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ARTICLE

Polycrisis and Systemic Risk: Assessment, Governance, and Communication

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Abstract
The emphasis of integrated disaster and risk research has shifted from topical analysis, such as dealing with natural hazard-related disasters, technological accidents, or environmental crises, to a comprehensive analysis of interconnected and mutually interactive risk sources and crises. This interaction has often been framed in the language of "polycrisis" indicating the potentially amplifying and cascading effects of each crisis from one domain to the next. At the same time, the literature on systemic risk also includes the effects of multiple, interacting risks on the functionality and survivability of entire systems such as climate stability, cybersecurity, or energy production. This review article provides first a summary of the literature on both concepts, explicates the commonalities and differences and develops a risk and crisis concept that builds a bridge between the two research traditions. Based on this concept, the review delineates the implementations of a joint understanding of polycrisis and systemic risk for risk assessment, risk and crisis governance, and effective communication to different audiences.

Keywords Cascading and amplifying impacts · Cooperative · Integrative and inclusive risk governance · Effective risk communication · Participation in risk management · Polycrisis and systemic risk

1 Introduction

The last few decades clearly demonstrated that global systems—ranging from finance to national security, to climate change and energy—are highly susceptible to global crises and multiple risks (Renn 2024). As illustrated by the Covid-19 pandemic, Russia's war on Ukraine, geopolitical tensions, and climate change and others, systemic risks do not remain confined to the global systems in which they originate. With the increasing complexity and interactive dynamics of our interconnected world, these crises are not isolated events, but rather intertwined. They can quickly spread across borders and sectors, as well as amplify and cascade the impact of each crisis from one domain to the next (Lawrence et al. 2024a). For example, the global financial crisis of 2008 not only caused widespread economic disruption but also led to severe political instability (Helleiner 2024). The Covid-19 pandemic has not only induced a health crisis but has also led to severe economic downturns, strained international relations, and accelerated environmental degradation due to constrained supply chains, lack of sustainable substitutes for replacing energy imports, and trade restrictions (Alizadeh et al. 2023). Similarly, climate change, which affects multiple systems simultaneously, including ecosystems, economies, and social structures, also acts as a multiplier, exacerbating existing social and economic inequalities and contributing to political instability and conflict (Kahn et al. 2021; Sillmann et al. 2022). Allegedly separate crises in different global systems influence and amplify each other, creating multiple interacting crises that must be comprehended and responded to collectively as a whole (Moure-Peñín 2024).

In light of these new developments, the emphasis of integrated disaster and risk research has shifted from topical analyses to comprehensive analyses of interconnected and mutually interactive risk sources and crises (Renn 2024). Such interactions have often been framed in the language of "polycrisis," suggesting that each crisis has the potential to expand, amplify, and cascade from one domain to the

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next (Lawrence 2024b). The notion of a "polycrisis" serves as an insightful approach for comprehending and tackling significant challenges confronting humanity and has gained traction among an increasing number of commentators, agencies, and researchers who seek to capture the intricate interactions between the world's conjoined crises (Lawrence, Janzwood, et al. 2022; Hoyer et al. 2023; Helleiner 2024; Lawrence et al. 2024a; Renn 2024). It has been defined and applied in different disciplines over the past two decades, but there are still some disagreements on the definition of the concept, and deficiencies in common understanding as the discussion about polycrisis is still evolving and new elements and aspects have been suggested to create a more comprehensive and operational definition (ASRA 2024).

At the same time, the literature on systemic risk addresses this situation from the perspective of risk assessment and governance (Lucas et al. 2018a; Renn and Lucas 2022; Renn et al. 2022). The concept of systemic risk includes the need to focus on multiple, interacting risks and analyzes the effects of these risks on the functionality and survivability of entire systems such as climate stability, cybersecurity, or energy production. Understanding and managing multiple crises and systemic risks is critical for developing effective strategies to address the intricacies of contemporary global challenges, especially in times of political fragmentation (World Economic Forum 2023). Moreover, geopolitical fragmentation has been identified as a major cause for promoting geo-economic warfare and increasing risks of multidisciplinary conflicts (World Economic Forum 2023). Thus, the significance of studying multiple crises and systemic risks is further emphasized in an era of political fragmentation, highlighting the need for a systemic perspective that assists risk managers to navigate through the complexities of polycrisis and govern their cascading impacts. The conventional risk management framework is incapable of responding to the increasing systemic and existential risks posed by decades of globalization, digitalization, and political segmentation (Lawrence et al. 2024a; Renn 2024).

This review therefore aimed to provide a comprehensive survey of current state-of-the-art research on both polycrisis and systemic risk, and to delineate the implementations of a joint understanding of polycrisis and systemic risk for risk assessment, risk and crisis governance, and effective communication to different audiences. The article first reviews the definitions and concepts of polycrisis and systemic risk, highlighting the commonalities and differences between them. It then summarizes the methods used to assess and model these risks, reviewing new trends for assessing, managing, and governing systemic risks in a complex world. Based on the insights gained from the current literature, it discusses the deficiencies of existing risk assessment, governance, and communication frameworks in the context of addressing systemic risk in polycrisis, and strategies to address these deficiencies. These strategies focus on enhancing the capacity of governance structures to manage interconnected crises, improving the assessment and modeling of systemic risks, and developing effective governance instruments as well as communication strategies to engage diverse stakeholders and affected citizens. Ultimately, the article suggests some lessons to policymakers and practitioners for building more resilient and adaptive response systems capable of dealing with the complexity of interconnected and contemporary global challenges. By synthesizing insights from the polycrisis and systemic risk research, this review also includes implications for future studies.

The article is organized as follows: Section 2 introduces the origin, definition, and concept of polycrisis, followed by Sect. 3, in which we introduce the history and concept of systemic risk, discuss the challenges for risk assessment, governance, and communication, and identify the commonalities and differences between polycrisis and systemic risk. Sections 4, 5, and 6 define the application of a joint understanding of polycrisis and systemic risk to methods of risk assessment, methods of risk management and governance, and types of effective communication to different audiences. In addition, these sections also address the new requirements for coping more adequately than today with systemic risks in situations of polycrisis. Finally, Sect. 7 discusses and summarizes the implications of this review work and delineates directions for future research. Figure 1 presents the overall framework of this review article.

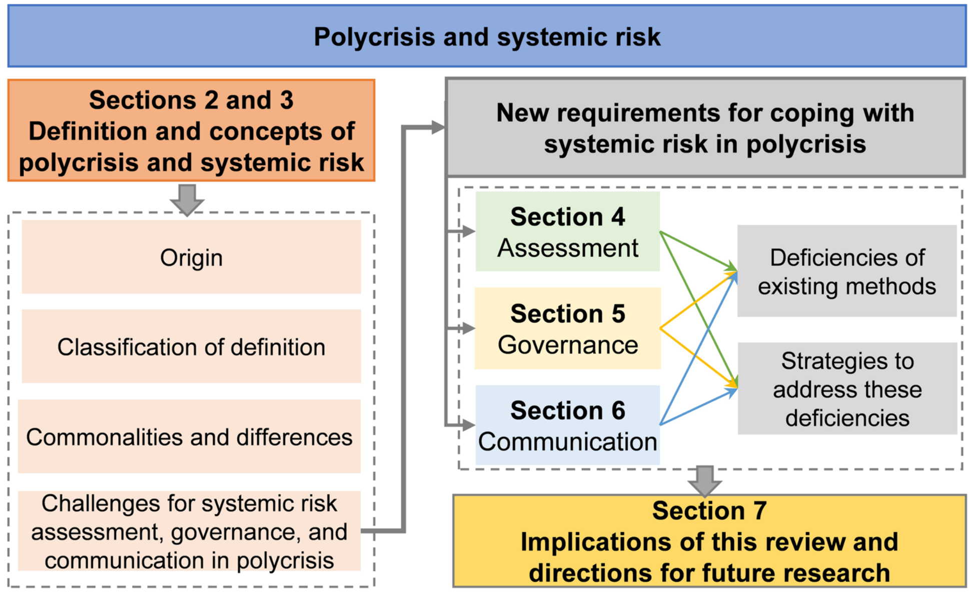
2 Polycrisis: Definitions and Concepts

Recent literature (Lawrence 2023; ASRA 2024; Lawrence et al. 2024a; Lawrence et al. 2024c) has provided a detailed overview of the history and evolution of polycrisis, thus this section only briefly describes the origin of the term "polycrisis" but focuses more on summarizing the various conceptual definitions and proposing a classification for different concepts of polycrisis.

2.1 Origin

The term "polycrisis" was first introduced by complexity theorists Edgar Morin and Anne Brigitte Kern in their 1999 book "Homeland Earth" (Lawrence et al. 2024a). They argued that the world does not face a single vital problem but many complex interconnected problems (Morin et al. 1999). Later, South African sociologist and sustainable transformation theorist Mark Swilling adopted this terminology to describe a complex set of globally interactive socioeconomic, ecological, and cultural-institutional crises that cannot be reduced to a single cause. Swilling also emphasized that climate change, growing inequality, and the

Fig. 1 Overall framework



financial crisis interact in ways that amplify their combined impact (Swilling 2013). Then, former European Commission President Jean-Claude Juncker used the term "polycrisis" to describe the series of government challenges facing Europe at a time when finance, immigration, and Brexit crises occurred in a 2016 speech, asserting that these crises were not only concurrent but also cascading (Juncker 2016; Ágh 2017; Zeitlin et al. 2019).

More recently, scholars have used the term "polycrisis" to describe the complex interplay between the Covid-19 pandemic, Russia's war on Ukraine, and climate change, among other issues (Lavell 2021; Sillmann et al. 2022). Columbia University historian Adam Tooze noted in his book *How Covid Shook the World Economy* that while "polycrisis" effectively captures the simultaneous occurrence of different crises, it does not explain their interactions (Tooze 2021). In a *Financial Times* opinion piece, Tooze further suggested that in multiple crises, different shocks interact, making the overall impact more overwhelming than the sum of individual crises (Tooze 2022).

In parallel, the Cascade Institute launched a research program on global multiple crises. In its 2022 discussion paper, the authors proposed the concept of "global polycrisis" as a framework to investigate the causal connections between crises across global systems, providing a clear definition (Lawrence, Janzwood, et al. 2022, p. 2): "A global polycrisis occurs when crises in multiple global systems become causally entangled in ways that significantly degrade humanity's prospects. These interacting crises produce harms greater than the sum of those the crises would produce in isolation, were their host systems not so deeply interconnected."

Yet the term "polycrisis" really came into the public eye when it became the main buzzword at the January 2023 annual meeting of the World Economic Forum (WEF) in Davos (Serhan 2023; Lawrence et al. 2024a). The term was placed prominently throughout the document in their first annual report, emphasizing that: "Concurrent shocks, deeply interconnected risks and eroding resilience are giving rise to the risk of polycrisis—where disparate crises interact such that the overall impact far exceeds the sum of each part" (World Economic Forum 2023, p. 9).

The various definitions and characterizations of polycrisis are summarized in Table 1. As one can clearly see, the scope of definitions and concepts is still limited, and most definitions show similar patterns and characteristics. The definitions differ in what they emphasize but they are almost identical in identifying the key features of polycrisis.

2.2 A Proposal for Classifying Different Concepts of Polycrisis

Based on the literature review (see Table 1), we came up with a list of crucial features that most sources agree are constitutive for polycrisis: (1) the simultaneity of allegedly independent crises; (2) the potential loss or breakdown of system functionality; (3) the likelihood of crises "infecting" other systems; (iv) the likelihood of risk cascading within and between systems; and (5) the likelihood of amplifying impacts. These features highlight the interconnectedness and complexity of polycrisis, leading to cascading failures across systems and amplifying the effects of individual crises (Lawrence, Williams, et al. 2022; UNDP 2022; Lawrence et al. 2024a; Renn 2024).

Given these characteristics, we found it necessary to produce a more generic framework for understanding and

Table 1 Definition of polycrisis

References/Authors	Definition
Morin et al. (1999, p. 74)	"The most 'vital' problem of the day was not any single threat but the complex intersolidarity of problems, antagonisms, crises, uncontrollable processes, and the general crisis of the planet."
Swilling (2013, p. 98)	"The complex interactions between crises in the global political economy that multiply those crises' overall impact."
Tooze (2021, p. 2)	"In multiple crises, the shocks are different, but they interact to make the whole more overwhelming than the sum of its parts."
Lawrence, Janzwood, et al. (2022, p. 2)	"A global polycrisis occurs when crises in multiple global systems become causally entangled in ways that significantly degrade humanity's prospects. These interacting crises produce harms greater than the sum of those the crises would produce in isolation, were their host systems not so deeply interconnected."
Hagens (2023, p. 6)	"It describes the polycrisis on its website as 'the sum total of all stressors affecting planetary health,' distinguishing between 'biosphere stressors' (e.g., climate crisis, biodiversity loss, ocean acidification), 'societal stressors' (e.g., poverty, supply chain vulnerabilities, war), and 'technological stressors' (e.g., automation and AI, cyber threats, data threats to democracy)."
World Economic Forum (2023, p. 57)	"A cluster of related global risks with compounding effects, such that the overall impact exceeds the sum of each part."
Lawrence et al. (2024a, p. 9)	"Global polycrisis is the causal entanglement of crises in multiple global systems in ways that significantly degrade humanity's prospects."
Helleiner (2024, p. 2)	"A cluster of distinct crises that interact in ways that they and/or their effects tend to reinforce each other. This core definition enables the identification of distinct types of polycrisis that capture multiple uses of the term to date. These types vary according to the spatiality, temporality, and level of generality of each polycrisis as well as the traits of its constituent crises."

addressing polycrisis. This framework can be categorized into four main dimensions: interconnectedness, complexity and uncertainty, temporal and spatial dimensions, and systemic impacts (Lawrence, Janzwood, et al. 2022; Tooze 2022; Hoyer et al. 2023; Helleiner 2024; Lawrence et al. 2024a; Renn 2024).

- *Interconnectedness* is a defining feature of polycrisis, where multiple crises are interlinked, and their interactions can amplify the effects of individual crises, leading to cascading failures across systems. This interconnectedness means that a crisis in one domain, for instance economic collapse, can trigger or exacerbate crises in other domains. Understanding these linkages is crucial for developing effective strategies to mitigate the impact of polycrisis.
- *Complexity and uncertainty* arise from the multiple, intertwined causes and effects that characterize polycrisis. This complexity makes it difficult to predict outcomes and manage the situation effectively. The unpredictable nature of the interactions between different crises adds a layer of uncertainty, complicating efforts to devise coherent responses. Policymakers and stakeholders must navigate this uncertainty by adopting flexible and adaptive approaches that can respond to evolving conditions.
- *Temporal and spatial dimensions* of polycrisis reflect how these crises can span different geographical regions and evolve over time. The impact of a polycrisis can vary significantly across sectors and populations, affecting different regions and communities in diverse ways. Recognizing these temporal and spatial dimensions is essential for tailored interventions that address the specific needs of affected populations.
- *Systemic impacts* underscore the broad reach of polycrisis, which can affect entire systems such as economic, social, environmental, and political systems. Unlike isolated incidents, polycrisis can disrupt the functionality of multiple systems simultaneously, leading to widespread instability, which highlights the need for integrated approaches that consider the systemic nature of polycrisis.

Therefore, developing a comprehensive framework for understanding polycrisis involves recognizing these features and adopting strategies that address the intricate web of interactions between different crises. By focusing on these four dimensions risk analysts are better prepared to provide more accurate and policy-relevant risk assessments and risk managers to develop more effective, efficient, fair, and resilient coping strategies for dealing with polycrisis (Renn 2024). Such holistic approach is crucial for mitigating the cascading failures and amplifying impacts that characterize polycrisis, ultimately leading to more resilient and adaptive systems.

3 Systemic Risks: Definitions and Concepts

To comprehensively compare and contrast polycrisis and systemic risk, this section first introduces the concept of systemic risk and explores how systemic risk is framed and understood in a variety of academic disciplines. It then elaborates on the commonalities and differences between the two concepts, followed by challenges for risk assessment, governance, and communication.

3.1 History of the Concept of Systemic Risk

The concept of systemic risk has evolved significantly over the decades, reflecting its roots in complexity science and network dynamics. Emerging in the 1950s, it initially focused on mathematical equilibrium and agent-based models to understand impacts such as virus transmission and ecological breakdowns. These early models, however, were limited to assessing risk exposure effects rather than predicting or addressing the systemic nature of risk itself (Faulhaber et al. 1990).

The understanding of systemic risk expanded significantly in the early 2000s, driven by the recognition of "wicked problems" (Rittel and Webber 1973). This period saw an increased focus on how specific events could trigger cascading effects across interconnected systems, leading to widespread losses and potential systemic collapse. The 2007/08 financial crisis and climate-related disasters underscored the importance of these cascading effects, the experience of tipping points in cause-effect relationships, and the relational and procedural aspects of systemic risk (Schweizer 2021; Renn and Lucas 2022; Schweizer et al. 2022).

A major milestone occurred in 2003 when the Organization for Economic Co-operation and Development (OECD) adopted the concept of systemic risks to address threats to essential societal systems like infrastructure, healthcare, and telecommunications. This broadened the concept's visibility beyond academia into policymaking. Kaufman and Scott (2003) further refined the definition, emphasizing the systemic nature of risk as the probability of breakdowns in an entire system, evidenced by co-movements among its parts. Other authors such as Rodriguez et al. emphasized the systemic relationship between the financial sector and the real-world economy pointing out that allegedly purely financial transactions had systemic impacts on world trade and corporate governance (Rodriguez et al. 2014).

The global financial crisis of the late 2000s, and much later events like the war in Ukraine and the Covid-19 pandemic, clearly demonstrated the real-world manifestations of systemic risks. These crises emphasized the global, catastrophic, and even existential nature of such risks (Helbing 2013; World Economic Forum 2021). De Bandt and Hartmann (2019) characterized systemic risk through the dual components of shocks and propagation mechanisms, highlighting how these elements trigger systemic impacts.

Further refining the concept, Billio et al. (2012) defined systemic risk as circumstances threatening financial system stability and public confidence. Smaga (2014) proposed that systemic risk involves shocks leading to significant imbalances, impairing financial systems and adversely affecting the real economy. The European Central Bank (ECB) (2010) and other scholars have echoed these definitions, focusing on various mechanisms like imbalances, correlated exposures, and feedback behaviors (Caballero 2011; Mishkin 2011; Acharya et al. 2017).

Beyond the financial focus, systemic risk has been recognized as a threat to critical societal systems with impacts extending beyond their origin, as proposed by Renn (2016) and Schweizer and Renn (2019). Other authors studied the connection between physical and political risks (Homer-Dixon et al. 2022; Jerez-Ramíre and Ramos-Torres, 2022). The International Risk Governance Council (IRGC 2018) highlighted the cascading effects that are typical for systemic risks. The extension of systemic risk to include all natural, social, and technological domains led to an inflation of definitions and conceptualizations that emphasize specific features of systemic risks over conventional risks. Table 2 provides an overview of the most popular definitions and characterizations of systemic risks.

Based on the intensive discussion on the nature and characteristics of systemic risk, several scholars have suggested core properties of systemic risks, highlighting their complex behaviors (Renn 2016; Lucas et al. 2018a, b; Lawrence, Janzwood, et al. 2022; Renn et al. 2022; Schweizer 2022; Sillmann. et al. 2022). Although terminology may differ, there is consensus that systemic risks possess four key properties (Lawrence, Janzwood, et al. 2022; Lawrence et al. 2023):

- Extremely complex and dynamic networks with multiple, synergistic causes and feedback loops.
- Highly nonlinear cause-effect relationships characterized by disproportional causation, with multiple equilibria, unpredictable tipping points, and hysteresis.
- Causal processes that transcend the boundaries of administrative and political units, social sectors, and scientific disciplines, operating on multiple time scales across natural, social, and technological systems.
- Stochastic relationships involving deep uncertainty about both underlying causes and ultimate consequences.

Table 2 Definitions and characterizations of systemic risks based on a literature review

References/Authors	Definition
Group of Ten (2001, p. 126)	"Systemic financial risk is the risk that an event will trigger a loss of economic value or confidence in, and attendant increases in uncertainty about, a substantial portion of the financial system that is serious enough to quite probably have significant adverse effects on the real economy."
OECD (2003)	Address threats to essential societal systems like infrastructure, healthcare, and telecommunications.
Kaufman and Scott (2003, p. 371)	"Systemic risk refers to the risk or probability of breakdowns in an entire system, as opposed to breakdowns in individual parts or components, and is evidenced by co-movements (correlation) among most or all parts."
Adrian and Brunnermeier (2011, p. 1)	"Systemic risk as the risk that the intermediation capacity of the entire financial system is damaged, with potentially adverse consequences for the supply of credit to the real economy."
De Bandt et al. (2012)	Characterized systemic risk through the dual components of shocks and propagation mechanisms, highlighting how these elements trigger systemic impacts.
Kaufman (1995, p. 47)	Systemic risk is the risk of a "chain reaction of falling interconnected events."
Billio et al. (2012, p. 537)	Systemic risk is "any set of circumstances that threatens the stability of or public confidence in the financial system."
Smaga (2014, p. 5)	"Systemic risk involves shocks leading to significant imbalances, impairing financial systems and adversely affecting the real economy".
Renn (2016), Schweizer and Renn (2019), Schweizer et al. (2022)	Systemic risks refer to potential threats that endanger the functionality of systems of critical importance for society and their scope in time and space. The impacts may extend beyond the system of origin to affect other systems and functions.
International Risk Governance Center (2018, p. 9)	"Systemic risks are characterized by cascading effects that affect the larger system."
Hochrainer-Stigler et al. (2020a, b)	Systemic risks as a potential for a threat or hazard to propagate disruptions or losses to multiple connected parts of complex systems.
Sillmann et al. (2022, p. 255)	"Systemic risk is associated with cascading impacts that spread within and across systems and sectors (e.g., ecosystems, health, infrastructure and the food sector) via the movements of people, goods, capital and information within and across boundaries (e.g., regions, countries and continents)."
Mitra and Shaw (2023, p. 125)	"Systemic risk refers to the risk that the whole system will break down, not just the failure of individual parts."
ASRA (2024, p. 5)	"Systemic risk is defined as the potential for multiple, increasingly severe, abrupt, differentiated yet interconnected, and potentially long-lasting and complex impacts on coupled natural and human systems."

However, there have been also critical reviews of the concept of systemic risks. Getmansky et al. (2015) argued that the current situation in the literature regarding the definition of systemic risk is not satisfactory and lacks precision and clarity.

Overall, the concept of systemic risk has evolved from its initial mathematical models to a comprehensive understanding encompassing financial, ecological, and societal systems, emphasizing the interconnectedness and cascading effects that characterize modern systemic threats.

3.2 Multiple Perspectives from Different Disciplines

Systemic risk is understood and conceptualized differently across various disciplines, each offering unique insights into its nature and implications (Renn et al. 2022). This section aims to provide a coherent and precise overview of how systemic risk is perceived in fields such as economics, social sciences, engineering, ecology, and disaster risk management.

Economics and Financial Systems: In economics, particularly within financial systems, systemic risk is primarily associated with financial crises, regulatory measures, and market interdependencies. Early research focused on bank failures and the theoretical underpinnings of bank runs. Diamond and Dybvig (1983) pioneered the formal modeling of liquidity transformation in banks, illustrating how this could lead to bank runs. Subsequent work by Jacklin and Bhattacharya (1988) and Donaldson (1992) expanded on this by exploring panics, interbank trading, and the probability of financial crises. Kaufman and Scott (2003) provided a widely accepted definition of systemic risk in finance, describing it as the risk of breakdowns in an entire system, evidenced by co-movements among its parts. Systemic risk in banking often refers to a macro-shock affecting the entire financial system (Bartholomew and Whalen 1995) or a sudden event disrupting financial markets (Mishkin 1997). It also includes the micro-level transmission of shocks through interconnected institutions (Kaufman 1995) and the risk of cascading failures triggered by participant defaults (Group of Ten 2001).

Social Sciences: Social scientists view systemic risk through the lens of social systems and their vulnerabilities, with a primary emphasis on the unintended or unforeseen effects of multiple interactions between individuals, groups, and organizations modified or shaped by social, economic, political, and cultural context conditions (Lucas et al. 2018a, b). Helbing (2013) highlighted the nonlinear interdependencies resulting from human interactions, which can lead to unpredictable outcomes like social unrest and revolutions. Such systemic risks manifest when societal equilibrium is significantly disrupted by radical movements (Schroter et al. 2014).

Engineering and Technological Systems: In engineering, systemic risk is often discussed in the context of infrastructure and technological systems, focusing on resilience, safety engineering, and interdependencies. Technological systemic risk involves potential disruptions within systems like cybersecurity, artificial intelligence (AI), and critical infrastructure, leading to widespread and cascading effects (Schweizer and Renn 2019; Liu et al. 2021). These risks can propagate through interconnected digital infrastructures, affecting sectors ranging from national security to personal privacy.

Ecology and Environmental Sciences: Environmental scientists link systemic risk to ecological and environmental systems, assessing interactions between human interventions and natural responses. Systemic risk in this context refers to the potential collapse of ecosystems or widespread disruptions with cascading effects on both ecological and socioeconomic systems (Scheffer et al. 2009; Helbing 2013; Lenton 2013). Examples include climate change, biodiversity loss, and industrial pollution, all of which have far-reaching and interconnected impacts.

Natural Hazards and Disaster Risk Management: In disaster risk management, systemic risk involves the potential for natural hazards and disasters to cause widespread, cascading effects across interconnected ecological, social, and economic systems (Lade et al. 2020; Mitra and Shaw 2023; Richardson et al. 2023). This type of risk is shaped by the complexity and interdependencies of modern societies, where disruptions in one area can trigger failures in others. Systemic risks related to natural hazards require comprehensive and integrated approaches to risk assessment and management (UNDRR 2021; Sillmann et al. 2022).

By integrating insights from different disciplines, a more comprehensive understanding of systemic risks can be accomplished. Simultaneously, collaborative governance, adaptive strategies, and holistic analysis are essential for addressing the multifaceted nature of these risks. This multidisciplinary approach is crucial for assessing and analyzing systemic risk as well as developing effective mitigation and management strategies.

3.3 Synopsis: The Relationship between Polycrisis and Systemic Risk

In an increasingly interconnected and complex world, the relationship between polycrisis and systemic risk has gained significant attention. Although these concepts are intimately related, they are also distinct (Lawrence et al. 2024b).

Polycrisis incorporates two core features of systemic risks. First, they both arise from the high degree of interconnectivity among system elements, where a single disruption can generate cascading impacts throughout the system. Second, both imply that discernible boundaries separate one system from another, although discrete systems may influence each other by exchanging energy, matter, information, and people (Lawrence, Janzwood, et al. 2022; Lawrence et al. 2024a; Lawrence et al. 2024c; Renn 2024).

However, polycrisis differs from systemic risk in three important aspects (Lawrence, Janzwood, et al. 2022). First, the studies on systemic risk are primarily focused on the pre-crisis conditions looking into the drivers and causes for interrelated disasters and suggesting potential measures and policies to avoid, prevent, or mitigate these risks. The studies on polycrisis also include the investigation of causal roots of each crisis element but are more focused on how to handle multiple crises once these interconnected crises have manifested themselves. Second, systemic risk is generally assumed to arise within a single system, whereas polycrisis emphasizes the causal entanglement of crises across multiple systems, including coincidences that are not causally related but connected through interacting impacts. This distinction is well established by the concepts of intra-systemic and inter-systemic impacts (Lawrence et al. 2024a). Finally, while systemic risk literature highlights the complexity and nature of interacting risks, polycrisis underscores the complexity of the systems' environment in which these risks arise (Lawrence, Janzwood, et al. 2022; Lawrence et al. 2024a). Figure 2 provides an overview of the evolution of the debate on systemic risk and polycrisis.

3.4 Challenges for Risk Assessment, Governance, and Communication

The increasingly interconnected and complex world, the emergence of polycrisis and systemic risk—where multiple crises occur simultaneously and interact with each other—presents significant challenges for risk assessment, governance, and communication (Renn 2024). In risk assessment, one of the main challenges is addressing the complex interdependencies between different types of

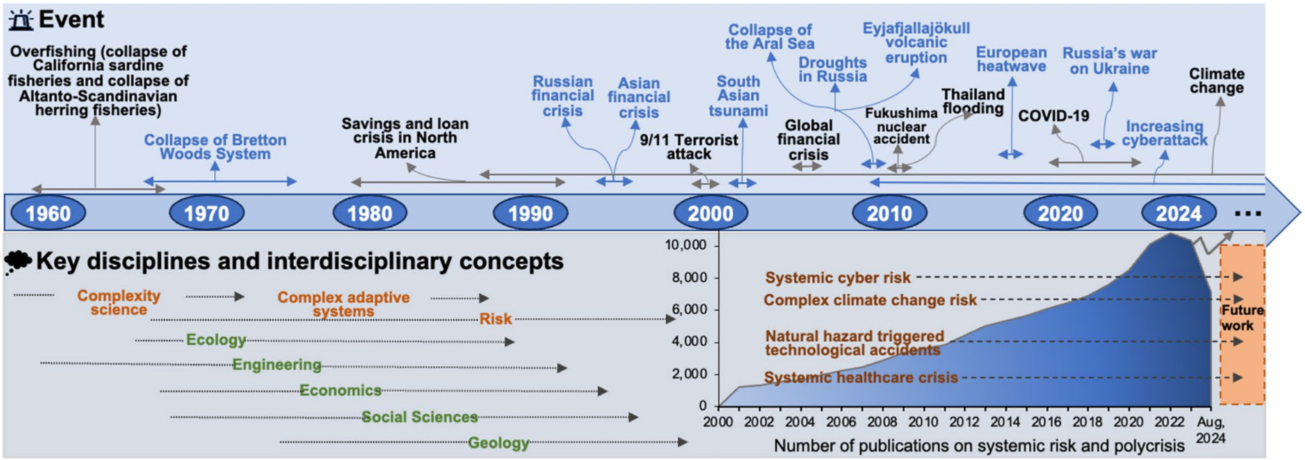


Fig. 2 Overview of the evolving debate and number of publications on systemic risk and polycrisis. *Source* Adapted from Sillmann et al. (2022), refined by authors.

risks. Economic, social, environmental, and political crises do not occur in isolation; they are interconnected through intricate feedback loops (Schweizer 2021). Also, polycrisis situations often exhibit nonlinear dynamics, where small changes in one area can lead to disproportionately large impacts elsewhere (Lucas et al. 2018b). In addition, the combined effect of multiple crises can give rise to emergent properties—outcomes that are not predictable by analyzing individual crises in isolation (Scheffer et al. 2009). Accurate risk assessment relies on the availability of comprehensive data, which are often scarce, incomplete, or difficult to obtain (Sillmann et al. 2022).

Governance in the context of polycrisis is often hindered by fragmented structures and siloed approaches (Renn 2008; Pildes 2023). Different sectors and agencies may operate independently, with limited coordination and communication. This fragmentation can lead to inefficiencies and gaps in the response to crises. Also, polycrisis situations are characterized by rapid changes and high levels of uncertainty. Therefore, enhancing the adaptability and flexibility of governance systems is essential for managing systemic risks (Pildes 2023). Besides, effective governance requires the active participation of a wide range of stakeholders, including government institutions, civil society organizations, the private sector, and local communities (Klinke and Renn 2014). While engaging these diverse stakeholders in decision-making processes can be challenging, they add valuable information and experiential insights for assessing and managing risks. In addition, managing polycrisis requires significant resources, including financial, human, and technical capacities. Many governance structures, particularly in developing regions, may lack the necessary resources to effectively address systemic risks (Sillmann et al. 2022).

Communicating the complexities of systemic risk and polycrisis to diverse audiences is a major challenge (Wachinger et al. 2013; Schweizer et al. 2022). In times of crisis, misinformation and rumors can spread rapidly, undermining public trust in institutions and the measures they implement. The role of media and technology in risk communication has grown significantly. While these tools offer opportunities for reaching wide audiences, they also pose challenges such as the spread of misinformation and the need to manage multiple communication platforms. Besides, effective communication must take into account cultural and contextual factors (Twyman et al. 2008; Briggs 2009).

In the face of these challenges posed by systemic risk in polycrisis, the following three sections summarize traditional methods for risk assessment, governance, and communication and their inadequacies, further address strategies to cope with these inadequacies. An overview of the three sections below is presented in Fig. 3.

4 Assessment of Systemic Risk in Polycrisis

To cope with the challenges for risk assessment in polycrisis, this section first summarizes the shortcomings of traditional risk assessment methods and then proposes new assessment methods and appropriate tools. Moreover, the prospects and limitations of assessment concepts and methods are discussed.

4.1 Inadequacy of Traditional Risk Assessment Methods

Traditional risk assessment methods typically involve (1) the identification of a specific hazard (that is, natural event, technological failure, emission of pollutants, release of a virus, and so on); (2) the calculation of potential exposures (who or what is exposed to the hazard); (3) the estimation of cause- (or dose-) effect-relationships based on the intensity

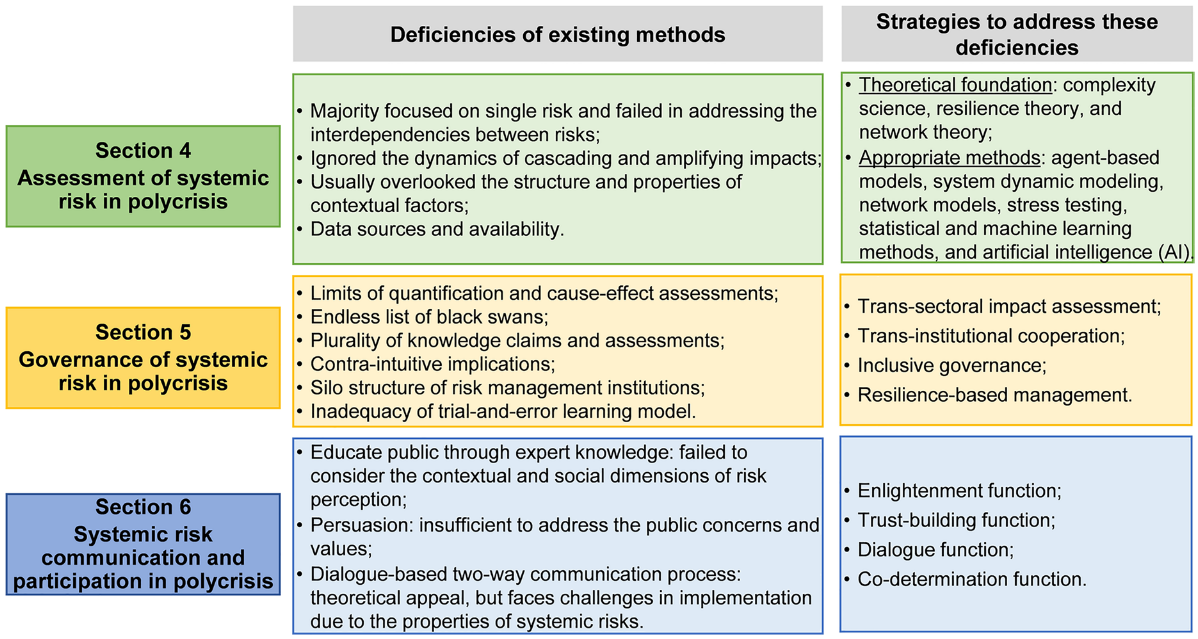


Fig. 3 Overview of assessment, governance, and communication of systemic risk in polycrisis

of an exposure and the vulnerability of the exposed target; and (4) the delineation of a probability function of resulting damages (IRGC 2018). In an ideal case, enough data are available to conduct a quantitative probabilistic risk assessment. More often, though, some of these parameters need to be estimated by expert judgment or qualitative characterization. Risks are by definition associated with some degree of uncertainty, which can be partially modeled but never fully calculated.

Most risk assessments are focused on single risk causes or individual agents where either experimental or observational data are available. The data stem from historical data, statistical and probabilistic models, and different kinds of numerical or narrative simulations (Vaiman et al. 2012; Ledwoch et al. 2018). Risk assessments assume that risks can be assessed and managed independently—one after another, which is problematic when traditional risk assessments are applied to multiple risks and interacting impacts. It fails to consider the interdependencies between different risks leading to a polycrisis. In addition, most risk assessments are abstracting from locality and time, thus ignoring the dynamics of cascading and amplifying impacts, which is a typical feature of systemic risks. They cannot adequately capture the dynamic nature of multiple simultaneous crises (Vaiman et al. 2012). Also, traditional risk assessments are inadequate in scenarios where multiple crises interact, potentially amplifying their mutual impacts in unpredictable ways (Renn 2021; Schweizer 2021). Finally, traditional risk analysis and modeling have usually overlooked the structure and properties of the contextual factors that amplify or attenuate the emergence of interacting impacts (Schäfer et al. 2018; Lawrence, Janzwood, et al. 2022).

There is an agreement among most scholars of systemic risks that the classic risk assessment methodology is inadequate or at least inconclusive when dealing with systemic risks (Lucas et al. 2018b; Homer-Dixon et al. 2022; Renn et al. 2022; Lawrence et al. 2024b). Therefore, increasing numbers of researchers argue that assessing systemic risk in polycrisis contexts necessitates a new approach to risk assessment. This new approach should be designed to be comprehensive and integrative and be able to accommodate complexity, uncertainty, ambiguity, nonlinear dynamics, and interconnectivity (Renn 2024).

4.2 New Methods Based on Complexity, Resilience, and Network Theory

New approaches for risk assessment are thus needed that can accommodate complexity, uncertainty, and interdependencies (Sillmann et al. 2022; Renn 2024). To this end, new methods have recently been developed that draw on concepts from complexity science, resilience theory, and network theory.

4.2.1 Complexity Science: Application to Systemic Risks

Complexity science emphasizes how interactions among components can lead to unexpected and often nonlinear macro-level impacts (Mitchell 2009; Renn and Lucas 2021). In a world increasingly characterized by interconnected subsystems and intricate networks, traditional cause-effect models fall short in effectively addressing the multifaceted nature of polycrisis or multiple disasters. The pervasive interconnectivity facilitated by modern technology renders the prediction of intervention outcomes highly complex or nearly impossible (Pelletier et al. 2011). This complexity extends across various global subsystems, such as energy and agriculture. Consequently, a focus on systemic interactions between and among elements is essential, rather than relying on linear aggregation of isolated data sets (Wever et al. 2022). This approach is universally applicable to all systems and processes, encompassing natural phenomena, technology, medicine, business, and society (Lucas et al. 2018a).

All systems are characterized by a set of elements and the relationships (or functions) between them. They are delineated by defining their boundaries, which determine which elements are included and which are excluded. Most real-world systems are open systems, meaning they exchange information, energy, and material with external systems, as opposed to closed systems that do not (Homer-Dixon et al. 2022; Lawrence et al. 2024a). When modeling the complexities of the world, complexity research constructs these models based on what they know about the systems, characterizing their states and interactions through mathematical functions or, in simpler cases, using expert judgments (Bayesian statistics) to indicate positive or negative feedback (Lucas et al. 2018a; Gil et al. 2021).

In addition, this theory helps to understand how crises emerge in time and space, how different risks interact and propagate through different systems, and how human interventions can be designed to adapt to multiple crises in situations where knowledge is incomplete and major uncertainties remain unresolved. For example, Low and Honegger (2022) assessed the systemic risks associated with geoengineering technologies, using complexity science to understand potential unintended consequences and socio-political challenges of large-scale climate interventions.

What does complexity theory tell us about systemic risks? The linear model of a risk agent being released by a natural event, technology, or human activity and causing harm to a specific target, the so-called risk absorbing system, may be too simplistic to describe how multiple and simultaneously occurring threats to the various targets that humans value emerge and promulgate. Natural, technical, and behavioral agents interact with each other and the results of their interactions are often not predictable; they may pose unexpected or unseen consequences on the risk absorbing system. The risk absorbing system may become an agent in itself by channeling the incoming risk agents towards another absorbing system thus entering into a cascade of vagabond risk agent movements that meander within and between systems until they find the most vulnerable entry point into the targeted system (Lucas et al. 2018a). This oscillating pattern is well documented in cybersecurity where viruses or malware circulate around potential targets until the firewall of one target is breached and the target itself becomes a weapon against other targets. Beyond cybersecurity, societal forces and institutions may act as risk agents in conjunction with technologies and natural forces such as floods, earthquakes, or extreme weather events.

Systemic risk analysis is not confined to technical failures and their management but include the influence of many factors within large socio-technical systems, including state governance, organizations, market developments, civil society actors, participation, guiding principles, acceptance and acceptability, social cohesion, trust (credibility), usability, understandability, and the scandalization potential of topics (for example, food versus fuel debate) (IRGC 2017). Complexity theory is closely related to the analysis of resilience, covered in the next paragraphs.

4.2.2 Resilience Theory

Resilience theory focuses on the capacity of risk absorbing systems to maintain the functionality of a system or recover from disruptions or multiple simultaneous shocks in due time (Holling 1973; Reid and Botterill 2013). The governance framework suggested by the International Risk Governance Council (IRGC 2017) depicts resilience as a normative goal for risk management systems to deal with highly uncertain events or processes (surprises). It is seen as a property of risk-absorbing systems to withstand stress (objective resilience) but also the confidence of risk management actors to be able to master crisis situations (subjective resilience). Pulling from an interdisciplinary body of theoretical and policy-oriented literature, Longstaff et al. (2010) regarded resilience as a function of resource robustness and adaptive capacity. Resilience-based assessments emphasize the importance of thresholds, adaptability, and transformability when assessing the potential of harm in situations where multiple stressors are interacting. They help to design systems to be less vulnerable to all kinds of stressors and are able to recover from crises (Ledwoch et al. 2018).

To develop a systemic concept of resilience applicable to systemic risks and polycrisis, it is crucial to emphasize the dynamic aspect of resilience, which refers to the system's capacity to adapt when pushed beyond its usual boundaries (Hoffman and Hancock 2017). This dynamic understanding is deeply connected to the degree of internal changes within socio-technical systems—such as adaptation, improvisation, learning, innovation, and evolution—in response to disturbances and failures. Viewing resilience as a dynamic and systemic feature within the transformation towards more sustainable practices allows for the identification of specific objectives, capabilities, and design principles that can be implemented through resilience assessment and subsequent risk management.

The literature identifies three types of dynamic resilience (Renn et al. in print):

- *Bounce-back resilience (ductile and robust behavior):* This type focuses on system preservation, resistance, robustness, and the fastest possible return to the system's original state. It emphasizes the system's ability to withstand shocks and quickly revert to its previous functioning state, minimizing downtime and disruption. However, this approach may not always lead to long-term improvements or innovations within the system, as it primarily seeks to restore the status quo.
- *Adaptive resilience:* This type involves the capability to flexibly respond to shocks, potentially increasing the system's performance through a learning process. Adaptive resilience enables systems to absorb disturbances, learn from them, and adjust their functions to better cope with future challenges. This approach promotes continuous improvement and innovation, enhancing the system's capacity to handle a wider range of disruptions over time and building back better than before.
- *Transformative resilience:* This type entails a comprehensive reconstruction of the system to maintain or improve its services. Transformative resilience allows for significant changes in the system's structure and operations, facilitating a fundamental shift towards more sustainable and resilient practices. This approach is essential when existing systems are no longer viable or effective, enabling a transition to new paradigm that can better address complex, interlinked crises.

These three modes of resilience engineering can be complemented by a fourth mode, known as the *biomimetic resilience approach* (Gleich and Giese 2019). This approach goes beyond the stimulus-response paradigm and aims to implement a more comprehensive understanding of precaution. Rather than preparing for specific disruptive factors (the "what if" scenario), it focuses on extensive precaution (the "whatever may come" mindset). The biomimetic approach draws on evolutionary successful strategies and system designs that have emerged over millions of years. It utilizes the evolutionary strategy where innumerable designs are created randomly and tested through natural selection, resulting in systems that are gradually equipped to handle almost any disruption—for instance, mimicking the distributed collaborative behavior of ant colonies to create community disaster relief networks (Yi and Kumar 2007). The idea here is to provide a learning environment, created by evolution or by institutional provisions, in which adaptation to external stress is part of the daily routines based on careful resource management and multiple feedback integration (Gleich and Giese 2019).

In conventional risk assessment, the disruptive factor is identified first and then it acts on the existing system. In Darwinian evolution, innumerable designs are generated randomly first, and these designs are then tested by natural selection. The surviving systems evolve towards resilience. This reverse mode of analysis—creating randomly modified digital twins of the risk-absorbing system and exposing them to various systemic risks—may provide a more effective way of designing resilient systems. The digital twin that performs best can then serve as a blueprint for designing or modifying the real system.

4.2.3 Network Theory

Network analysis focuses on the structure and dynamics of networks, which are composed of nodes (for example, entities, individuals) and edges representing their interactions, such as communication or power relations (for example, relationships, interactions) (Lucas et al. 2018a; Hochrainer-Stigler et al. 2020a, b). Understanding how risks propagate through networks can help identify potential points of failure and cascading effects.

Network analysis is particularly effective in investigating non-causal connections between different entities, such as individuals, organizations, or institutions. These non-causal connections include the density of communication (both symmetric and asymmetric), power relationships (hierarchical, competitive, cooperative), and formal (legal) responsibility and accountability. By examining these connections, network analysis can provide a comprehensive understanding of the complex web of interactions that influence systemic risks.

In addition, network analysis can identify weak ties or central nodes that provide opportunities for effective interventions and enhance our ability to predict, manage, and mitigate the impacts of systemic risks across various domains (Gill and Malamud 2016). Weak ties, which are connections that are not strong but bridge different parts of the network, can be critical in spreading information or mitigating risks. Central nodes, which are highly connected and influential points within the network, can serve as key leverage points for intervention strategies aimed at enhancing resilience and preventing cascading failures.

Overall, network theory offers powerful tools for assessing systemic risks by providing insights into the intricate interdependencies and non-causal relationships within complex systems (Kheybari et al. 2020). And numerous network models have been developed and applied to the analysis of financial risks, by studying contagious links and fragile network structures (Elsinger et al. 2013). These models help to uncover the underlying vulnerabilities within financial systems and guide the design of more robust regulatory frameworks and intervention strategies.

4.3 Overview of Appropriate Assessment Tools for Systemic Risks

Over the last decades, several advanced assessment tools and techniques have been developed based on the principles of complexity, resilience, and network theory as outlined above. These include: agent-based models, system dynamic modeling, network models, stress testing, statistical and machine learning methods, and—as a new kid on the block—artificial intelligence (AI). These tools are designed to better capture the nonlinear interactions and feedback loops characteristic of systemic risks, offering comprehensive and nuanced insights into the nature and causal structures of systemic risks in the context of polycrisis.

Agent-based models simulate the interactions of individual agents (for example, people, organizations) to understand how these interactions give rise to emergent phenomena and evaluate the effectiveness of regulatory measures (Neveu 2018). These models explore different patterns of complex adaptive behavior and heterogeneous agents, facilitating the investigation of how diverse individual and social behaviors and decisions can lead to system-wide transformations (Pickett 2014). By modeling the micro-level interactions and observing the macro-level outcomes, agent-based models can help identify leverage points for policy interventions and enhance the robustness of socio-technical systems.

System dynamic modeling uses feedback loops and time delays to model the behavior of complex systems over time, capturing the evolution of systemic risk and its potential impacts under different scenarios (Choi and Douady 2012; Renn 2021). This approach helps to understand how different variables interact and influence each other, providing insights into long-term dynamics and potential tipping points. Most system-dynamic models are based on equilibrium theory, which posits that systems reach a temporary equilibrium resilient to minor changes. However, if stress levels reach a tipping point, the system may bifurcate and emerge into a new stage, potentially leading to a new equilibrium over time. These models are useful in risk analysis to explore potential tipping points and identify early warning signals, helping to predict existential threats that may jeopardize the existing equilibrium (Lenton 2013; Fuchs and Thaler 2017; Wever et al. 2022).

Network models explore the relationships and interactions among various entities to predict the propagation of risks. They identify critical nodes and pathways through which risks propagate and cascade, pinpointing vulnerabilities and potential intervention points (Neveu 2018). As stated before, examining non-causal connections such as the density of communication, power relationships, and formal responsibilities, network analysis provides a detailed understanding of the complex web of interactions that influences systemic risks.

Stress testing assesses the resilience of systems by subjecting them to extreme but plausible scenarios. Stress tests have been frequently applied for assessing financial systemic risks, particularly the capital adequacy of banks post "Great Financial Crisis (GFC)," used by both risk managers and regulators (Hopper et al. 2023). Stress tests allow for identifying weaknesses and controlling the effectiveness of mitigation strategies across different institutions or sectors. By simulating adverse conditions, stress tests provide valuable information of how systems respond to extreme shocks and how effective strategies can be designed to enhance their resilience. In particular, stress tests may include "black swan" scenarios that are unlikely to happen but if they happen may cause tremendous damage (Taleb 2007; Aven 2015). Since in complex systems many external events and incidents are likely to turn into black swans, the likelihood that one of the many potential black swans will materialize is rather high. Stress tests can help to investigate the resilience of a system when confronted with a variety of black swans. It is unlikely that the black swans that are tested will on the end occur, but if the system is resilient enough to cope with a variety of black swan scenarios one can be fairly confident that the black swan that will eventually materialize will not be able to destroy the functionality of the entire system (Homer-Dixon et al. 2022; Lawrence et al. 2024b).

Statistical and machine learning methods involve the use of algorithms to identify patterns, correlations, and potential risk factors in systems (Kou et al. 2019). By combining microscopic nonlinear dynamics techniques with macroscopic statistical analysis, researchers can analyze the vulnerability of networks of cascading failures (Schäfer et al. 2018). Machine learning methods can process vast amounts of data to detect hidden patterns and predict risk scenarios, thereby improving the accuracy and reliability of systemic risk assessments.

AI for modeling complex systemic impacts: Artificial intelligence holds significant promise for modeling complex systemic impacts due to its ability to handle large datasets and uncover intricate patterns that traditional methods might miss. Artificial intelligence has the potential to enhance predictive power by learning from historical data and continuously improving its predictions as new data become available (Kamruzzaman et al. 2024). This adaptability makes AI particularly useful for identifying emerging risks and adapting to rapidly changing conditions. Moreover, AI-driven models can integrate various types of data (for example, social, economic, environmental) to provide a holistic view of systemic risks, facilitating more effective and timely interventions (Gil et al. 2021). By leveraging AI, policymakers and risk managers can gain deeper insights into the dynamics of complex systems and develop more robust strategies for mitigating systemic risks.

4.4 Prospects and Limitations of Assessment Concepts and Methods

The assessment of systemic risk in the context of polycrisis is a complex and evolving field, that must take into account the diversity of potential stressors, the interdependencies between multiple risks and hazards (cascading and amplifying each other), and the idiosyncratic nature of the various natural, social, and cultural contexts in which risks manifest themselves (Renn 2024). Currently, unanswered questions include how to define a system's boundaries and how to identify crucial interdependencies and feedback loops. To better understand the nature of these interconnections and to achieve analytical precision, it is beneficial to identify the key agents that have the potential to cause harm and focus on their interactions. By concentrating on the interactions among these agents, we can more accurately assess the risks and their implications within the system (Renn et al 2022; Okada and Renn 2025).

Quantitative data are central for developing a better understanding of systemic risk. However, a lack of data and theory makes model development challenging. Modern statistical inference and machine learning, for instance, only yield generalizable results when sufficient data have been collected under a variety of conditions and are most reliable when the system in question exhibits a certain degree of stability (for example equilibrium stage), effectively ignoring the dynamic nature of systems. Statistical models must be calibrated to multiple environments and validated against independent data samples when their aim is to generalize their application. However, depending on the application, all methods, tools, and models described above, including the use of AI, may help to reduce the risk of misguided statistical inferences, as their internal causal structure is predefined according to our understanding of the physical world. This basic knowledge remains to be valid even under altered conditions such as a warmer climate (Reichstein et al. 2019; Reichstein et al. 2021).

As a consequence, data-driven and empirical approaches are crucial for developing coherent and robust theories, but the absence of sufficient data and theoretical frameworks makes this task challenging. This challenge necessitates a reconsideration of the types of data deemed relevant for supporting modeling systems (Dillenberger et al. 2009). If data are not available or highly uncertain, expert judgments may be used to define the boundaries of what is deemed to be certain, highly probable, in principle possible but unlikely, and absurd (Colangeli et al. 2023). Also, models must be calibrated to various environments and validated using independent data samples to ensure their broader applicability (Sillmann et al. 2022). Finally, integrating diverse methods and a variety of quantitative and qualitative information can elucidate the complex nature of systemic risk and polycrisis, identifying multiple entry points for effective risk mitigation.

5 Governance of Systemic Risk in Polycrisis

Effectively managing polycrisis and systemic risks requires a holistic and integrated approach to risk governance (Renn 2021, 2024). Therefore, this section summarizes the shortcomings of traditional risk management methods and then proposes an integrated approach for cooperative, integrative, and inclusive risk governance.

5.1 Inadequacy of Traditional Risk Management Methods

Traditional risk management methods, which typically involve qualitative and quantitative techniques such as risk assessment matrices, scenario analysis, value-at-risk (VaR) calculations, cost-effectiveness analysis, risk-benefit balancing, multi-criteria optimization, and multi-attribute decision making (Pflug 2000; Aven 2016; Acharya et al. 2017; Hochrainer-Stigler et al. 2020a, b), are increasingly inadequate in addressing the challenges posed by dynamic, complex, and interconnected systems (Hubbard 2020; Renn 2024).

Traditional methods for managing risks offer simplicity and structure, providing useful qualitative insights, but they face significant limitations when applied to systemic risks. One major challenge is the limits of quantification and cause-effect assessments. In complex systems, quantifying risks and their interactions often involves high uncertainty (Renn et al. 2022). The relationships between risk management interventions and their impacts are often stochastic, with nonlinear interactions that can lead to unpredictable outcomes. This unpredictability is exacerbated by the risk of unintended consequences, where reducing one risk may inadvertently increase another (Mitra and Shaw 2023). For instance, replacing a fossil-fueled power plant with a solar facility may reduce climate risks but could also increase the risk of blackouts when the sun is not shining.

Another critical issue is the endless list of potential "black swans" (see Sect. 4.3). Complex and interconnected risks are susceptible to numerous low-probability, high-impact events, making it challenging to design effective risk reduction or preparedness measures. The unpredictability of which "black swan" event will materialize complicates the process of risk management, leading to a reactive rather than proactive approach (Taleb 2007; Aven 2015).

The plurality of knowledge claims and assessments further complicates risk management. Due to the high complexity, uncertainty, and ambiguity inherent in systemic risks, there is often significant debate among experts, policymakers, and stakeholders regarding the most appropriate management methods (ASRA 2024; Klinke and Renn 2014). This debate can lead to the politicization of risk management, resulting in either political paralysis or the adoption of populist measures that resonate with public preferences but are ineffective in reducing risks (Mostafavi et al. 2022). For example, emphasizing educational tools on climate change risks may garner public support but could be less effective than implementing regulatory rules and economic incentives to reduce fossil fuel use.

Contra-intuitive implications pose yet another challenge. Public perception of risk is often influenced by personal experience, familiarity, and plausibility. Many systemic risks are new or unfamiliar, making them less intuitively plausible for the general public (Schweizer 2021; Schweizer et al. 2022). Moreover, the complexity of these risks often involves distant events in time and space that may have significant impacts, as seen in the case of climate change, where past behaviors in industrialized countries affect present generations in the Global South.

The silo structure of risk management institutions is another significant barrier to effective systemic risk management. Risk governance, which refers to how society and entities assess, evaluate, regulate, and manage risks, is often fragmented into institutions that focus on specific types of risks, such as natural hazards, chemical hazards, or technological accidents (Assmuth et al. 2010). However, systemic risks cross these boundaries, leading to interactions between different domains, sections, institutions, and localities. For example, a natural hazard and disaster might trigger a technological accident, releasing toxic chemicals into water sources, thereby exacerbating the risk to public health and livelihoods. Institutions operating in silos tend to maximize their specific mandates at the expense of increasing other connected risks, such as imposing expensive building regulations that impede affordable housing in flood-prone areas, which in turn contributes to poverty risk.

Lastly, the inadequacy of the trial-and-error learning model is a significant challenge in managing systemic risks. Human learning is often guided by trial and error, where negative outcomes lead to changes in behavior or interventions (Aase and Tjensvoll 2003). However, systemic risks are frequently associated with tipping points, where outcomes may appear positive or indifferent until a tipping point is reached, at which point it may be too late to change behavior. This necessitates the anticipation of potential damages and the implementation of precautionary measures before negative impacts become visible (Schweizer et al. 2022). Enforcing these preemptive measures can be challenging, especially when they are costly or face public resistance.

These challenges underscore the inadequacy of traditional risk management methods in dealing with systemic risks and polycrisis. To address these issues, there is a need for a new management style that emphasizes trans-sectoral impact assessment, trans-institutional cooperation, inclusive governance, and resilience-based management methodology. This combined approach should integrate diverse knowledge sources, foster collaboration across different sectors and institutions, and engage stakeholders in decision-making processes. How to develop such an integrated approach is described in the next section.

5.2 Focus on Cooperative, Integrative, and Inclusive Risk Governance

The requirements for an effective risk governance approach for dealing with systemic risks are still contested and new appropriate concepts are in the stage of development. However, several components for such a new governance perspective can be listed here:

Trans-sectoral impact assessment: As stated several times in this review, systemic risks are interconnected. Causes as well as impacts interact with each other, building cascades of risk events and contributing to the emergence of polycrisis. Any management system that attempts to deal with systemic risks can only be successful if the management team includes the many potential interactions between the various risks or their impacts and develops a seriousness of risk matrix assisting managers to navigate prudently through a complex web of risks. One major task of risk management is to assign reasonable trade-offs that reflect the best realistic compromise between conflicting goals and outcomes. This requires a value-based and evidence-informed decision process aimed at finding an optimal balance between multiple positive and negative outcomes of risk reduction measures.

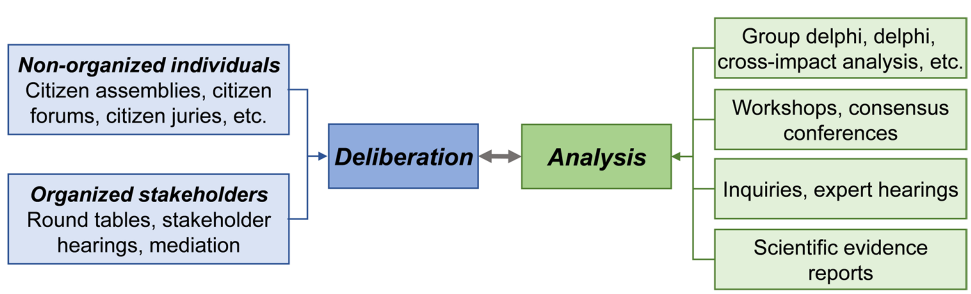
The precondition for such a comprehensive assessment and management approach is the *cooperation between different risk agencies or institutions*. This is by far not as trivial as it sounds. Almost all countries in the world manage risks separately according to familiar categories such as natural hazards, technical accidents, environmental risks, health risks, and so on (Klinke 2021). Cooperative governance requires an institutional structure that facilitates, encourages, and fosters cooperation between different specialized risk management organizations, ranging from corporate departments (such as financial risk, environmental risk, reputational risk) to national or supranational institutions such as ministries or United Nations (UN) programs (Comes et al. 2022).

Inclusive governance: The concept of cooperation does not only include the traditional risk managing agencies and organizations but also important stakeholders and members of the public, who are or might be affected by the risk management measures. For a governance system to be effective in a complex social and political environment, interdisciplinary and cross-sectoral cooperation as well as active engagement by scientists, regulators, and stakeholders from private and public spheres are essential (Schweizer 2021). Furthermore, inclusive risk governance necessitates transdisciplinary approaches that integrate diverse types of knowledge and expertise (Lawrence, Janzwood, et al. 2022). The complexity of systemic risks requires, most prominently, analytical and specialized expertise to understand and address the multifaceted interdependencies involved. In addition, due to the inherent uncertainties and ambiguities associated with these risks, judgments about conflicting values and objectives are inevitable. In democratic societies, such a balancing task needs political legitimization and the input of various stakeholders, ensuring that diverse interests and perspectives are represented (Renn et al. 2022; Radtke and Renn 2024). In addition, ambiguity in risk situations requests deliberative discourse within society, fostering open dialogues that can clarify differing interpretations and values associated with risks.

Therefore, comprehensive and inclusive governance is a necessary requirement for managing systemic risks and polycrisis, for basically two reasons. First, stakeholders and local residents often possess indigenous, experiential, or tacit knowledge that may be crucial for selecting and designing appropriate risk management policies (Renn 2010). This is particularly relevant if the interacting effects of risks are strongly context-dependent (Okada and Renn 2025). Second, the assignment of trade-offs requires a deliberation about the relative weight of one objective or one outcome against the other (Lodge 2009). The question of which value should be given more weight than a competing value cannot be answered by scientific inquiry or purely legal regulations. It is an issue of balancing different interests, values, and preferences of those who will be exposed to these policies. For this balancing deliberation, the US Academy of Sciences has advocated an analytic-deliberative approach that can be characterized by two interrelated steps (US National Research Council et al. 2008): (1) a joint learning process of different expert communities (providing the analysis of potential impacts of risk management options) and (2) a deliberative discourse among representatives of stakeholders and the public (deciding about the social, economic, and cultural desirability of each management option. Figure 4 illustrates the two components of an analytic-deliberative approach and lists some participatory formats that have been used and tested for each component.

Inclusive approaches such as the analytic-deliberative concept of participation not only enhance the legitimacy and acceptance of risk management decisions but also improve the adaptive capacity of governance frameworks to handle evolving and interconnected crises (Hynes et al. 2020; Schweizer et al. 2022; Lawrence et al. 2024a). Concerning the methodology to deal with systemic risks the focus should be on resilience-based management, which involves fortifying systems to overcome vulnerabilities and effectively absorb risks (Sulfikkar Ahamed et al. 2023). One key strategy is the use of stress testing, as mentioned in Sect. 4.3. Stress tests do not only provide reliable information on how risk absorbing systems might perform under different stress exposures but will also point to weaknesses and vulnerabilities associated with an entire socio-technical system (such as energy supply and demand, healthcare system during a pandemic, and so on). The test provides clues of how such a system can cope with multiple stressors by simulating a variety of unlikely, yet plausible, adverse scenarios (Hopper et al. 2023). This helps risk management organizations to identify weaknesses and understand the potential impacts of extreme events. Additionally, reverse stress testing offers a proactive approach by starting with known vulnerabilities and assessing what specific stressors could exploit these weaknesses (Hopper et al. 2023). This method can be used for anticipating and preparing for potential threats before they materialize. Another important strategy involves the use of black swan scenarios for identifying weak nodes in the system and provide technical or organizational solutions to improve resilience (see Sect. 4.3). These comprehensive methods assist risk managers to design more comprehensive and integrative risk management policies and measures

Fig. 4 Analytic-deliberative approach to inclusive risk governance



ensuring long-term sustainability and operational stability (Lawrence et al. 2024a).

6 Systemic Risk Communication and Participation in Polycrisis

Risk communication has evolved significantly from its initial focus on bridging the gap between expert assessments and public perceptions of risk, to include deliberative discourses between and among all relevant actors in society about risk acceptability and appropriate management strategies (Sellnow and Seeger 2021). To address the constraints and challenges faced in risk communication, this section proposes basic functions for effective risk communication and develops systematic responses to risk communication challenges.

6.1 Basic Functions for Effective Risk Communication

Early efforts for risk communication concentrated on educating the public through expert knowledge, with the assumption that a well-informed populace would align its perceptions with expert judgments (Fischhoff 1995; Leiss 1996). However, these attempts largely failed, as they did not consider the contextual and social dimensions of risk perception. Public understanding proved resistant to purely expert-driven communication, revealing the need for a more nuanced approach. In response, risk communication shifted towards persuasion, utilizing public relations techniques to influence behavior, particularly concerning health risks like smoking or drinking. However, this approach also struggled to alter public perceptions of broader systemic risks, as the one-way communication model proved inadequate in addressing the public's concerns and values (Leiss 1996).

Recognizing these limitations, contemporary risk communication now emphasizes a two-way process that fosters mutual learning between the public and risk managers (Fineberg and Stern 1996; Renn 2020). This dialogue-based approach aims to build trust and collaboratively shape risk management strategies that are responsive to both individual and collective concerns about systemic risks. This model aligns with the principles of inclusive and integrative risk governance, which stress the importance of stakeholder and public engagement and shared responsibility.

Despite its theoretical appeal, implementing this two-way communication model presents significant challenges (Siegrist and Árvai 2020). Systemic risks, characterized by complex, uncertain, and nonlinear causal relationships, are particularly difficult to communicate. Effective risk communication must not only convey complex information but also build and maintain trust, provide opportunities for stakeholder participation, and ensure that risk management processes are both competent and efficient. The rise of populist strategies that exploit fake news and simplistic narratives further complicates these efforts (Ágh 2017; Buštíková and Baboš 2020).

To address these challenges, risk communicators should structure their strategies around four primary functions: Enlightenment, Trust-building, Dialogue, and Co-determination (Renn 2020).

- *Enlightenment function:* This function focuses on fostering a deeper understanding of risks among various constituencies, including stakeholders, consumers, media professionals, and the general public. Effective communication must consider the dominant risk perception patterns of the target audiences and provide clear, accessible information that enhances public awareness and understanding of risks (Sata and Nara 2017).
- *Trust-building function:* Building and maintaining trust in institutions that manage risks is crucial. Risk communication should prioritize transparency, consistency, and responsiveness to public concerns, as these are essential for establishing and sustaining credibility (Adler and Kranowitz 2005).
- *Dialogue function:* Risk communication should facilitate open dialogue and provide avenues for mutual learning. This involves creating inclusive platforms where stakeholders and public representatives can express their views, engage in discussions, and contribute to decision-making processes. Effective dialogue ensures that diverse perspectives are considered and that risk management practices reflect a broad range of inputs (Palenchar and Heath 2007).
- *Co-determination function:* This function emphasizes the importance of shared decision making in risk management. By involving stakeholders and the public in the planning and regulation of risks, risk communication can promote democratic processes, empower communities, and align risk management strategies with the values and priorities of the broader community (Boholm and Corvellec 2013).

These functions underscore the critical role of risk communication in managing systemic risks, particularly in an era where public trust and engagement are increasingly challenged by populist movements and anti-democratic tendencies (Ágh 2017). The specific challenges and potential strategies for each of these functions are explored in the following section and are outlined in Fig. 5.

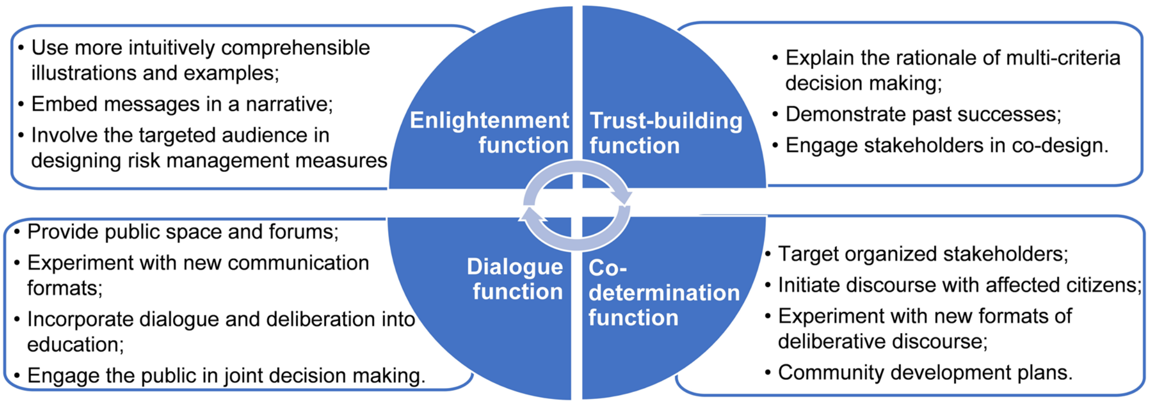


Fig. 5 Potential strategies for each function for effective risk communication

6.2 Systemic Responses to Risk Communication Challenges

Effective communication about systemic risks requires extraordinary efforts to ensure that messages are clear, trustworthy, and empowering. However, the challenges and potential solutions differ depending on the specific function of risk communication being addressed.

Enlightenment function: To effectively inform and educate the public about systemic risks, it is essential to convey a basic understanding of complex and stochastic relationships. Such understanding requires interdisciplinary cooperation, integrating insights from economics, environmental science, sociology, disaster science, and public health (Aven and Renn 2010). Risk communication must summarize key points, explain underlying assumptions and uncertainties, and present potential impacts in a way that fosters comprehensive knowledge of systemic risks.

Communicating these messages to the public implies further challenges, as complex causal structures often defy intuitive understanding (Schweizer 2021). People tend to prefer simple explanations and may find it difficult to grasp the logic of stochastic reasoning, especially when faced with uncertainty and probabilistic outcomes, as seen during the Covid-19 pandemic (Paulik et al. 2020).

To improve communication about complex and stochastic relationships, three strategies are recommended (Chabay et al. 2019; Schweizer et al. 2022; Amoakoh et al. 2024):

- *Use more intuitively comprehensible illustrations and examples:* Employ relatable, everyday examples to illustrate complex concepts, making them more accessible and easier to understand.
- *Embed messages in a narrative:* Craft narratives that connect complex messages to everyday life experience, helping the audience intuitively grasp the relevance and implications of the information.
- *Involve the targeted audience in designing risk management measures*. This engagement fosters curiosity, openness, and a willingness to learn, leading to more effective communication and mutual understanding.

Trust-building: Building and maintaining trust is critical for effective risk communication. However, managing systemic risks often involves contested issues, where stakeholders may disagree on the best approach or even the existence of the risks (telling example is climate change). Additionally, the crosscutting impacts of systemic risks make it challenging to assure the public that all side effects are being monitored and controlled (Warren and Lofstedt 2022).

To address these challenges, the following strategies are recommended (Chryssochoidis et al. 2009; Renn 2020):

- *Explain the rationale of multi-criteria decision making*: Clearly articulate the need for balancing conflicting goals and accepting trade-offs, using everyday examples to illustrate these concepts.
- *Demonstrate past successes:* Highlight previous successful risk management efforts and demonstrate that commitments have been fulfilled, as a strong track record is key to building and sustaining trust.
- *Engage stakeholders in co-design:* Involve stakeholders and the public in co-designing risk management and crisis preparedness programs. This co-production of knowledge and management actions enhances trust between authorities and citizens.

Dialogue function: Sustaining a productive dialogue with the public is increasingly difficult due to time constraints, information overload, and the pervasive influence of social media, which often fosters echo chambers and resistance to genuine interaction. Effective dialogue requires time, space, and the motivation of all parties to engage in mutual learning.

To overcome these challenges, the following strategies are recommended (Renn 2020; Okada 2021; Okada and Renn 2025):

- *Provide public space and forums:* Establish physical and virtual forums for deliberative dialogues, such as disaster universities in Japan, where risk experts train citizens to become community educators.
- *Experiment with new communication formats:* Use innovative formats like serious games, cooperative planning, and computer-assisted deliberation to engage social media followers and promote meaningful interaction.
- *Incorporate dialogue and deliberation into education*: Introduce these practices as intensive learning experiences in schools, universities, and other educational institutions to foster a culture of engagement and critical thinking.
- *Engage the public in joint decision making*: As with the other functions, involve people in the decision-making process for risk management and crisis preparedness, empowering them to take an active role in shaping their future.

Co-determination function: Engaging the public and stakeholders in the co-determination of risk management strategies is essential for fostering trust and ensuring that these strategies reflect the values and priorities of the community. However, convincing public authorities to share power and encouraging citizens to actively participate can be challenging.

To improve communication for co-determination, the following strategies are recommended (OECD 2011; Hynes et al. 2020; Klinke 2021; Okada 2021; Schweizer et al. 2022; Okada and Renn 2025):

- *Target organized stakeholders:* Focus on engaging organized stakeholders, such as corporations and nongovernmental organizations (NGOs), through interactive approaches like round tables, stakeholder hearings, and workshops. This engagement ensures that diverse inputs are integrated into risk management strategies.
- *Initiate discourse with affected citizens:* Engage directly with citizens who are impacted by systemic risks or risk management measures. Participatory discourse allows their voices to be heard and ensures that risk management measures are responsive to community needs and values.
- *Experiment with new formats of deliberative discourse:* To enhance co-determination in risk management, it is crucial to experiment with innovative formats of deliberative discourse that engage both organized groups and ordinary citizens. Multi-stakeholder forums or round tables are effective platforms for organized groups, allowing diverse stakeholders to collaboratively discuss and shape risk management strategies. For ordinary citizens, new formats like citizen assemblies, citizen forums, or mini-publics offer valuable opportunities for participation. These formats are based on random selection, ensuring that every citizen has an equal chance of being drafted into the co-determination process, thereby enhancing the legitimacy of the outcomes. By involving a representative cross-section of the public, these approaches foster more inclusive and democratic decision making in risk governance.
- *Design and implement community development plans:* Another vital strategy for co-determination is the development of community-wide plans that integrate risk management and crisis preparedness. These plans are designed to build community identity, resilience, and social cohesion by involving residents in a collective planning process. Tools for achieving this include voluntary planning boards, where community members collaborate on developing strategies that address local risks while promoting broader community development goals. By embedding risk management within the fabric of community planning, these efforts empower citizens to take ownership of their future, leading to more resilient and adaptable communities.

In summary, a comprehensive and targeted approach to risk communication not only enhances the effectiveness and acceptability of risk management decisions but also improves the flexibility and adaptability of governance frameworks to respond to dynamic and interconnected crises.

7 Conclusion

This review has examined the concepts of polycrisis and systemic risks, highlighting their commonalities and differences, and discussing their implications for risk assessment, governance, and communication. Based on the analysis above, this section summarizes key insights and explores future research needs in the field.

7.1 Insights from the Review

Both concepts deal with the complexity and interconnectivity of modern risks, but they differ in emphasis. Systemic risk focuses on potential harms within a system, while polycrisis emphasizes the realization of interconnected crises across multiple systems, often involving coincidental but interacting impacts.

Polycrisis is marked by the simultaneity of independent crises, potential systemic breakdowns, cascading risks across systems, and the amplification of impacts (Lawrence et al. 2024a). Similarly, systemic risks are characterized by highly complex and dynamic networks, nonlinear cause-effect relationships, and stochastic processes that transcend administrative, social, and scientific boundaries (Renn et al. 2022). Despite these similarities, the key distinction lies in that polycrisis focuses on the entanglement of crises across different systems and the activation of causal chains leading to harm, while systemic risks are focused on triggers of the multiple risks that occur simultaneously and the resilience of the risk absorbing systems (Lawrence, Janzwood, et al. 2022; Lawrence et al. 2024c). The emergence of polycrisis and the manifestations of systemic risks require new approaches for risk assessment, management, and communication:

Risk assessment: Addressing polycrisis and systemic risks requires new risk assessment methods that accommodate complexity, uncertainty, and interdependencies (Sillmann et al. 2022; Renn 2024). Advanced approaches such as agent-based models, system dynamics modeling, network models, stress testing, statistical and machine learning methods, and AI-driven analyses are crucial. These methods, rooted in complexity, resilience, and network theory, provide the necessary tools to understand and mitigate the multifaceted nature of these risks.

Risk management and governance: Effective management of polycrisis and systemic risks calls for a comprehensive and integrated governance approach (Schweizer 2021; Renn 2024). Traditional risk management techniques are often inadequate in the face of dynamic and interconnected systems. A new governance perspective should include trans-sectoral impact assessments, collaboration between diverse institutions, and inclusive governance that fosters resilience and adaptability. The goal is to develop flexible management strategies that can absorb and adapt to risks, rather than simply react to them (Sulfikkar Ahamed et al. 2023).

Risk communication and participation: Communicating systemic risks is inherently challenging due to their complexity and uncertainty (Schweizer et al. 2022). Effective communication strategies must go beyond simply conveying information; they must build trust, facilitate stakeholder participation, and adapt to the evolving nature of crises. In a landscape increasingly dominated by populist narratives and misinformation, risk communication must be structured around four core functions: enlightening audiences to enhance risk literacy, building and maintaining institutional trust, creating spaces for open dialogue, and involving stakeholders in co-determination processes (Renn 2020). Such a comprehensive approach ensures that risk management is not only effective but also accepted and supported by the public, thereby enhancing the resilience of governance frameworks to respond to complex crises.

In summary, understanding and managing polycrisis and systemic risks require innovative approaches in assessment, governance, and communication. By embracing complexity and fostering inclusive participation, risk management can be better equipped to address the dynamic challenges of our interconnected world.

8 Research Needs

The study of polycrisis and systemic risks is a rapidly evolving field, and while substantial progress has been made in conceptualizing these complex phenomena, significant gaps remain. Future research is essential to refine existing theories, validate proposed frameworks, and translate academic insights into practical tools for risk management and governance.

Advancing conceptual frameworks: Although recent efforts have led to the development of more coherent and consistent concepts surrounding polycrisis and systemic risks, further refinement is necessary. Current frameworks provide a solid foundation, but there is a need for greater clarity and specificity in distinguishing between polycrisis and systemic risks, particularly investigating the mechanism of amplification and cascading effects. Future research should focus on refining these distinctions and enhancing the conceptual integration of these frameworks with broader risk governance theories.

Enhancing modeling tools and simulations: Recent advances in modeling tools and simulations have significantly contributed to our understanding of systemic risks and polycrisis. However, many of these models are still in the experimental stages, requiring further validation and refinement. Future research should prioritize the testing and calibration of these models against real-world data, ensuring that they can accurately represent the dynamic, nonlinear interactions that are so typical for polycrisis. Moreover, there is a need for models that not only predict potential crises but also provide actionable insights for risk mitigation and crisis management. This includes the development of user-friendly tools that can be integrated into decision-making processes at various levels of governance.

Empirical evidence and hypothesis testing: While the theoretical implications of polycrisis and systemic risks for risk assessment, governance, and communication are well-articulated, they largely remain in the realm of hypotheses. More empirical research is required to test these hypotheses and develop robust, evidence-based insights. Such research should focus on case studies, historical analyses, and real-time crisis monitoring to gather data that can validate or challenge existing theories. Additionally, interdisciplinary and cross-sectoral studies are needed to examine how different types of risks interact within and across systems, providing a deeper understanding of the cascading effects and potential tipping points that define polycrisis.

Practical applications for governance and management: The potential for applying research on polycrisis and systemic risks to risk management and governance is substantial, but more work is needed to make these applications more effective, cooperative, and inclusive. Emphasis should be placed on developing governance strategies that prioritize cooperation over the compartmentalization of management tasks. This includes fostering interdisciplinary and cross-sectoral integration, enhancing resilience against multiple stressors, and ensuring inclusive decision-making processes that actively involve stakeholders and citizens. Future research should explore the most effective designs, formats, and practices for implementing an integrative, cooperative, and inclusive governance style. This may involve pilot programs, comparative studies across different governance contexts, and evaluations of existing models of risk governance.

The study of polycrisis and systemic risks is not only academically important but also politically and socially urgent. In an increasingly interconnected and interdependent world, the ability to understand, anticipate, and manage complex crises is crucial for ensuring global stability and resilience. As such, future research in this field must be geared towards generating insights that are not only academically robust and valid but also politically practicable and publicly acceptable. This will require ongoing collaboration between researchers, policymakers, and practitioners, as well as a commitment to translating complex theoretical concepts into practical solutions that can be implemented in real-world contexts.

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