) beyond a local or national policy makers' gaze and where the question of "risk ownership" becomes much more significant but complex.

As Nadin and Roberts (2018, p. 8) note, the governance of transboundary climate risk is beset by "fundamental political barriers, such as questions of sovereignty, jurisdiction and responsibility." The inherent cross-border nature of transboundary climate risks, the diversity of ways in which they manifest and the sheer number (and multistakeholder nature) of potential actors involved make it hard to identify who is the "owner" (Young et al. 2015) of such risks, both within and across national contexts. In some cases, transboundary climate risks may not be "owned" at all; in other cases, there may be a form of what Young et al. (2015, p. 29) term "unacknowleged ownership"—where some forms of governance exist to manage the risk, but without being explicitly defined. Even in cases where transboundary climate risks are known, ownership is likely to be multilayered: numerous potential "owners" each with their own agendas, bound by different governance arrangements and influenced by disparate practices of risk assessment and management[5] [see Young et al. (2015) and Florin and Bürkler (2017) for further elaboration of the complexity of risk ownership and management].

The lack of clear ownership means there is no one to push for research on adaptation *to* transboundary climate risk. This appears to be a challenge reflected in many national adaptation plans and (intended) nationally determined contributions, which increasingly recognize transboundary climate risk (Nadin and Roberts 2018) but rarely attribute ownership or accountability for designing an adequate response (Benzie et al. 2016).

The wider institutional and political context also plays a role. As Benzie and Persson (2019) note, the lack of adequate and integrated functions at the national level to manage long-term or systemic risks prevents effective oversight of transboundary climate risk. On the global stage, the backlash from some corners against the value of multilateralism undermines collaborative action to identify and manage risks of common concern (Collins 2019). Within the adaptation community, the dominance of what Benzie and Persson (2019, p. 376) frame a "territorial approach" translates into few explicit opportunities to identify and account for such risks. While the field of academic literature on adaptation may benefit from the application of (for example) political ecology and socioecological systems theory, today's climate risk assessments (that inform the governance of adaptation planning) are based on local or national climate projections rather than

[5] Risk ownership can also evolve over time, as the composition of the risk changes or new knowledge is brought to bear, as the perceptions and interests of concerned parties shift, or as new institutional arrangements in the policy/regulatory environment are introduced (Young et al. 2015).

vulnerability assessments that account for the links and flows to the countries upon which socioeconomic stability may depend (Hedlund et al. 2018). National adaptation planning certainly offers a significant *opportunity* to account for transboundary climate risk, but one that is not automatically realized (Challinor et al. 2017). And in light of the difficulties in "downscaling" transboundary climate risks—to the extent that effective adaptation responses *can* be developed at a subnational level—there are few opportunities for local authorities, the actors most frequently charged with adaptation responsibilities, to manage them (Aall et al. 2012).

This analysis of the "push and pull" factors affecting stakeholders' motivations and opportunities to assess and address transboundary climate risk indicates that current *demand* for case-study research is likely to be low. But that there are also important avenues for researchers focusing on different aspects of transboundary climate risk to drive demand in the future. These include case studies that draw out the collective implications of transboundary climate risks for both high- and low-income countries, compare and contrast exposure to domestic and transboundary climate risk, assess national-level contributions to regional and global resilience, shed light on questions of transboundary climate risk ownership, and substantiate the cobenefits of adaptation across scales (see Lager et al. 2021).

3. The application of climate risk assessment frameworks to case studies on transboundary climate risk

a. *Climate risk assessment frameworks and the impact chain approach*

An assessment of the capability, motivation, and opportunity of researchers to undertake case studies on transboundary climate risk is not complete without a deeper appraisal of the suitable application of established climate risk assessment frameworks (and supporting guidelines) in such contexts.

The impact chain framework aims to support researchers to "understand, systemise and prioritise the factors that drive risk in the system of concern" (Zebisch et al.2017, p. 27). It guides researchers through a series of steps to develop an impact chain, namely to: scope likely impacts and risks from climate change; detect "intermediate impacts"; establish the vulnerability of the system; determine the exposure of the system; and (if desired) appraise adaptation options and responses (Zebisch et al.2017, p. 27). These series of steps are integrated within wider guidelines that together function as a comprehensive methodology for an operational climate risk assessment.

The impact chain framework's innovations and strengths—both as they pertain to the field of study (outlined below) and in relation to more traditional climate risk assessment frameworks (which only account for the direct impacts of a climate trigger)—as well as its growing uptake and application in research for adaptation, make it a strong subject for an appraisal of the degree to which established climate risk assessment frameworks can be usefully applied in the context of transboundary climate risk.[6] For a comprehensive review of the iteration and application of the impact chain framework, and related methods for climate risk assessments, see Menk et al. (2022).

b. *Enablers and constraints of the impact chain framework for case studies on transboundary climate risk*

This paper finds that the impact chain framework contains certain traits that suggest either a strong alignment with a transboundary climate risk perspective or a strong applicability in the context of a transboundary climate risk assessment:

1) The innovative focus on risk drivers and the "cause–effect relationships" that define them (Hagenlocher et al. 2018, p. 37): the impact chain method creates a specific space in the conceptual framework for intermediate impacts generated by "a function of both hazard and vulnerability factors" (Zebisch et al.2017, p. 29) that make it conducive to analyzing the (often cascading) interactions that drive transboundary climate risks (Aall et al. 2020).
2) The emphasis on a systems-first approach: the impact chain framework proposes a focus on the "system of concern" and recognizes that such systems are likely to be impacted by multiple climate risks that first need to be recognized before specific hazards are identified or assessed (Hagenlocher et al. 2018); this is conducive to the identification of transboundary climate risks[7] and an effective understanding of their drivers' propagation through interdependent biophysical and social systems.
3) The opportunities to distil "entry points" for adaptation responses that strengthen resilience at multiple points in a system (Hagenlocher et al. 2018, p. 24): the impact chain framework facilitates the identification of adaptation options that could produce cobenefits across scales, systems, or social groups—recognizing that interventions to reduce vulnerability might occur in the same place as the benefits are realized or *they may not*—and that adaptation actions could themselves have "trade-offs and unintended consequences" (Hagenlocher et al. 2018, p. 77); such an approach is particularly valuable in a transboundary context with multiple stakeholders and interests to account for.
4) The creation of a participatory and flexible process: the impact chain framework emphasizes stakeholder engagement at all stages and has the flexibility to combine data-driven and expert-informed approaches (Hagenlocher et al. 2018); this approach aligns well with the (explorative and iterative) needs of a transboundary climate risk assessment—particularly to accommodate new or context-specific

[6] While we are aware of one project utilizing impact chains to assess transboundary climate risks—a study of Germany's exposure to global climate risk via trade (Peter et al. 2019, 2020)—a detailed consideration of the framework's suitability in this context has not been undertaken before, to our knowledge.

[7] The identification of a possible impact within an actor's sphere of concern might constitute a stronger incentive to commission a transboundary climate risk assessment than a potential cross-jurisdictional effect of a domestic climate-related hazard.

methods and account for expert perspectives, local knowledge, and stakeholder experiences.

However, this paper also finds a number of potential challenges with the application of the impact chain framework to the study of transboundary climate risk, or areas where further guidance may be useful or required:

1) A conceptualization of risk drivers as linear chains of impact: while the impact chain framework prompts the researcher to adopt a "systems view," the conceptualization of linear chains to characterize the propagation of impacts (Hagenlocher et al. 2018)—while of clear practical and analytical value—could be reductive in its depiction of cause–effect relationships and potentially omit or oversimplify important interactions that constitute key drivers of risk within a system,[8] particularly in a transboundary context. In this regard, the provision of additional "lines of inquiry" may support researchers to conceptualize a system in ways that acknowledge and account for its inherent complexity *and* relationships with other systems of concern.
2) A focus on standardized and indicator-based approaches: the impact chain framework aims to provide guidance for standardized assessments—promoting "consistent methods that are proven on the ground" (Fritzsche et al. 2014, p. 12)—and devotes a significant section of the guidelines (stages 3–7) to an indicator-based approach to "quantify the factors determining the risk" (Hagenlocher et al. 2018, p. 43);[9] in light of the practical challenges associated with assessing highly complex, dynamic and/or cascading climate risks,[10] where a highly structured and instrumental approach may not be conducive to the innovation required, a complementary level of detail on the research questions underpinning a more qualitative and iterative assessment could usefully support researchers in this regard.
3) Implied local and narrow definitions of system boundaries: the impact chain framework was not deliberately designed for application to a transboundary climate risk analysis, where the scope of the system will arguably be much broader than conventional assessments, potentially much more complex and conceivably much more exposed to multiple types of climate hazard—complicating the sequencing of analytical steps proposed;[11] a transboundary climate risk assessment could benefit from more deliberate flexibility and the option to combine different analytical approaches for different parts of the system.
4) Limited applicability to fragmented governance landscapes: while there is a strong emphasis in the impact chain framework on stakeholder participation, it does not explicitly explore questions of risk ownership—including mandates or motivations to manage risk—which could lead to limited uptake of the findings, particularly in a fragmented governance landscape; in a transboundary context, there could be multiple target audiences each with their own needs and interests and each with a different perspective of whose role it is to manage the risk—a deeper exploration of risk ownership is critical if one of the goals in applying the framework is "to increase political support for identified adaptation actions" (Hagenlocher et al. 2018, p. 84).

Through its form (participatory, flexible, and iterative) and focus (on risk drivers, cause–effect relationships, systems-first approaches, and entry points for adaptation options), the impact chain framework is far more suited to the effective identification and assessment of transboundary climate risk than many climate risk frameworks.

However, the study of transboundary climate risk requires new viewpoints (Challinor et al. 2018; Pescaroli and Alexander 2018; Lawrence et al. 2020). We argue that to overcome some of the barriers inhibiting the capability, motivation, and opportunity of stakeholders to assess and account for transboundary climate risks, it is perhaps not enough to have a climate risk assessment framework that is "possible" to apply in a transboundary context. To stimulate much-needed research into this "blind spot," to equip and empower case-study researchers to ask the "right" questions and to overcome some of the challenges in the application of the impact chain approach, a novel protocol is required: one designed specifically for the exploration of transboundary climate risk.

4. A protocol for case-study research on transboundary climate risk

This protocol builds on key components of the impact chain framework, but also adapts and applies new perspectives to support the assessment of transboundary climate risks in ways that acknowledge their systemic nature[12] and puts questions of ownership at the heart of risk analysis and response. Specifically, it builds on

- the International Risk Governance Council's framework, which was explicitly devised to provide guidance "to cope with risks in situations of high complexity, uncertainty or

[8] As Hagenlocher et al. (2018) acknowledges, and others such as Kabisch et al. (2014) note.

[9] Although the method facilitates the accommodation of expert opinion when data are unavailable and in weighing indicators' relevance and importance.

[10] Including difficulties: attaining good-quality, spatially explicit, and broadly comparable data (when sourced from across countries or sectors) (Aall et al. 2020); selecting indicators with the potential to yield what Hagenlocher et al. (2018) articulate as clear, substantive, and unambiguous results; and quantifying and validating the "intermediate" effects that Fritzsche et al. (2014) outline.

[11] Following analysis of the system of concern, a transboundary climate risk assessment *might* opt to focus on a specific hazard (as the impact chain framework subsequently proposes; Hagenlocher et al. 2018) or it might proceed to assess the exposure or vulnerability of multiple nodes in a complex system to any kind of hazard. Drawing on propositions articulated by Florin and Bürkler (2017), one could argue that identifying the ways in which climate change might impact an entire system is a better approach in conditions of deep uncertainty and complexity, and to reveal adaptation options that strengthen systemic resilience to multiple climate impacts across jurisdictional and policy domains.

[12] For examples and analysis of the conceptualization of risk within interconnected systems, see Goldin and Mariathasan (2015) and Renn et al. (2019).

ambiguity . . . [to] increase the capacity to deal with unanticipated consequences of risk, unknown impacts and social conflicts over trade-offs . . . [and] find common denominators for risk handling in a globalised and plural world" (Florin and Bürkler 2017, 7–8); and
- the Cooperative Research Centre for Bushfire and Natural Hazards' framework, which aims to "enable more effective decision-making in relation to the allocation of risk ownership at the institutional scale" (Young et al. 2015, p. 1).

Our protocol provides a modular guide for collecting and structuring information on transboundary climate risk, with the objective that case-study researchers will be better able to identify, assess and appraise these sorts of risks, as well as pursue lines of inquiry to evaluate how well they are governed, managed, and addressed. Our ultimate aim is to support decision-makers to better harness any opportunities that the transboundary effects of climate impacts may present, while managing their adverse consequences in effective, equitable and enduring ways. As with any case-study protocol, or decision support system, the efficacy of our proposed framework depends on how it is applied and the context in which it is applied. We acknowledge the limits of such protocols, while at the same time recommending its adoption and implementation by researchers in the field.

a. *Theoretical framing*

Given the transmission of transboundary climate risks through socioecological systems—and the possibility for risks to disrupt such systems through what Collins (2020, p. 2) terms "exponential propagation"—this protocol has its theoretical roots in systems theory, as a means of understanding the systemic nature of climate risk and the interactions and interdependencies of the systems within which it is embedded (Helbing 2013). Systems theory originates from, and has been implemented in, a number of disciplines, including ecology (von Bertalanffy 1969; Holling 1973); environmental science (Meadows 2008); organizational theory and sociology (Bogdanov 1980; Urry 2003; Perrow 2011); mathematics, physics, and philosophy (Capra 1996); business and management (Sterman 2000); risk (Renn 2008; Helbing 2012); and psychology (Bateson 2000). Earth systems science blends knowledge from these fields to analyze combined biophysical and social systems and reveal particular components that constitute key leverage points in the amplification of risk and/or at which to target response measures (Meadows 2008; Perrow 2011; Helbing 2013). We suggest these insights are underutilized in case-study research for adaptation and in climate risk assessment frameworks used to inform adaptation planning.

There are several theoretical strands to draw on for analysis of complex system components, whether through the lens of the catastrophic potential of complex and tight couplings (Perrow 2011), the properties of networks (Lorenz et al. 2009; Helbing 2013) or the spillover effects within telecoupled systems (Liu et al. 2013). Some of these are elucidated below. More broadly, we emphasize the need for case-study researchers to adopt a systems-based approach as a means of recognizing and accounting for the complexities, uncertainties, ambiguities, and interdependencies of the structures and networks that define our global systems today (Helbing 2013; Pescaroli and Alexander 2018; Lawrence et al. 2020). As such, our protocol invites researchers to be explicit in naming and identifying the boundaries of the systems within which their case studies are embedded and, in applying the insights of system literatures referred to above, equips and encourages them to account for the complex dynamics of these systems in their adaptation case studies.

b. *The protocol*

Here we introduce the seven stages of a protocol for incorporating transboundary climate risk in case-study research for adaptation. These are synthesized in Fig. 2, and Table S1 in the online supplemental material provides an account of key research questions that case-study authors may consider at each stage when operationalizing the protocol.

1) SCOPING[13]

This stage supports researchers to lay the groundwork for a focused and impactful case study by developing a preliminary understanding of the dynamics of the system of concern to identify one or more transboundary climate risks. The steps outlined in the impact chain framework (Hagenlocher et al. 2018) provide an essential starting point—of conducting a context analysis, formulating objectives, defining scope, and considering practical implementation requirements—but to these we add a number of exploratory research questions within five key areas:

1) Defining and characterizing the system of concern and the boundaries within which the framework for assessing transboundary climate risk should be applied.
2) Identifying key actors within the system (and influencing the system) and the relationships between them.
3) Scoping possible impacts of climate change on system components.
4) Identifying and selecting transboundary climate risks, based on their likely significance or feasibility of assessment.
5) Considering risk ownership [the roles and responsibilities of actors identified in (ii)].

This protocol calls for strong stakeholder engagement and coproduction of knowledge from the outset as an important step in managing the uncertainty and complexity of transboundary climate risk and to highlight paths toward clear risk ownership and effective risk governance.

2) CLASSIFICATION[14]

This stage encourages researchers to classify where in a proposed matrix their case study sits. The approach to assessing transboundary climate risks will be influenced to a high degree by two factors: *when* in the process of case-study design the decision is taken to incorporate a transboundary

[13] Termed "pre-assessment" in Florin and Bürkler (2017) and "preparing the risk assessment" in Hagenlocher et al. (2018).
[14] Authors' own.

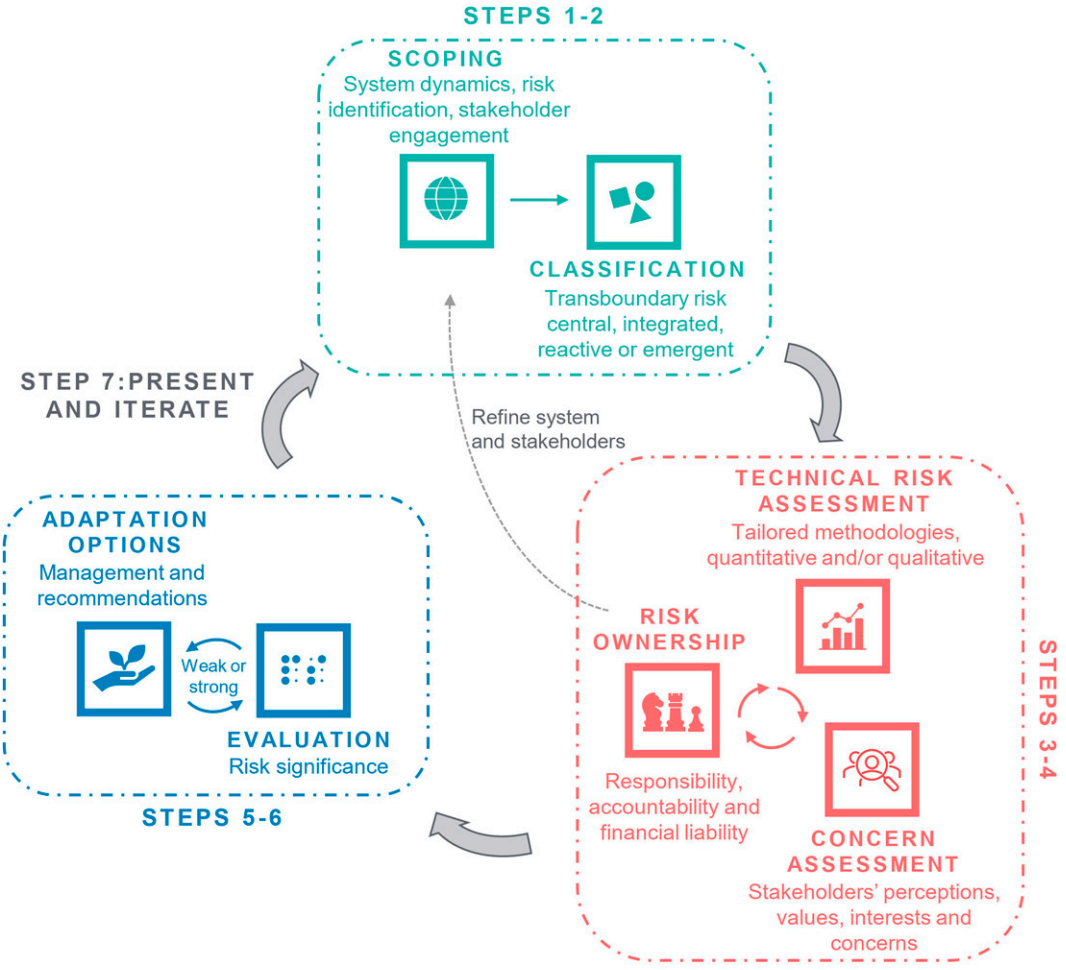

FIG. 2. A protocol for case-study research on transboundary climate risk.

assessment, and *whether* transboundary climate risks are the only risks to be explored. Figure 3 outlines this matrix and facilitates the categorization of case studies into an A–D typology. This typology supports the determination of different approaches advised at each stage of the case-study protocol, synthesized in Table S2 of the online supplemental material. Having classified their case study, researchers may wish to revisit some elements of the scoping stage.

3) ASSESSMENT[15]

This stage guides researchers through two distinct stages of an assessment of transboundary climate risk: a technical risk assessment and a "concern assessment" of stakeholders' views and interests with regard to the risk—"a systematic analysis of the associations and perceived consequences (benefits and risks) that stakeholders may associate with a hazard, its cause(s) and consequence(s)" (Florin and Bürkler 2017, p. 13).

(i) Technical risk assessment

The technical risk assessment should evaluate how exposed or vulnerable the system components are to the effects of climate impacts, and how likely they are to occur, expanding the field of vision beyond the climate hazards extant or forecast in the "domestic" realm to the "exogenous" climate hazards originating internationally. Case-study researchers may wish to adapt the quantitative or qualitative approaches others have adopted in transboundary climate risk assessments (as outlined in section 2a), considering the methodologies best suited to the nature of the risks revealed. Our guidelines are not prescriptive in this regard. The steps outlined in the impact chain framework (Hagenlocher et al. 2018) may prove instructive, with some proposed modifications of

- the risk framework (to account for the exogenous nature of the hazard);
- the impact chain (to instead assess the exposure and vulnerability of relevant system components, such as "nodes"—a location that could be considered the source or origin of an input into the system—and "links"—the connections, pathways or

[15] Termed "appraisal" in Florin and Bürkler (2017); encompasses modules 2–7 in Hagenlocher et al. (2018).

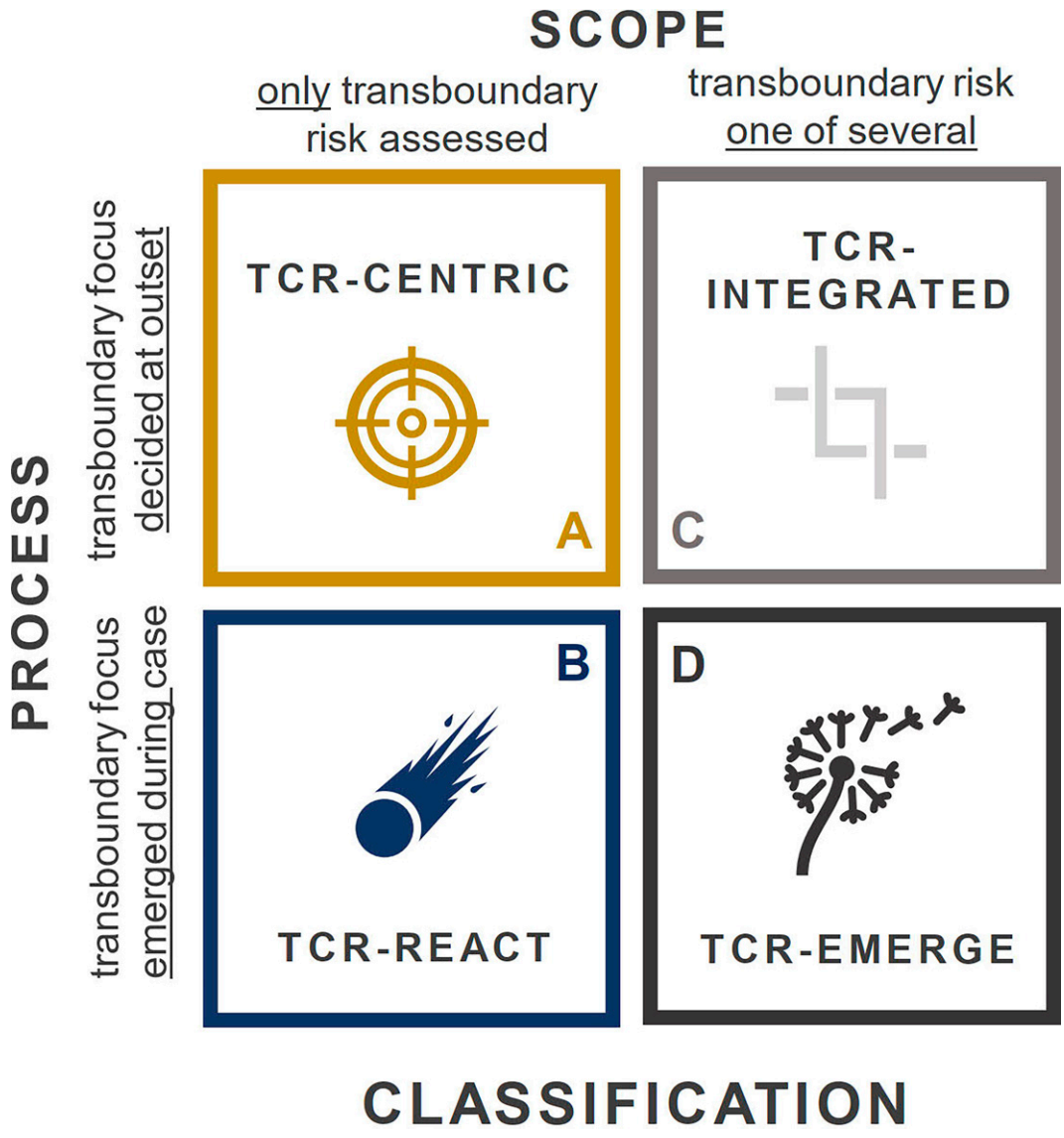

FIG. 3. Case-study classification matrix.

flows that connect the nodes in the system to the point of impact);[16] researchers could consider how the nodes and links relate to each other within the system, as well as interact with other systems, to support the formation of impact chains or identify the potential for the creation and propagation of systemic risks; and

- the sequencing of analytical steps as required.

(ii) Concern assessment

The concern assessment should support identification of second- or third-order drivers and effects through a system, as well as analyses of vulnerability (to the risks revealed) for particular stakeholders or the system itself[17] (Florin and Bürkler 2017; Collins 2020). Researchers may wish to consider the relevant stakeholders to consult to understand different risk perspectives; the use of social or institutional network analysis to build a picture of the interconnections between them; and the research questions best suited to drawing out their values, interests, and concerns (Florin and Bürkler 2017; Collins 2020). The concern assessment is particularly important to the study of transboundary climate risk, in light of the methodological challenges associated with a technical assessment of complex risk.

[16] Noting that nodes and links in a socioecological system might not be physical or fixed entities.

[17] Researchers may draw on various theoretical frameworks to assess system vulnerability; for example, Perrow's (2007) theory of social risk might suggest that increasingly tight cross-border couplings and complex levels of global integration increase the vulnerability of a system to transboundary climate risk.

This stage will have multiple feedback loops with the risk ownership stage.

4) Risk ownership[18]

This stage supports researchers to identify the allocation or distribution of "ownership" of the transboundary climate risks revealed. The concept of risk ownership [as defined by Young et al. (2015, p. 1)] is an analytical device for identifying the different rights, roles, and responsibilities of state and nonstate actors in governing risk and assessing the division of labor between them: an "owned" risk has an attributable person or entity accountable or responsible for managing its effects, while an "unowned" risk has no such oversight. Researchers are prompted to inquire who is accountable and responsible for managing the transboundary climate risk(s), and through what mechanisms and instruments governance of the risk(s) and response(s) is determined (Young et al. 2015; Florin and Bürkler 2017). Subsequent stages will explore how well these actors fulfil these roles and are in a position to manage the transboundary climate risks revealed, including questions of legitimacy, effectiveness, and justice in the assigned or assumed ownership of each risk.

Young et al. (2015, p. IV) propose three research questions to consider in light of the transboundary climate risks revealed: "Who pays for the risk, who manages (is responsible for) the risk [and] who is accountable for the risk?" We advise researchers to map the actors involved *in* the case-study system, and others' spheres of influence *on* the system, in the above three capacities—identifying owners that are both acknowledged and default—and the governance arrangements that outline and define such protocols (Young et al. 2015; Florin and Bürkler 2017).

For each question, researchers might wish to consider ownership: within and across all relevant governance scales, administrative levels, and jurisdictions; associated with all studied system components and second- or third-order effects; operating in all types of institution and spanning all relevant policy domains (Young et al. 2015). Case-study teams could also consider whether their answers to the above questions change in accordance with key variables, such as the type of hazard that triggers the risk, the stage or task in the risk management process in question, the perceived level or threshold of the risk (and assumed coping capacity of the owners), and from whose perspective ownership is allocated (Young et al. 2015; Florin and Bürkler 2017).

Note that the *allocation* of risk ownership is an inherently political process, generating what Beck posited as "'conflicts of accountability' over how the consequences of risk can be attributed, controlled, and legitimated" (Bulkeley 2001, p. 430). Risk ownership in the context of climate change may infer notions of blame and obligation; allocation of ownership may therefore serve and reinforce particular interests as well as have practical consequences for subsequent liabilities (Bulkeley 2001). These power dynamics mean that the allocation and distribution of ownership should be analyzed through a political economy lens (see, e.g., Lange and Mørck Jensen 2013) that accounts for the influence of the wider context in shaping risk perceptions, priorities, and responsibilities.

5) Evaluation[19]

This stage supports researchers to evaluate the significance of the transboundary climate risks revealed (Florin and Bürkler 2017). Researchers may first consider a relatively simple characterization of the risk(s)[20] (Florin and Bürkler 2017) while approaches to *evaluate* the risk will depend to a great extent on the methodologies employed to measure the risk. These can range from complex quantitative calculations to simple qualitative ratings based on the perceived fragility or resilience of the system to withstand the disruption that the risk represents (Collins 2020).

Case studies involving both domestic and transboundary climate risks may be in a position to compare and contrast their relative significance and assess the extent of "double exposure" to such risks (Benzie and Persson 2019, p. 375).

6) Adaptation options[21]

This stage supports researchers to explore how the risk is managed (if at all), appraise the extent to which the owners of the risk are in a position to implement measures to manage its effects, and potentially generate adaptation options and recommendations (Young et al. 2015). The following questions support researchers to shed light on current practices to manage the risk and draw general conclusions about their efficacy:[22]

1) *who* is managing the risk and *why*: is ownership actively exercised and through what governance arrangements are responsibility and accountability determined?
2) *what* is being done to manage the risk: are there identifiable adaptation options or response measures?
3) *where* and *when* is the risk being managed: is risk ownership cohesive within the system and comprehensive throughout the risk management process?
4) *how* effectively are these measures operated or implemented: what is enabling or constraining management of the risk (Florin and Bürkler 2017; Young et al. 2015)?

[18] Stages 4 and 6 are collectively termed "management" in Florin and Bürkler (2017); risk ownership is not a standalone module in Hagenlocher et al. (2018) and represents the entire focus of Young et al. (2015).

[19] Termed "characterisation and evaluation" in Florin and Bürkler (2017). For further details, see Table S1 in the online supplemental material.

[20] The analytical frameworks developed by Carter et al. (2021) and Adaptation Without Borders (2021) may prove instructive in this regard; Florin and Bürkler (2017) also outline useful distinctions between types of risk.

[21] Stages 4 and 6 are collectively termed "management" in Florin and Bürkler (2017) and as "identifying adaptation options" in Hagenlocher et al. (2018).

[22] This protocol does not seek to equip researchers with the tools for a detailed evaluation of specific adaptation responses.

Researchers may subsequently wish to revisit their evaluation, so that an indication of the risk's significance can account for findings on capacities and options to manage the risk.

Researchers are also encouraged to provide their normative recommendations for how transboundary climate risks might be better known and managed in the future:

1) What adaptation options can be distilled?[23]
2) To what extent are current risk assessment and adaptation planning processes enabling or constraining the identification or management of transboundary climate risks?
3) What sorts of new or differentiated capabilities might cross-border approaches to adaptation demand, to enable action across sectors and scales?

7) PRESENTATION AND ITERATION[24]

This stage supports researchers to present their case study. An emphasis is placed on conveying research in accessible and communicable ways to the actors of concern. The clear interpretation and articulation of results, in light of the original aims of the assessment, is of crucial value to increase research uptake in policy and practice: the suggestions outlined in the impact chain framework, including the emphasis on visual illustrations and representations, provide a good guide in this respect (Hagenlocher et al. 2018).

We also encourage researchers to, where possible, iterate the steps of the protocol for a more rigorous approach.

5. Conclusions

This article introduced a new protocol for the exploration of transboundary climate risk in case-study research for adaptation.

The article first sought to demonstrate the differing capabilities, motivations, and opportunities that stakeholders—including case-study researchers—could possess to both assess and account for transboundary climate risks when compared with domestic climate risks. Using the impact chain framework as an illustrative example, the article then analyzed the potential feasibility and utility of applying existing climate risk assessment frameworks to the novel context of transboundary climate risk. The article demonstrated that the advantages of the impact chain framework for such research include its form (participatory, iterative, and flexible) and focus (on risk drivers, cause–effect relationships, systems-first approaches, and entry points for adaptation options). Its constraints lie in in the unaddressed area of risk ownership and in the trade-offs that it acknowledges—to sacrifice both the management of systemic complexity (for analytic simplicity and linearity) and the accommodation of innovation and iteration (within the broader strive for standardization).

The paper thus built a case—first, that transboundary climate risks are distinct (in character *and* analytical treatment) from the domestic climate risks that have been the traditional subjects of case-study research for adaptation, and second, that the climate risk frameworks that have evolved to assess direct climate risks have significant strengths but also various challenges when applied to transboundary climate risks. This laid the groundwork for the introduction of a new case-study protocol, one specifically designed to equip and empower researchers to identify, assess, and appraise transboundary climate risk. The protocol aims to stimulate explorative and iterative research, in part by structuring case studies into four different classes (A–D), and accounts for critical new perspectives on the management of complex risk and the exploration of risk ownership.

There is clearly a need to go beyond assessment frameworks that have evolved on the assumption that all climate impacts are local. The impact chain framework takes a step in this direction; it is hoped that the protocol introduced here advances us further. Its challenges and limitations—particularly as a decision-support tool—are acknowledged: we do not (currently) have well-established quantitative methods that could drive and assure credible and comparable assessments of transboundary climate risks. But if we continue to apply a territorial approach to case-study research for adaptation we will fail to develop responses that adequately reduce the full range of climate risks facing society in a globalized world. The consequence would be that our climate risk assessments underestimate levels of risk exposure, fail to identify actors who may be vulnerable to climate risk, and neglect to motivate the necessary investments in—and cooperation on—adaptation, especially at national and international scales. Meeting the challenge of adaptation in the context of transboundary climate risk requires us to experiment and to learn. We call for more innovation in adaptation research to better reflect the complexity and interdependency that characterize today's world *and* our common future.

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[23] It is too early to theorize about the kinds of adaptation options that could best manage transboundary climate risks, and their diversity demand a context-specific response; however, drawing on propositions articulated by Florin and Bürkler (2017), one could argue that high levels of ambiguity and uncertainty clearly necessitate the design of adaptation options that are resilient in the face of gaps in knowledge and understanding, while deep complexity and interdependency call for responses that target key risk drivers and raise levels of coping and adaptive capacity across the systems within which they are embedded.

[24] Termed "presenting and interpreting the outcomes of the risk assessment" in Hagenlocher et al. (2018).

REFERENCES

Aall, C., A. C. Kanyama, and G. Hovelsrud, 2012: Local climate change adaptation: Missing link, Black Jack or blind alley? *Local Environ.*, **17**, 573–578, https://doi.org/10.1080/13549839.2012.699772.

——, and Coauthors, 2020: Methods for climate change risk assessments: An international knowledge review. Vestlandsforsking Rep. 7-2020, 130 pp., https://www.vestforsk.no/en/publication/methods-climate-change-risk-assessments-international-knowledge-review.

Adaptation Without Borders, 2021: Adaptation Without Borders: An overview. Overseas Development Institute, Stockholm Environment Institute, and Institute for Sustainable Development and International Relations Doc., 12 pp., https://adaptationwithoutborders.org/sites/weadapt.org/files/2017/transboundary_climate_risks_web.pdf.

Atteridge, A., and E. Remling, 2017: Is adaptation reducing vulnerability or redistributing it? *Wiley Interdiscip. Rev.: Climate Change*, **9**, e500, https://doi.org/10.1002/wcc.500.

Bateson, G., 2000: *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology.* University of Chicago Press, 533 pp.

Benzie, M., and Å. Persson, 2019: Governing borderless climate risks: Moving beyond the territorial framing of adaptation. *Int. Environ. Agreements*, **19**, 369–393, https://doi.org/10.1007/s10784-019-09441-y.

——, J. Hedlund, and H. Carlsen, 2016: Introducing the transnational climate impacts index: Indicators of country-level exposure—Methodology report. Stockholm Environment Institute Working Paper 2016-07, 48 pp., https://www.sei.org/wp-content/uploads/2016/06/introducing-the-transnational-climate-impacts-index-indicators-of-country-level-exposure-methodology-report.pdf.

——, and Coauthors, 2018: Meeting the global challenge of adaptation by addressing transboundary climate risk: A joint collaboration between SEI, IDDRI, and ODI. Stockholm Environment Institute Discussion Brief, 10 pp., https://www.sei.org/wp-content/uploads/2018/04/meetingtheglobalchallengeofadaptation.pdf.

Bogdanov, A., 1980: *Essays in Tektology: The General Science of Organization.* Intersystems Publications, 291 pp.

Bulkeley, H., 2001: Governing climate change: The politics of risk society? *Trans. Inst. Br. Geogr.*, **26**, 430–447, https://doi.org/10.1111/1475-5661.00033.

Capra, F., 1996: *The Web of Life: A New Synthesis of Mind and Matter.* Flamingo, 336 pp.

Carter, T. R., M. Benzie, E. Campiglio, H. Carlsen, S. Fronzek, M. Hildén, C. P. O. Reyer, and C. West, 2021: A conceptual framework for cross-border impacts of climate change. *Global Environ. Change*, **69**, 102307, https://doi.org/10.1016/j.gloenvcha.2021.102307.

Challinor, A. J., W. N. Adger, and T. G. Benton, 2017: Climate risks across borders and scales. *Nat. Climate Change*, **7**, 621–623, https://doi.org/10.1038/nclimate3380.

——, ——, ——, D. Conway, M. Joshi, and D. Frame, 2018: Transmission of climate risks across sectors and borders. *Philos. Trans. Roy. Soc.*, **376**, 20170301, https://doi.org/10.1098/rsta.2017.0301.

Collins, A., 2019: The Global risks report 2019. World Economic Forum, 114 pp, https://www3.weforum.org/docs/WEF_Global_Risks_Report_2019.pdf.

——, 2020: COVID-19: A risk governance perspective. EPFL Spotlight on Risk Doc., 8 pp., https://www.epfl.ch/research/domains/irgc/spotlight-on-risk-series/covid-19-a-risk-governance-perspective/.

Davis, M., M. Benzie, and J. Barrott, 2016: Transnational climate change impacts: An entry point to enhanced global cooperation on adaptation? Stockholm Environment Institute Policy Brief, 4 pp., https://mediamanager.sei.org/documents/Publications/Climate/SEI-PB-2016-TCI-insights-for-UNFCCC.pdf.

Florin, M.-V., and M. T. Bürkler, 2017: Introduction to the IRGC Risk Governance Framework, revised version. IRGC Rep., 52 pp., https://doi.org/10.5075/epfl-irgc-233739.

Fritzsche, K., S. Schneiderbauer, P. Bubeck, S. Kienberger, M. Buth, M. Zebisch, and W. Kahlenborn, 2014: The Vulnerability Sourcebook: Concept and guidelines for standardised vulnerability assessments. Deutsche Gesellschaft für Internationale Zusammenarbeit Rep., 180 pp., https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf.

Goldin, I., and M. Mariathasan, 2015: *The Butterfly Defect: How Globalization Creates Systemic Risks, and What to Do about It.* Princeton University Press, 320 pp.

Gotangco, C. K., A. M. Favis, M. A. L. Guzman, M. L. Tan, C. Quintana, and J. C. Josol, 2017: A supply chain framework for characterizing indirect vulnerability. *Int. J. Climate Change Strategies Manage.*, **9**, 184–206, https://doi.org/10.1108/IJCCSM-04-2015-0046.

Hagenlocher, M., S. Schneiderbauer, Z. Sebesvari, M. Bertram, K. Renner, F. Renaud, H. Wiley, and M. Zebisch, 2018: Climate risk assessment for ecosystem-based adaptation: A guidebook for planners and practitioners. Deutsche Gesellschaft für Internationale Zusammenarbeit Rep., 120 pp., https://www.adaptationcommunity.net/wp-content/uploads/2018/06/giz-eurac-unu-2018-en-guidebook-climate-risk-asesment-eba.pdf.

Haraguchi, M., and U. Lall, 2015: Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. *Int. J. Disaster Risk Reduct.*, **14**, 256–272, https://doi.org/10.1016/j.ijdrr.2014.09.005.

Hedlund, J., S. Fick, H. Carlsen, and M. Benzie, 2018: Quantifying transnational climate impact exposure: New perspectives on the global distribution of climate risk. *Global Environ. Change*, **52**, 75–85, https://doi.org/10.1016/j.gloenvcha.2018.04.006.

Helbing, D., 2012: Systemic risks in society and economics. *Social Self-Organization*, D. Helbing, Ed., Springer, 261–284.

——, 2013: Globally networked risks and how to respond. *Nature*, **497**, 51–59, https://doi.org/10.1038/nature12047.

Hildén, M., F. Groundstroeam, T. R. Carter, M. Halonen, A. Perrels, and H. Gregow, 2016: Ilmastonmuutoksen heijastevaikutukset Suomeen (Crossborder effects of climate change in Finland). Finnish Government's Investigation and Research Activities Publ. Series 46/2016, 69 pp., https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/79783/Ilmastomuutoksen%20heijastevaikutukset%20Suomeen.pdf?sequence=1&isAllowed=y.

——, H. Huuki, V. Kivisaari, and M. Kopsakangas-Savolainen, 2018: The importance of transnational impacts of climate change in a power market. *Energy Policy*, **115**, 418–425, https://doi.org/10.1016/j.enpol.2018.01.039.

Holling, C. S., 1973: Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.*, **4**, 1–23, https://doi.org/10.1146/annurev.es.04.110173.000245.

Janssens, C., and Coauthors, 2020: Global hunger and climate change adaptation through international trade. *Nat. Climate Change*, **10**, 829–835, https://doi.org/10.1038/s41558-020-0847-4.

Kabisch, S., R. Chakrabarti, T. Wolf, W. Kiewitt, T. Gorman, A. Chaturvedi, and R. Arora, 2014: Climate change impact chains in the water sector: Observations from projects on the East India coast. *J. Water Climate Change*, **5**, 216–232, https://doi.org/10.2166/wcc.2013.118.

Lager, F., K. M. Adams, A. Dzebo, M. Eriksson, R. J. T. Klein, and M. Klimes, 2021: A just transition for climate change adaptation: Towards Just resilience and security in a globalising world. Adaption Without Borders Policy Brief, 12 pp., https://www.weadapt.org/system/files_force/pb2_rev4_web.pdf?download=1.

Lange, R. D., and K. Mørck Jensen, 2013: Climate politics in the lower Mekong basin: National interests and transboundary cooperation on climate change. DIIS Rep. 2013:19, 46 pp., https://www.econstor.eu/bitstream/10419/97038/1/774510501.pdf.

Langer, L., J. Tripney, and D. Gough, 2016: The science of using science: Researching the use of research evidence in decision-making. University College London EPPI-Centre Final Rep., 62 pp., https://eppi.ioe.ac.uk/cms/Portals/0/PDF%20reviews%20and%20summaries/Science%202016%20Langer%20report.pdf?ver=2016-04-18-142701-867.

Lawrence, J., P. Blackett, and N. A. Cradock-Henry, 2020: Cascading climate change impacts and implications. *Climate Risk Manage.*, **29**, 100234, https://doi.org/10.1016/j.crm.2020.100234.

Liu, J., and Coauthors, 2013: Framing sustainability in a telecoupled world. *Ecol. Soc.*, **18**, 26, https://doi.org/10.5751/ES-05873-180226.

Lorenz, J., S. Battiston, and F. Schweitzer, 2009: Systemic risk in a unifying framework for cascading processes on networks. *Eur. Phys. J. B*, **71**, 441–460, https://doi.org/10.1140/epjb/e2009-00347-4.

Meadows, D. H., 2008: *Thinking in Systems: A Primer*. Chelsea Green Publishing, 218 pp.

Menk, L., S. Terzi, M. Zebisch, E. Rome, D. Lückerath, K. Milde, and S. Kienberger, 2022: Climate change impact chains: A review on applications, challenges, and opportunities for climate change risk assessments. *Wea. Climate Soc.*, **14**, https://doi.org/10.1175/WCAS-D-21-0014.1, in press.

Moser, S. C., and J. F. Hart, 2015: The long arm of climate change: Societal teleconnections and the future of climate change impacts studies. *Climatic Change*, **129**, 13–26, https://doi.org/10.1007/s10584-015-1328-z.

——, and ——, 2018: The adaptation blindspot: Teleconnected and cascading impacts of climate change on the electrical grid and lifelines in Los Angeles. California's Fourth Climate Change Assessment Rep., 122 pp., https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-008_ADA.pdf.

Munia, H. A., J. H. A. Guillaume, W. Yoshihide, T. Veldkamp, V. Virkki, and M. Kummu, 2020: Future transboundary water stress and its drivers under climate change: A global study. *Earth's Future*, **8**, e2019EF001321, https://doi.org/10.1029/2019EF001321.

Nadin, R., and E. Roberts, 2018: Moving towards a growing global discourse on transboundary adaptation. ODI Briefing Note, 12 pp., https://cdn.odi.org/media/documents/12139.pdf.

National Academies of Sciences, Engineering, and Medicine, 2021: *Global Change Research Needs and Opportunities for 2022–2031*. National Academies Press, 101 pp., https://doi.org/10.17226/26055.

Perrow, C., 2007: *The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters*. Princeton University Press, 430 pp.

——, 2011: *Normal Accidents: Living with High Risk Technologies*. Updated ed. Princeton University Press, 456 pp.

Pescaroli, G., and D. Alexander, 2018: Understanding compound, interconnected, interacting, and cascading risks: A holistic framework. *Risk Anal.*, **38**, 2245–2257, https://doi.org/10.1111/risa.13128.

Peter, M., M. Guyer, and J. Füssler, 2019: Folgen des globalen Klimawandels für Deutschland—Erster Teilbericht: Die Wirkungsketten in der Übersicht (Consequences of global climate change for Germany—First sub-report: An overview of the impact chains). Climate Change Rep. 20/2019, 106 pp., https://www.infras.ch/media/filer_public/00/0f/000f7523-3924-4cfe-8950-f227c519940e/teilbericht_die_wirkungsketten_in_der_ubersicht.pdf.

——, ——, ——, B. Bednar-Friedl, N. Knittel, B. Gabriel, R. Schwarze, and M. von Unger, 2020: Folgen des globalen Klimawandels für Deutschland—Abschlussbericht: Analysen und Politikempfehlungen (Consequences of global climate change for Germany—Final report: Analyses and policy recommendations). Climate Change Rep. 15/2020, 111 pp., https://www.infras.ch/media/filer_public/81/e0/81e0c02f-b071-4117-ac3b-92b62082b38e/abschlussbericht_folgen_des_globalen_klimawandels_fur_deutschland.pdf.

——, ——, ——, ——, ——, B. G. Wegener, and R. Schwarze, 2021: The transnational impacts of global climate change for Germany: Abridged version. Umwelt Bundesamt Climate Change Rep. 03/2021, 40 pp., https://www.umweltbundesamt.de/en/publikationen/the-transnational-impacts-of-global-climate-change.

Promchote, P., S.-Y. S. Wang, and P. G. Johnson, 2016: The 2011 great flood in Thailand: Climate diagnostics and implications from climate change. *J. Climate*, **29**, 367–379, https://doi.org/10.1175/JCLI-D-15-0310.1.

PwC, 2013: International threats and opportunities of climate change for the UK. PwC Final Rep., 153 pp., https://pwc.blogs.com/files/international-threats-and-opportunities-of-climate-change-to-the-uk.pdf.

Renn, O., 2008: *Risk Governance: Coping with Uncertainty in a Complex World*. Risk in Society Series, Earthscan, 480 pp.

——, K. Lucas, A. Haas, and C. Jaeger, 2019: Things are different today: The challenge of global systemic risks. *J. Risk Res.*, **22**, 401–415, https://doi.org/10.1080/13669877.2017.1409252.

Sterman, J., 2000: *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill Education, 768 pp.

Taylor, M., 2013: Climate change, relational vulnerability and human security: Rethinking sustainable adaptation in agrarian environments. *Climate Dev.*, **5**, 318–327, https://doi.org/10.1080/17565529.2013.830954.

Urry, J., 2003: *Global Complexity*. John Wiley and Sons, 184 pp.

von Bertalanffy, L., 1969: *General System Theory: Foundations, Development, Applications*. George Braziller, 289 pp.

Wei, D., and M. Chase, 2018: Climate and supply chain: The business case for action. Climate Nexus Rep., 22 pp., https://www.bsr.org/reports/BSR_Climate_and_Supply_Chain_Management.pdf.

Young, C. K., J. Symons, and R. N. Jones, 2015: Whose risk is it anyway? Desktop review of institutional ownership of risk associated with natural hazards and disasters. Bushfire and Natural Hazards CRC Rep. 2015.074, 52 pp., https://www.vu.edu.au/sites/default/files/cses/pdfs/2015-young-et-al-whose-risk-is-it-anyway.pdf.

Zebisch, M., S. Schneiderbauer, K. Renner, T. Below, M. Brossmann, W. Ederer, and S. Schwan, 2017: Risk supplement to the Vulnerability Sourcebook: Guidance on how to apply the Vulnerability Sourcebook's approach with the new IPCC AR5 concept of climate risk. Deutsche Gesellschaft für Internationale Zusammenarbeit Doc., 68 pp., https://www.adaptationcommunity.net/wp-content/uploads/2017/10/GIZ-2017_Risk-Supplement-to-the-Vulnerability-Sourcebook.pdf.

——, ——, K. Fritzsche, P. Bubeck, S. Kienberger, W. Kahlenborn, S. Schwan, and T. Below, 2021: The Vulnerability Sourcebook and climate impact chains—A standardized framework for a climate vulnerability and risk assessment. *Int. J. Climate Change Strategies Manage.*, **13**, 35–59, https://doi.org/10.1108/IJCCSM-07-2019-0042.

Zhou, J., L. M. Dellmuth, K. M. Adams, T. S. Neset, and N. von Uexkull, 2020: The geopolitics of food security: Barriers to the sustainable development goal of zero hunger. SIPRI Insights on Peace and Security 2020/11 Doc., 16 pp., https://www.sipri.org/sites/default/files/2020-11/sipriinsight2011_zero_hunger_2.pdf.