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RESEARCH ARTICLE

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Understanding the dynamic nature of risk in climate change assessments—A new starting point for discussion

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Abstract

This article sets out the current conceptualisation and description of risk used by the Intergovernmental Panel on Climate Change (IPCC). It identifies limitations in capacity to reflect the dynamic nature of risk components, and the need for standardisation and refinement of methods used to quantify evolving risk patterns. Recent studies highlight the changing nature of hazards, exposure and vulnerability, the three components of risk, and demonstrate the need for coordinated guidance on strategies and methods that better reflect the dynamic nature of the components themselves, and their interaction. Here, we discuss limitations of a static risk framework and call for a way forward that will allow for a better understanding and description of risk. Such advancements in conceptualisation are needed to bring closer the understanding and description of risk in theory with how risk is quantified and communicated in practice. To stimulate discussion, this article proposes a formulation of risk that clearly recognises the temporally evolving nature of risk components.

KEYWORDS

climate change, dynamic change, IPCC, risk

1 | INTRODUCTION

Failure of climate change mitigation and adaptation and extreme weather events are ranked as two of the most likely and high impacting risks that businesses face (WEF, 2019). Whilst cost estimates of how climate related impacts will change over time vary considerably; some estimate up to $1trillion of losses per year within the next 20 years (Viner et al., 2015). Thus far, 2017 is likely to be the most costly year in terms of economic and insured losses from climate and weather events (Munich, figures to be announced), with the previous record losses occurring in 2005 (Munich, 2007). However, large uncertainty exists around the actual cost of hazardous weather events due to incomplete understanding of the economic value of the current global asset base (such as energy or transport infrastructure, or natural capital) (Jones et al., 2014) and the extent to which resilience buffers the impact (e.g., the ability of communities, or services in a community to cope in the event of a hazardous event). Therefore, understanding current risks and how these will dynamically change over time is essential, if not fundamental, to manage damage costs or losses, adaptation costs, and to build a society that is resilient to future climate and weather shocks.

The Intergovernmental Panel on Climate Change (IPCC) is tasked by governments globally to provide periodic comprehensive assessments of our understanding of climate change including how to assess climate risks. Its description of climate risks has varied over time, now gaining increasing prominence in the most recent reports and through the Sixth Assessment Report (AR6) cycle. Earlier reports, up to and including the AR4 gave, what can only be described as a passing reference to risk with vulnerability defined as a '... function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity' (where adaptive capacity is defined as the ability of a system to adjust to, and cope with, climate change (IPCC, 2007; Endbox 1.). The IPCC Special Report on Managing the Risks of Extreme Events (SREX) (IPCC, 2012) sets out IPCC's vision on conceptualisation, definition and management of risk in a climate change context (visualised in Figure 1). It largely equates climate risk with disaster risk, identifying its components as hazard, exposure and vulnerability, noting that ability to capture the dynamic nature of exposure and vulnerability makes for more successful adaptation and risk management policies and practices. In AR5, the SREX terminology for climate risk is adopted, further developed, and described as a function of not only changing characteristics of the climate systems, but also altering socioeconomic change and potential change in norms and values. The report discusses risk in the context of decision-making, proposing that iterative risk management is useful in this process, though noting that good scientific and technical information is rarely sufficient to lead to better decision-making (Jones et al., 2014).

Whilst recognising the existence of a dynamic element of risk in AR5, it was not clearly stated in the accompanying Glossary, which simply notes that '*...Risk results from the interaction of vulnerability, exposure, and hazard...*'. Minor adjustments of this definition in the report Glossary are found in the In the most recent IPCC report, the Global Warming of 1.5°C Special Report (IPCC, 2018), as the full definition of risk reads as:

> Risk the potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.

In the definition above, IPCC recognise that exposure can vary over time, but there is still little clarity on the relevance of the temporal dimension for other components or indeed if risk refers to one or multiple hazards. It is likely that a comprehensive definition of risk covering the three Working Groups of the IPCC will be produced for the AR6 cycle.

Whilst providing an informative context on how to frame and contextualise climate risks, it is difficult to obtain practical advice on how to assess climate risks on a local scale from the IPCC reports. To understand how

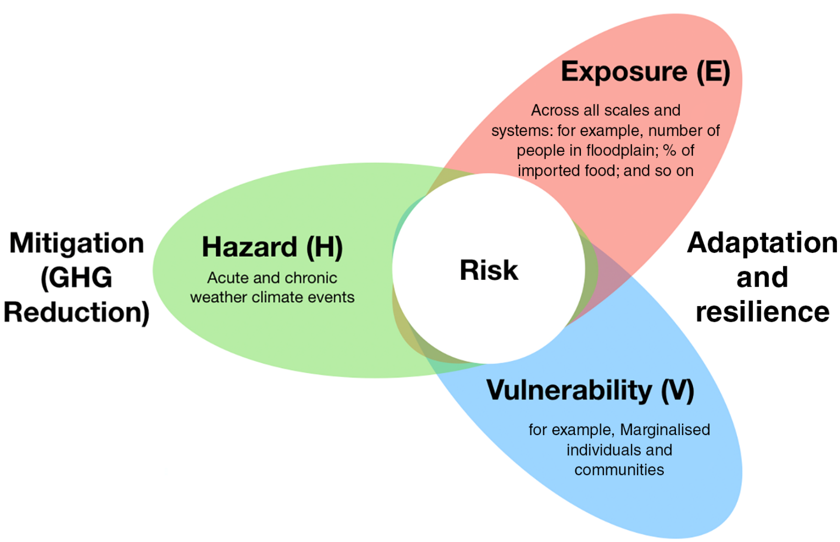

FIGURE 1 A conceptual representation climate risk as a function of hazard, exposure and vulnerability based upon the IPCC SREX definition of risk

risk is translated into risk assessments across different sectors and nations we can learn from the recent review of climate change vulnerability and risk assessment across Europe, and the indicator evidenced assessment of climate change, impact and vulnerability in Europe by the European Environment Agency (EEA; EEA, 2017, 2018).

The EEA provides a helpful overview on different definitions and frameworks of 'risk' and 'vulnerability', noting that 'climate change risk assessment' is sometimes used similarly to 'climate change vulnerability assessment' (EEA, 2018; Box 1.1). The EEA suggests that whilst the use of the terms 'risk' and 'vulnerability' in a general sense is unproblematic, different communities have somewhat different conceptual models which makes interpretation of results difficult. This is particularly true when using quantitative indicators of the terms as it may reduce comparability across studies from different sources (EEA, 2017, p. 47). On the use of indicators to evidence risk and vulnerability, the EEA notes that many studies follow the IPCC TAR/AR4 definition of vulnerability (see Section 2), using a combination of individual indicators for 'exposure', 'sensitivity' and 'adaptive capacity" into a single composite indicator of vulnerability or risk. Whilst these composites can be useful as a synthesis stage, or as a communication tool, they are critiqued on methodological shortcomings, on issues such as: comparability (normalisation, weighting of individual variables), conceptualisation of vulnerability is constructed without sufficient understanding of influencing factors, interdependencies, non-linearities, spatial scale, or fundamental relationship to vulnerability, and lack of explicit declaration of assumptions and interpretations of for example, risk and vulnerability. Indeed, for sector-specific, region-specific and climate hazard-specific decision making, non-composite metrics may be more informative, but the more narrow definition may ignore important cross-sectoral interactions (EEA, 2017, p. 49).

Whilst providing insights on how risk can be meaningfully estimated for different purposes, the EEA reports do not discuss specifically the potential for risk components to change over time and how this might be captured in indices used to quantify this. However, the EEA (2018) notes that approximately half the assessments reviewed considered current adaptive capacity in qualitative terms, with fewer considering future conditions. Similarly, non-climatic factors of vulnerability (current and socio-economic information) was limited with less than half of the assessments including a quantitative scenario of non-climatic developments.

With growing emphasis on building a resilient society and natural environment there has been an increasing need to understand the risk posed by climate change and extreme weather. However, the current framing of risk as a function of hazard, exposure, and vulnerability (or susceptibility to damage/harm) does not readily demonstrate how to incorporate key elements of the dynamic and emerging risk landscapes. This can be summarised as:

$$R = HEV \tag{1}$$

R = Risk on an asset, system, population, individual or location being the product of variables: H = hazard, E = exposure, and V = vulnerability (detailed definition follows below).

More broadly, the shortcomings of conventional risk assessments to deal with interaction between multiple risk factors, and multiple time scales was noted in a recent review of large-scale risk assessment for adaptation policy-making by Adger et al. (2018), who suggests better understanding of transmission of risk across sectors and scales (spatial and temporal) in risk assessments could come through engagement with practitioners.

The following section introduces the risk components as they are currently defined by the IPCC, discusses limitations as identified in the academic literature and calls for an action by contributing authors of upcoming IPCC reviews to place a greater emphasis on distilling evidence on methodological aspects of risk assessment, and to ensure that summative statements (such as Glossary definitions and infographics) reflect important characteristics sought in risk metrics.

2 | RISK AND RISK ELEMENTS, AS DEFINED BY THE IPCC

In many respects, the IPCC reports act as a standard for many scientists and practitioners when working on matters relating to climate change. Their definition and description of climate risk and its components is no exception. The evolvement of the risk concept was described in the previous section; here we focus instead on the components of risk, as adopted into the IPCC definition (Glossary). These components are: hazard, exposure and vulnerability defined by the IPCC (IPCC, 2018) as:

> **Hazard** The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

> **Exposure** The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
>
> **Vulnerability** The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

There is of course a different conceptualisation of these components in the wider academic literature (Jurgilevich et al., 2017). Some includes non-climatic drivers as well as climatic in the exposure component, with the concepts of "double exposure" (O'Brien and Leichenko, 2000) or "multiple exposures" (Belliveau et al., 2006) terms referring to exposure to more than one driver (e.g., globalisation). Conceptual variations also exist for vulnerability, a fundamental variation being, for example,:

> Outcome (end point) vulnerability Vulnerability as the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability (Kelly and Adger, 2000).
>
> Contextual (starting point vulnerability)A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes (O'Brien et al., 2007).

Some argue that because vulnerability is essentially a socially constructed concept (Hinkel, 2011), it can be difficult to quantify; others note that *both* vulnerability and exposure are socio-economic factors (Mechler and Bouwer, 2015). Certainly, recent debates across the literature, and within the IPCC process, have highlighted the conflicting interpretations of vulnerability; a discussion that has been underway since at least 2004 (O'Brien et al., 2004).

2.1 | Weaknesses in current risk assessments

Mechler and Bouwer (2015) suggest that vulnerability in a disaster risk context is linked to the degree of damage (or loss) in a natural event, whereas in the climate community, vulnerability is considered a function of sensitivity and adaptive capacity to climate change. The relevance of these different interpretations are illustrated in a study of resilience for remote disadvantaged communities by (Maru et al., 2014). The authors showed that a framework that focused on addressing short-term vulnerability improved risk exposure in some respects but could result in an overall increased vulnerability for the community. Hence, the risk equation (being the product of hazard, exposure and vulnerability) is often estimated with a static perspective, due to its origin from a disaster risk community, where the temporal dimension is significantly shorter compared to the long-term climate change risk assessments, stretching over decades to come.

However, we know that risk components, such as exposure and hazard, will change over time (Figure 2). Climatic and non-climatic drivers will push species, individuals or assets into areas that will become more affected by climate change over time, for example, coastal exposure through increased sea levels and storm surge (Seabloom et al., 2013), or exposure to fire danger due to changing rainfall and temperature patterns (Fox-Hughes et al., 2014). Non-climatic drivers that can alter risk include degradation of infrastructure, for example, flood defences, or economic drivers (such as commercial insurance) and technologies providing incentives and opportunities to expand land-use into areas that previously were not considered suitable, and in the future will become less or more suitable. Conversely, denying crop insurance to producers who have converted grasslands in the United States resulted in a 9% drop in conversion and likely had positive mitigation impacts (Claassen et al., 2011).

In a systematic review of dynamics in climate risk and vulnerability literature, Jurgilevich et al. (2017) found that approximately half of the studies included a dynamic element to their assessment and that vulnerability was typically based on current understanding of socio-economic conditions, which can make predictions about future change difficult (Jurgilevich et al., 2017). Some studies also include a cumulative element. For example in Hansen et al. (2014), the cumulative impacts of climate change and high land use of protected areas were considered on individual areas and synergistically across areas.

In a biological context, there are several mechanisms for how vulnerability of individuals, populations and species might change over time. For example, specific

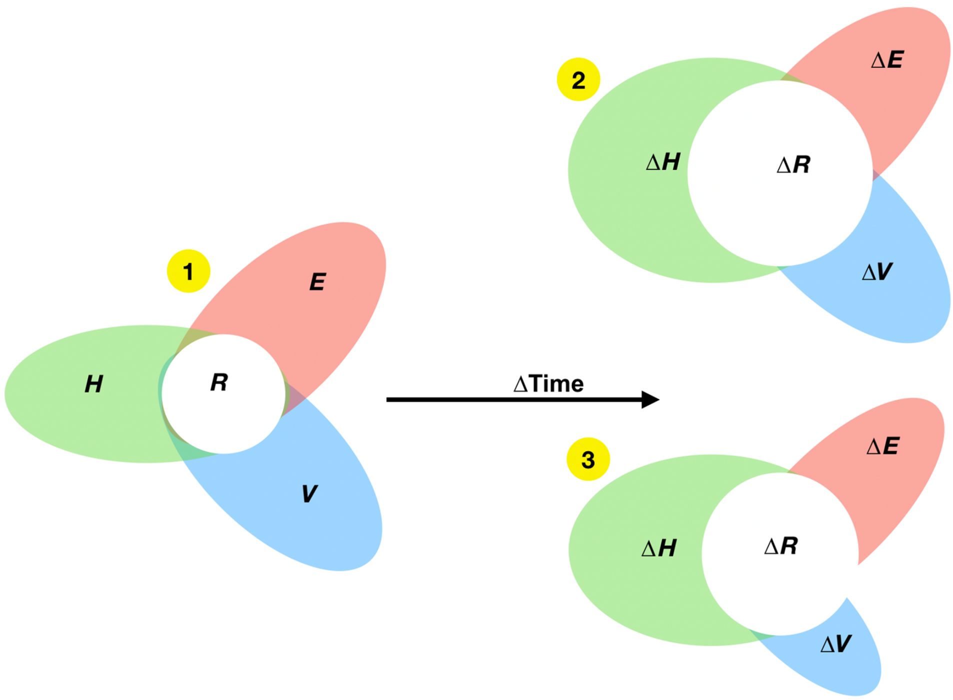

FIGURE 2 The impact of the dynamic contents of risk upon the measure of risk. Graphic 1 shows the static current value. Graphic 2 shows the impact of no climate mitigation on the magnitude of the Hazard and the subsequent increase in risk. Graphic 3 shows that even with climate adaptation and resilience response options implemented, risk will increase if the magnitude of the hazard continues to increase

genomic regions are involved in climate change adaptation in some bird species, for example, yellow warblers, and further specific genes may be involved in a first response necessary for adaptation (Fitzpatrick and Edelsparre, 2018). Not all populations have these, indicating a level of 'genomic vulnerability'. Furthermore, Chevin et al. (2010) note that longer lived species must evolve faster per generation to adapt to a given rate of environmental change. As an example, the inability of a sea bird population to adjust their breeding seasons over time or in response to changes in sea surface temperature, may lead to an increase in its vulnerability if species further down the food chain are shifting in parallel with sea surface temperatures, and sea birds cannot adjust behaviour by switching to other prey (Keogan et al., 2018). Hence, if attempting to quantify vulnerability for a specific species or ecosystem, recognising its ability to alter over time through adaptive phenotypic plasticity (such as altered breeding times) or genetic evolution (such as increased metabolism) can mediate the effects of environmental shifts (Chevin et al., 2010).

The importance of dynamic representation in vulnerability is also found in many other applications, such as assessment of flood risk losses. Using riverine flooding in Bangladesh as a case study, Mechler and Bouwer (2015) demonstrate that when taking into consideration that economic vulnerability (propensity to incur losses in a hazardous event) has reduced over the past decades, risk increases at much smaller rate compared to a static vulnerability case. The authors highlight challenges in capturing trend in losses that otherwise could support more robust projections of risk, noting that there can be large uncertainty in reports on losses for the same event, a lack of systematic long-term capturing of losses, and under-reporting for smaller loss events, and limited studies on non-market losses (e.g., health, culture and the environment). Hence, ability to capture the dynamics of economic vulnerability is a data quality issue as well as a methodological one.

Sections above give examples on how improved temporal representation of components of risk can lead to more realistic estimation of future risk. We can also consider methodological changes that supports a more systematic and refined characterisation of risk metrics, and an analysis and prioritisation of frameworks and practices favoured by different user groups. For example, in their literature review of social vulnerability, Rufat et al. (2015) highlight the situational variability in social vulnerability drivers, suggesting that context influences a specific driver's (such as age or class) impact on vulnerability. Authors further note that the influence of drivers on vulnerability can change during the temporal progression of a hazard. In terms of frameworks, we need to ensure that there are mechanisms and procedures to incorporate local knowledge to assist with risk assessments. For example, whilst many coastlines may share similar physical exposure from rise in sea levels and storm surge, different coastal communities have locally and regionally specific vulnerabilities, which requires substantial input from local community and decision makers to ensure that meaningful information is fed into observational and modelling programs used to address short- and long-term risks (Nichols et al., 2019).

Standardisation and refinement of the methods used to assess risks may also help to combat challenges in the process of constructing decision-making material; that is, challenges that impacts the relevance and quality of the information flow. Rozance et al. (2019, p. 105) refers to this dynamic decision-making process as 'scalar knowledge politics of risk', defined as '*... strategies for defining and managing perceived risks at specific scales*'. This concept goes beyond the physical concept of scale, considering also borders in a social (e.g., social connectivity within a neighbourhood) and political (e.g., addressing certain communities or causes) context. When considering these scales, or boundaries, authors identify five arenas of scalar politics of risk, moving from global scales (climate projections), to local scale (evaluation, certification and data production). In their framework, the creation of 'risks' occurs at the third scalar level, where biophysical impacts (derived from regionalised global projections) are given social, ecological, and technical dimensions. In a geographical sense, this scale represents somewhere between national and regional scales. Knowledge arising from this arena has certain challenges in that the process is shaped by what is currently known and valued by the social actors that conduct the assessment (i.e., who has the political powers and does spatial and social reapportioning of physical impacts address local issues?).

A standardisation of procedures may alleviate some of the challenges associated with risk assessments, working towards a best-practice approach. Whilst perhaps tangential to the focus of this paper, we further note that an improved representation of complex relations between components of risk that involve multiple, desirable outcomes and trade-offs between outcomes can impact preferences of donors of aid for developing countries who are generally multi-attribute risk adverse, preferring single risk outcomes (Gangadharan et al., 2019).

3 | SUGGESTIONS TO CONSIDER WHEN REVISING IPCC DEFINITION OF RISK ASSESSMENT

For practitioners, who deal with risk assessment as part of their operational environment (e.g., infrastructure or environmental consultancies), climate and weather risks to a given sector, asset, or location are understood and addressed through a climate change risk assessment process. These are tools for identifying and categorising risks, understanding their impacts; assessing how the design and operation will be impacted and how to implement necessary resilience measures (see e.g., the climate risk register template as produced by The Scottish Government (Adaptation Scotland, 2019)). These tools are essential components of business governance and an obvious pathway to mainstream an appreciation for the costs and losses of climate change through society, the economy and the environment.

To better understand how risk is implemented in the private sector we would need to review material outside the realm of the peer-reviewed literature, captured in commissioned assessments, or internal policy and reporting documents. This is outside the scope of this paper but should be considered increasingly when providing direction and guidance on climate change risk assessment by the IPCC.

To move forward the discussion on risk and its dynamic we suggest as a starting point the following approach: consider risk defined by two metrics, one that describes the baseline state (Equation (1)) estimated using observational data, and a second that captures change (ΔR, Equation 2) between a current (subscript C) and future (subscript F) time period. Whilst simple in format, the implementation is not necessarily straightforward as one would need to ensure that the estimates of current and future risk components are physically consistent, for example, not mixing observational information with potentially biased model simulation information. If combining observational climate data with model simulation, the latter would require bias correction. Alternatively use information from the same model in both the current and future risk component—assuming that biases are temporally stationary.

$$\Delta R_F = \frac{(H_F E_F V_F)}{(H_C E_C V_C)} = \frac{R_F}{R_C} \tag{2}$$

More complex formulations could capture the dynamic risk as a cumulative change or attempt to better capture the rate of change (e.g., through approximation to a parametric model). More broadly, we welcome further discussion across the academic, policy and practitioner nexus on approaches to address risk in a climate change context that:

- recognises that risk components can change over time, hence, requiring a temporal dimension in its construction,
- recognises that the complexity in a risk metric can reduce the interpretability of a metric and the need for standardisation and refinement of metrics representing risk components,
- recognise the need to standardise risk assessment frameworks and guidance of best practice.

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