Chapter 2: Systemic risks, the Sendai Framework and the 2030 Agenda

The preamble to the 2030 Agenda states that SDGs are integrated and indivisible, balancing the three dimensions of sustainable development: economic, social and environmental. However, this century is likely to be dominated by the emergence of large-scale dynamic risks that inherently cut across these dimensions. The Sendai Framework reflects the certainty that in an ever more populous, networked and globalizing society, the very nature and scale of risk has changed, to such a degree that it surpasses established risk management institutions and approaches. Recent events - such as large-scale prolonged droughts and heatwaves, financial and commodity market crashes, large scale and long term human migration, cybervulnerabilities and political upheavals - carry the potential to generate diverse types of damage and destruction simultaneously, to vital infrastructure and even to the life support systems of very large parts of societies and economies.

With non-linear change in hazard intensity and frequency a reality,[36] and now threatening all three dimensions of sustainable development, the imperative for greater ambition and accelerated systemic action pre-2030 to converge with the Sendai Framework is clear. The Sendai Framework compels new conceptual and analytical approaches to improve understanding and management of risk dynamics and risk drivers at a range of spatial and temporal scales. It requires particular emphasis on the interaction among physical, technological, social and environmental hazards, and attention to "anthropogenic metabolism". (Anthropogenic metabolism means the systemic interaction between humans and the environment that consists of the inputs, outputs and stock of materials and energy required to sustain physiological needs for food, air, water and shelter, as well as the products, substances and services necessary to sustain modern human life.[37] It emerges from the application of systems thinking to industrial and other human-made activities, and is central to sustainable development.)

Technical communities use models to better "see" risk in the present or near future, and so the view of risk is inherently shaped by the tools used to describe it. Most models have been based on historical data and observations, assuming that the past is a reasonable guide to the present and the future. That assumption is now rendered obsolete on almost every frontier: by the sheer number of human beings, never before seen on Earth; by the changing climate; and by the dynamic and global connectedness of biological and physical worlds, individuals and communities.

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36 (IPCC et al. 2018)
37 (Brunner and Rechberger 2002)

With the certainty of near-term non-linear changes, the critical assumption of the relationship between past and future risk must now be revisited. The Sendai Framework defines a new era for the classification, description and management of risk.

The Sendai Framework stipulates that the global community must come to terms with a new understanding of the dynamic nature of systemic risks, new structures to govern risk in complex, adaptive systems and develop new tools for risk-informed decision-making that allows human societies to live in and with uncertainty. Coming to terms with the limitations of a hazard-by-hazard view of risk management, the Sendai Framework spurs the dialogue and action necessary to refine, extend and enhance the ability to understand and manage systemic risks.

Today's environmental, health and financial systems, supply chains, information and communication systems are clearly vulnerable. They also create vulnerability on multiple spatial scales (local to global) and across different timescales (from immediate to decadal and beyond). They are challenged by, and are causal drivers, of disruptive influences such as climate change, loss of biodiversity and ecological systems degradation, disease outbreaks, food shortages, social unrest, political instability and conflict, financial instability and inequality.

The eruptions of Eyjafjallajökull in Iceland, the impacts of Hurricane Sandy in the United States of America, and the Great East Japan Earthquake, tsunami and Fukushima Daiichi nuclear accident are recent examples of complex risk events. They each encompass critical spatio-temporal contexts, including elements of surprise and non-linearity. All incurred immediate and prolonged impacts driven by significant underlying risk drivers that were underestimated, including background conditions related to critical infrastructure placement, vulnerability and lack of redundancy.[38]

In today's globalized economic system, networks of communication and trade have generated highly interdependent social, technical and biological systems. These networks are built on, and have built-in, incentives to be highly efficient and to generate economic gains. This narrow focus means there are often undetected fragilities that produce an array of changing systemic risks. In effect, through global interconnectedness, human civilization has become a "super-organism", changing the environment from which it evolved, and inducing new hazards with no analogue. Despite technical and analytical capabilities and the vast webs of information about social and Earth systems, human society is increasingly unable to understand or manage the risks they create. Humans have also been slow to realize that the degradation of the Earth's natural systems is becoming a source of large-scale, even existential, threat affecting fragile social systems at local, national, regional and global scales. Far-reaching changes to the structure and function of the Earth's natural systems represent a growing threat to human health.[39] While global economic integration continues to strengthen resilience to smaller shocks through trade adjustments, increasingly integrated network structures also create expanding vulnerabilities to traditionally recognized and novel systemic risks.[40]

This chapter explores the systemic risks that are embedded in the complex networks of an increasingly interconnected world. The behaviour of these networks defines quality of life and will shape the dynamic interactions among the Sendai Framework, the 2030 Agenda, the Paris Agreement, NUA and the Agenda for Humanity. Ultimately, the behaviour of these networks determines exposure and vulnerability at all scales. The regenerative potential of the social and natural systems envisaged in these aligned intergovernmental agendas will be better understood, and progress will be accelerated, by incorporating systemic risk and systemic opportunity into the design of policies and investments across all scales.

38 (Pescaroli and Alexander 2018)
39 (Whitmee et al. 2015)
40 (Klimek, Obersteiner and Thurner 2015)
41 (Harari 2018)

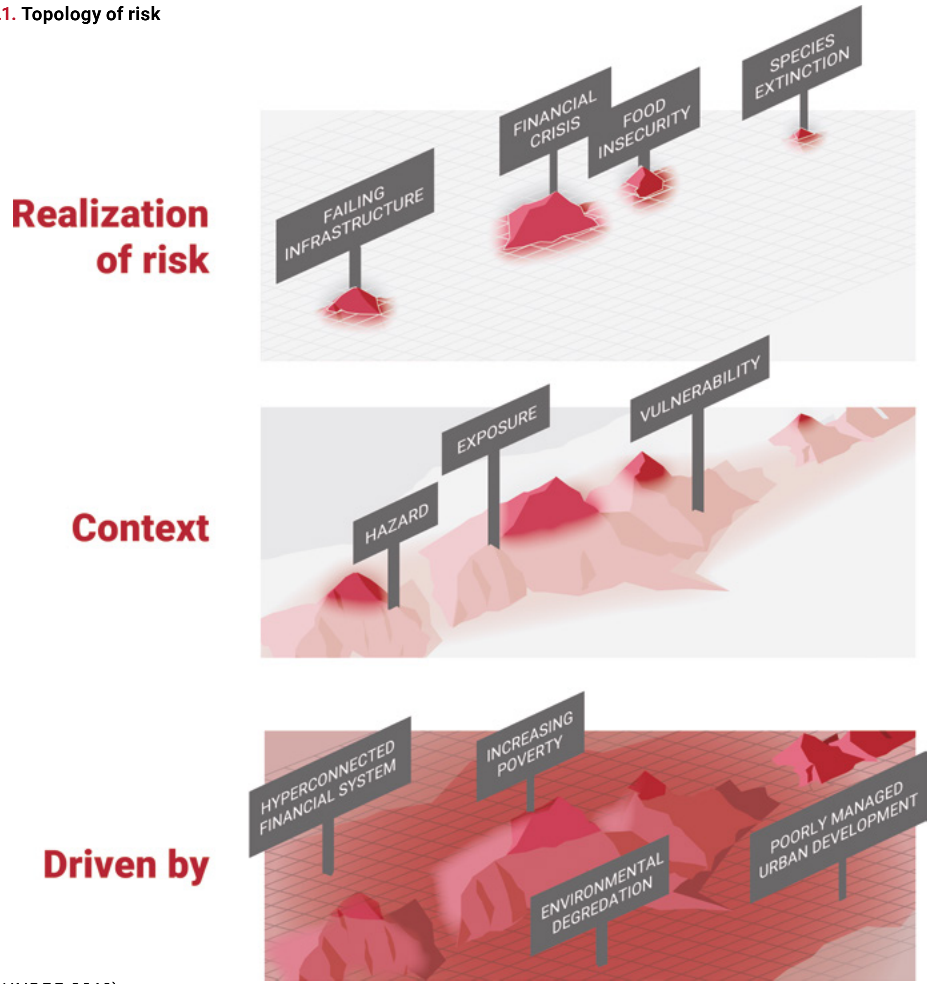
2.1

Assessing and analysing systemic risks: mapping the topology of risk through time

It takes strong nerves to question the very fabric of society.[41]

A paradigm shift has occurred since the mid-twentieth century. Enabled by increases in computational power and the availability and mobilization of vast streams of data and observations, models and narratives, systems approaches increasingly help make sense of the failure of linear constructs in a world where everything is connected. (Linear constructs refer to the pervasive extraction–production–distribution–consumption–disposal linear process of resource use in the current economic paradigm). Earth is one system – a system of systems. Systems thinking is obvious and essential to create the future enshrined in the 2030 Agenda.

Figure 2.1. Topology of risk



(Source: UNDRR 2019)

Traditional understanding of risk can be likened to a view of the Himalayan peaks from above, with a cloud cover that obscures the topography below. From above, humans have described and named these peaks of risk as if they are separate and independent, when in fact, below the clouds, the connections are clear. Significant and influential peaks of risk occur that do not rise to the level of the clouds and currently remain obscured from view but are nonetheless highly relevant. This chapter examines several of these, including food system instability, cyberrisk and financial systems.

2.1.1

Examples of systemic risks

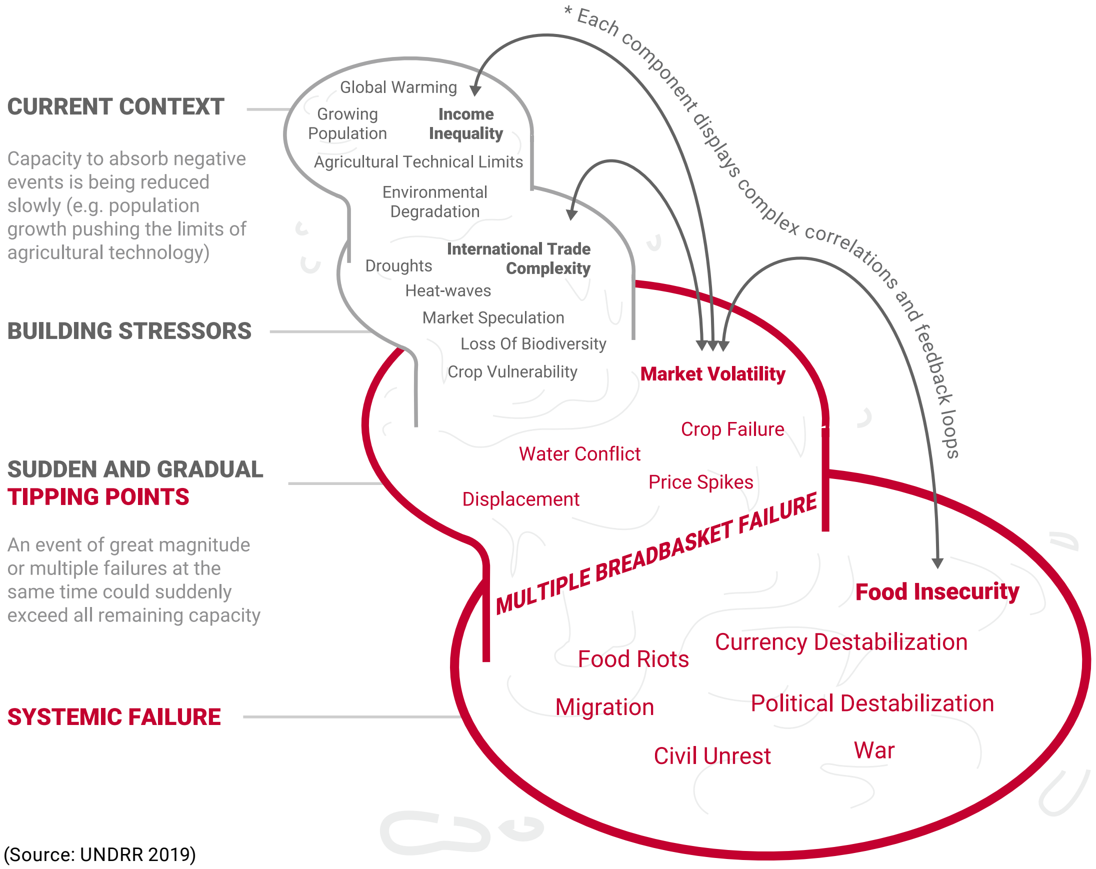
By definition, systemic risks are emergent, and not necessarily obvious using contemporary hazard-plus-hazard approaches, until the disaster occurs. Disasters resulting from systemic risks also may not fall into a traditional disaster taxonomy of a sudden event or an event with a clear start date. Emergent risks are typically obvious in retrospect – a result of a series of events that cross human-imposed boundaries, whether institutional, geographic, disciplinary, conceptual or administrative.

The term “emergent risk” is most commonly applied to financial systems (e.g. when one significant financial institution fails and others collapse because of opaque, complex, coupled relationships that connect them). In banking, emergent risks may result as a consequence of large interbank deposits, net settlement payment systems, investor panic or counterparty risk on derivative transactions, such as credit default swaps. Just as the “disease-fixing” medical establishment is not necessarily well suited for preventive, holistic approaches to achieving good health and happiness – and in many instances has inadvertently created new ills while curing old ones – traditional disaster response and mitigation capabilities are not the appropriate apparatus to increase community resilience or understanding of systemic risks.

Multiple breadbasket failure

A projected increase in extreme climate events and an increasingly interdependent food supply system pose a threat to global food security. Consequently, it is crucial that agricultural models take into account local parameters, as these represent binding constraints on global production resources. For instance, local shocks can have far-reaching effects on global agricultural markets. Consequently, it is crucial that agricultural models take into account local parameters, as these are critical variables in global food production. Increasing trade flows and trade network complexity also make the system more vulnerable to systemic disruption.[42] For example, climate shocks and consequent crop failure in one of the global cereal breadbaskets might have knock-on effects on the global agricultural market. The turbulences are exacerbated if more than one of the main crop-producing regions suffers from losses simultaneously – a scenario often described as multiple breadbasket failure (MBBF).

Figure 2.2. **Multiple Breadbasket Failure**



(Source: UNDRR 2019)

Academics, industry and policy experts warn that a better understanding of the risks of MBBF, as well as improved modelling, are needed to manage climate risks and the increasing global demand for food.[43] Of special interest are the effects of production shocks on crop prices and agricultural commodity markets. Due to increased demand and limited production capabilities, the volatility associated with agricultural prices is expected to rise in the coming decades.[44] This trend is already apparent, notably in the 2007–2008 food price crisis.[45] Energy shocks, increased energy demand and exchange rate fluctuations, as well as fiscal and monetary expansions, played a key role in this process, amplifying the impact of reduced production resulting from severe drought and heat-wave conditions.[46]

This experience suggests that the financial sector has a key role to play in agricultural markets.[47] For example, a number of studies have found ethanol policies in the United States of America significantly affect oil prices, as well as agricultural commodity prices.[48] The linkage of energy prices

42 (Puma et al. 2015)
43 (Bailey et al. 2015)
44 (FAO 2017a)
45 (Hovland 2009)
46 (Gilbert 2010); (Baffes and Haniotis 2010)
47 (Nazlioglu and Soytas 2011)
48 (Saghaian 2010); (Frank et al. 2015)

and agricultural markets is also documented in the reverse direction.[49] These effects are expected to increase in the future as a result of climate change.[50]

Moreover, changes in financial markets can also prompt agricultural producers to increase their production, either through cropland intensification or through expansion. Both of these responses can have negative environmental impacts, which would eventually feed back into the financial markets (through increased climate variability). This also implies that financial markets are in the unique position to support preventive action, avoiding GHG emissions, and potentially prevent or reduce climate risks, by reallocating trillions of dollars of investments and assets under management so as to be compatible with a global warming target of less than 1.5°C.

Paragraph 36(c) of the Sendai Framework explicitly includes the role of private sector financial institutions to integrate DRM into their business models and practices through disaster risk-informed investments.[51] The main challenge of implementing financial market policy and changing investor behaviour is the non-synchronous time horizons and spatial scope of the modelling instruments available to climate change researchers and financial policymakers and investors. Climate change models tend to focus on long-run horizon scenarios of development, typically until 2100, while financial market activity is evaluated on annual or multi-annual time horizons, something that Bank of England Governor Mark Carney has referred to as "the tragedy of the horizon".[52]

Scenario building in this context can help facilitate thinking and decision-making if those involved are able to consider local events, and regional and global drivers and trends. Exploratory scenarios start with the present situation in mind and explore the future impacts of various drivers, such as environmental degradation or climate change, shocks such as disasters, and trends such as urbanization and migration.

To fully understand the systemic risks of MBBFs, it is necessary to understand the gap between global, regional and local risks, risk perception, and risk prevention and mitigation strategies, and to evaluate the potential impacts of financial market regulations and possible innovative financial tools with regard to their impact on food security and the environment.

Societal resilience, cyberrisk and network hyper-risk

Interconnectedness is amplified by the connective tissue that runs through all of today's systems – the digital infrastructure that is itself susceptible to breakdowns and attacks from malicious third parties.

Understanding the degree of cascading risk and developing ways to isolate, measure and manage or prevent risk is a new challenge in today's environment of computer systems and computer actions that dominate economic, social and even environmental systems management. Consequently, our approaches to risk management and building our understanding of the interactive nature of the drivers of risk must focus on this emerging, massive threat and develop actions based on knowledge of systems and their interrelationships and interdependencies.

Box 2.1. Medjacking the infusion pump

Cyberattacks cascading into health systems and compromising patient lives through attacks on health-care monitoring devices ("medjacking") emerged in 2015. Security researchers discovered security flaws in the Hospira infusion pump that could remotely force multiple pumps to dose patients with potentially lethal amounts of drugs. In addition to insulin pumps, deadly vulnerabilities were found in dozens of devices, including X-ray systems, computerized tomography scanners, medical refrigerators and implantable defibrillators. After the discovery, regulators, including the United States Department of Homeland Security and Federal Drug Administration, began warning customers not to use the devices due to their vulnerability. The announcement was the first time the United States Government advised health-care providers to discontinue the use of a medical device.

(Source: World Economic Forum 2016)

Modern society has benefited from the additional efficiency achieved by improving coordination across interdependent systems using information technology (IT) solutions. Nonetheless, this IT dependence has also exposed critical infrastructure and industry systems to a myriad of cybersecurity risks, ranging from accidental causes, to technological glitches, to malevolent wilful attacks. The scale of systemic risk emanating from the increasing vulnerability to cyberattacks on critical infrastructure systems at national or local levels is still not fully understood. The cascading effect beyond the system under attack into interconnected systems can be devastating, creating chaos across economic, food and health systems over potentially prolonged periods well beyond the initial timing of a cyberattack. Consequently, approaches to risk management and building understanding of the interactive nature of the drivers of risk must focus on the emerging, massive threats in this area, and develop actions based on knowledge of systems and their interrelationships and interdependencies.

Models that can describe single-system vulnerabilities for cyberattack are not helpful for decision makers to understand and properly prepare for such systemic risks. By contrast, models that can describe the degree of risk expansion, as interrelated technological systems propagate the attack deep into the ecosystem of society, are now available.[53] Such models can begin to provide risk information helpful to governments, the insurance industry and the corporate world, so that proper preparations to prevent cyberattacks or manage the system components that are potentially vulnerable to attack may be considered.

These models bring together work from two fields: conceptual models exploring the impact of cyberattacks on insurance rate setting and other risk measurement mechanisms, and detailed mathematical models that explore the impact of cyberattacks on interconnected economic and infrastructure sectors. With the shift by Member States away from hazard-based disaster management to risk-based strategies enshrined in the Sendai Framework, these two streams of exploration are being united to highlight additional hazards, risks and dynamic interactions that need to be considered to understand the full impact of cyberattacks.

49 (Enders and Holt 2014); (Harri, Nalley and Hudson 2009); (Nazlioglu and Soytas 2011)
50 (Gilbert 2010)
51 (UNISDR 2015a)
52 (Carney 2015)
53 (Toregas and Santos 2019)

The relevance of this methodology to decision makers grappling with cascading risk problems is shown in the domain of food security within the United States of America. The rapid evolution of American agriculture from analogue to “smart” farming, transportation and food processing systems is opening new and often unappreciated cyberattack vectors. The structure and operation of modern highly networked food systems (and the obvious requirement for functional energy, transportation and other systems) fundamentally depends on networked information systems, some of which may not be secured from cyberattacks. The combined complexities of these networked systems interacting together stands to amplify threats and vulnerabilities that exist in any of the major systems, as well as risk to other dependent systems. The result is uncharacterized risks that are highly relevant for food safety and supply, manufacturing, banking, commodities, insurance and other sectors.

Among the salient large-scale features in contemporary, industrialized food systems that have potential to increase cyberrisk are:

a. Increasing farm consolidation with heavy and rapid reliance on smart technology with artificial intelligence (e.g. use of robotic milking machines).

b. Vertical integration through the food supply chains in which agricultural producers may directly process agricultural commodities (e.g. milk processed into dairy products on farms to directly supply supermarkets and grocery stores).

c. Widespread lack of compliance with food safety, traceability and insurance requirements.

d. Rapidly advancing use of smart technology throughout supply chains and transportation systems.

e. Increasing interdependency among food system components in smart markets resulting from new and often uncharacterized outsourcing relationships, service and highly coordinated supply arrangements, creating greater exposure to inter-organizational cascading defaults and failures.

f. Lack of systematic surveillance of social media, markets and other dynamic real-time or near-real-time reflections of food systems in a defensive mode to quickly detect precursor signals or system anomalies (physical and digital issues) of substantial concern.

Just-in-time distribution further exacerbates potential fragility in food supply between farm and table. All of these changes cause, or are caused by, advances in information flows and interactive systems that support the food system. Wherever information flows are crucial to the regular function of food systems, the potential for interruption or disruption via cyberattack exists.

2.1.2

Measuring and modelling systemic risks

> *Any information technology, from the most ancient money to the latest cloud computing, is based fundamentally on design judgments about what to remember and what to forget.*[54]

Established risk management techniques deal with threats generated by factors external, also termed “exogenous”, to the situation being assessed and managed. Typically, such situations allow a separation between risk assessment and risk management. Repetitive historical observations have been used to characterize risk by statements about the probability of certain interactions of hazards, vulnerability, exposure and capacity. However, the essential feature of the extreme, catastrophic, risk events actually witnessed in recent history, is the lack, or complete absence, of the patterns expected based on historical observations.

54 (Lanier 2013)
55 (Firth 2017)
56 (Lucas et al. 2018)

The complexity that underlies systemic risk may be sufficiently intricate that quantification and prediction of risk is not easy. In many instances, the capacity to make pertinent real-world observations is limited or absent, and yet an improved understanding of systems dynamics is required to elaborate estimates that are valid for improved decision-making. Systemic risk modelling may offer quantitative information to estimate spatio-temporal hazard exposures and potential catastrophic impacts. The design and computation of such models is typically a multidisciplinary endeavour with scientific challenges and important judgments as to what to include and what to exclude.

To make these complex, interconnected systems more manageable, a new view of risk is needed. This is analogous to clearing away the cloud cover to reveal the three-dimensional shape of risk, with a topology that also shifts through time. The Sendai Framework impels a move away from an obsession with prediction and control towards an ability to embrace multiplicity, ambiguity and uncertainty.[55]

There has been important recent work predicated on these concepts that suggests that the shape of risk is similar in very different systems. This "homomorphism" of systemic risks in different domains suggests that as attempts are made to understand the effects of endogenous triggers and critical transitions, there will be more patterns apparent in different domains, which will allow the development of a consistent understanding of the fundamental characteristics of systemic risk.[56] An apparently stable macroconfiguration of a complex system will break down, and will be re-shaped by amplifications of a series of microevents until a new macroconfiguration emerges. An example of this is the "invisible" asset price bubble in the housing sector, which remains unseen until the bubble bursts due to microscopic fluctuations in the system. To understand these critical aspects and disseminate new approaches for decision makers at various scales (in a simple-to-understand format) will require a more comprehensive understanding of spatio-temporal dimensions and the differentiated nature of complicated and complex systems.

Box 2.2. For the curious – systemic risk modelling

To characterize systemic risks, which necessarily involves dealing with information gaps or ambiguity, it helps to capture the random patterns of possible disasters, including those arising from extensive and intensive risks, on maps of values describing the vulnerability of objects, infrastructure and activities. A resulting systemic risk model will then allow for a quantification of mutually dependent losses in space and time, allowing for the use of stochastic risk management models. Stochastic systemic risk assessment tools recognize complexity and do not try to simplify things to make calculations easier. They need to represent how complex components are distributed across systems, and even if the probability is low, they need to encompass extreme events (distributional heterogeneity and additivity of extreme events). Such tools are therefore difficult to establish, and the approach differs from that taken in multi-hazard modelling, which relies on "regularity assumptions" that attempt to make reality less complex and disorderly to facilitate calculation.

Scenario analysis and stochastic simulation are used in many applications by the insurance industry. The purpose is to identify and evaluate risks and examine possible interconnections among them. For example, in the area of natural hazards, earthquake strength and possible hurricane paths are simulated, impact scenarios defined and potential losses analysed. The findings are used for purposes such as pricing, internal guidelines and management of a portfolio of insured assets. The ability to assess risks quantitatively has a direct effect on the insurability of the hazards concerned.

To focus the attention of analysts and decision makers on the indicators that most appropriately capture the character of systemic risk, the impending phase transitions and regime changes of the underlying complex system, new approaches to modelling are required. If appropriately co-produced, systemic risk modelling will uncover the incentives driving policymaker resistance to going beyond conventional views of risk, and which currently allow salient early warnings from systemic risk indicators to be ignored or rejected.

Modelling systemic risks – multi-agent systems research

The adoption of a multi-agent system in assessments subject to systemic risk is an emerging approach that is growing in importance, as it represents network effects and allows the random nature of human behaviour and (emotional) decision-making to be considered. A multi-agent system is a loosely coupled network of software agents that interact to solve problems beyond the individual capacities or knowledge of each problem solver. When certain agents pose a deliberate or unintentional threat, systemic risk management requires the countermeasures taken by other agents to be configured across all interconnected subsystems to maintain the integrity of the entire system. The application of multi-agent systems research may be considered appropriate in approaches to online trading, disaster management or social structure modelling for example.

Systemic risks might be easy to mitigate early on. However, failure or even intentional ignorance to capture the role of underlying drivers of systemic risk will allow small risks to grow into major problems, increasing the opportunity costs of failed interventions and missed opportunities. Developing and implementing multidisciplinary approaches to identify and act on precursor signals and systems anomalies is critical to minimizing or avoiding discontinuities in complex systems.

Assessment and management methodologies for systemic risks that have been conceived are still in early gestation, and are not yet part of the current operations of twenty-first century risk management institutions. Nonetheless, there is a growing sense of urgency for a paradigm shift hitting every major twentieth century risk management institution, as the limitations of the linear constructs of that era are now acutely revealed by the occurrence and prospect of massive failures and potential species-limiting vulnerabilities.

There are concepts that are often used interchangeably in the field of risk modelling and complex systems management, but which mean very different things. A non-exhaustive collection of types of risk in the context of systems is provided in Box 2.3 as guidance as to how these terms will be used in this GAR.

Box 2.3. Selected definitions relating to systemic risks

The origins of modern investigation in systems and the development of systems-based approaches can be traced back to the late nineteenth century. These lines of inquiry flourished through the twentieth century, in the study of complexity science and adaptive systems, through Ludwig von Bertalanffy's General System Theory in 1968, to cybernetics, catastrophe theory, complexity theory and complex adaptive systems.

And yet a commonly accepted vocabulary describing the manner in which risk features in systems is yet to be developed. The imperative to adopt systems-based approaches in understanding and managing risk that is enshrined in the Sendai Framework and the 2030 Agenda, has prompted UNDRR to propose the following definitions to guide the inquiry and the address of risk in systems, in this GAR, and potentially henceforth in implementation. Definitions may overlap each other.

Systemic risk – risk that is endogenous to, or embedded in, a system that is not itself considered to be a risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change.

Femtorisk – a seemingly small-scale event that can trigger consequences at a much higher level of organization, often through complex chains of events (after Simon Levin 2011).

Systems risk – the inherent risk of a system when substantive elements of the system contribute to the entire system having a certain risk profile, which could be anywhere on the risk spectrum from very low risk, like an intact rainforest ecosystem, to very high risk, like a tar sands mining system.

Network hyper-risk (after Dirk Helbing 2013) or **cascading multiple systems risk** – the inherent risk across multiple systems when there are substantive elements contributing to the system of systems having a certain risk profile, which could be anywhere on the risk spectrum from very low risk to very high risk. An example of very high risk might be the network hyper-risk across the entire food system as described by the analysis in the MBBF programme of work.

Existential risk – the risk of a fundamental, irreversible change in the performance of all systems relative to a specific perspective; for example, the existential risk to the survival of humans on Earth that is posed by the collective of risks associated with climate breakdown.

Topological map of risk through time (after Molly Jahn 2015) – a dynamic temporal and geospatial representation of risks at multiple scales including representation of the functioning of multiple complex, non-linear, interlocking systems across all scales and the interlinkages, dependencies, correlations and relationships among and across all types of risk (as broadly defined in the Sendai Framework, para. 15). The purpose is to provide an understanding of the current and future conditions on Earth to manage uncertainty through the identification of precursor signals and anomalies, including sensitivities to change, system reverberations, bleed-over and feedback loops, by utilizing artificial intelligence and collective human intelligence.

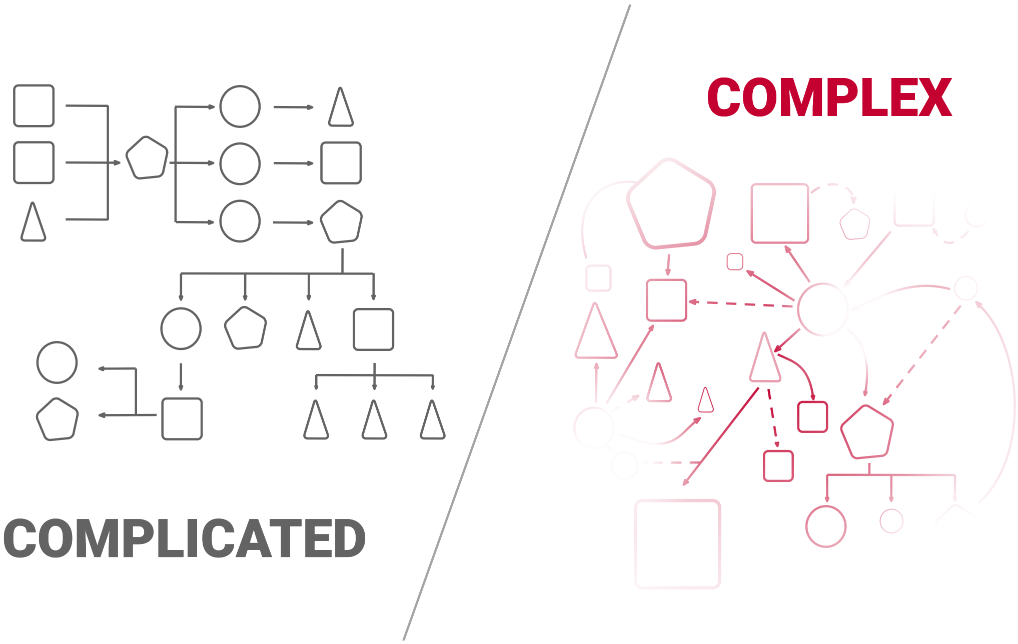
(Sources: von Bertalanffy 1968; Levin 2011; Helbing 2013a; Jahn 2015)

2.1.3

Complicated and complex systems

In discussing the different types of assessments of risk, it is important to clarify the distinction between a "complicated" system and a "complex" system. A complicated system can be (dis-)assembled and understood as the sum of its parts. Just as a car is assembled from thousands of well-understood parts, which combined allow for simpler and safer driving, multi-hazard risk models allow for the aggregation of risks into well-behaved, manageable or insurable risk products. By contrast, a complex system exhibits emergent properties that arise from interactions among its constituent parts. Examples of a complex system include a traffic jam, regime change or social unrest triggered by natural hazards.

Figure 2.3. Complicated and complex systems



(Source: Gaupp 2019)

The priorities for action of the Sendai Framework spur a new understanding of risk, and the obvious value of discerning the true nature and behaviour of systems rather than a collection of discrete elements. This view allows the use of complexity theory for risk management problems in the context of the Sendai Framework and the wider 2030 Agenda. Historically, risk management models, as well as economic models and related policymaking, have tended to treat systems as complicated. Applying this method, simplified stylized models are often applied to single entities or particular channels of interaction, to first define and then label the risk phenomena. Methods are then negotiated by stakeholders to quantify, or otherwise objectively reflect, the risk in question, and then to generalize it again to make policy choices. Most prevailing risk management tools assume underlying systems are complicated, rather than complex. In fact, these tools are often deliberately designed to suppress complexity and uncertainty. This approach is increasingly out-dated and potentially harmful in a globalizing and increasingly networked world, and is likely to produce results that simply fail to capture the rising complexity of the topology of risks.

Risk and uncertainty are measures of deviation from "normal". Risk is the portion of the unexpected that can be quantified by the calculation of probabilities. Uncertainty is the other portion of the unexpected, where information may exist but is not available, not recognized as relevant or simply unknowable. Therefore, probabilities for uncertainties cannot be reliably measured in a manner currently acceptable to the global risk management community. Converting uncertainty into acceptable risk quantities that essentially emanate from complex system behaviour is currently very difficult, even impossible. Some uncertainties in any complex system will always remain unmeasurable. The risks can be characterized and quantified, to some degree, by networks made up of individual agents whose interactions exert macroscopic consequences feeding back to individual behaviour. Understanding sensitivities to change and system reverberations is far more important and more challenging in the context of complex systems. Simulations of such systems show that small changes can produce initial ripples, which can be amplified by non-linear effects and associated path dependencies, causing changes that lead to significant, and potentially irreversible, consequences.

Increasing complexity in a networked world of anthropogenic systems within nature can be unstable and uncontrollable, and it may not be possible to understand them ex ante. This inability to adequately understand and robustly manage systemic risk is an important challenge for risk assessment in the context of the Sendai Framework and achievement of the 2030 Agenda.

To allow humankind to embark on a development trajectory that is at least manageable, and at best sustainable and regenerative consistent with the 2030 Agenda, a fundamental rethink and redesign of how to deal with systemic risk is essential. Improved understanding of system components, including precursor signals and anomalies, systems reverberations, feedback loops and sensitivities to change, will be imperative. Ultimately, the choices made in respect of risk and resilience will determine progress towards the goals of the 2030 Agenda.

2.2

Spatio-temporal characteristics of systemic risks

Systemic risk events can be sudden and unexpected, or the likelihood of occurrence can build up through time in the absence of appropriate responses to precursor signals of change. An understanding of systemic risk requires a time-dependent description of the interacting elements, the strength of interactions among elements, and the nature of trigger events. Modelling the systemic risk behaviour of complex systems is intrinsically difficult. The degree to which harm is caused depends on the temporal dependence of the underlying processes and the severity of the trigger event, which are usually studied through numerical simulations. In other words, the impacts of realized systemic risk depend on the rapidity of interaction of different parts of systems and how extreme the event is that triggers the risk.

Time and timing are critical parameters that determine the properties of the impacts of systemic risks when realized, or, in more familiar terminology, when the consequences of hazard, vulnerability and exposure manifest. It is salient to mention here two aspects concerning timing in the context of systemic risk. The first issue is related to the polysynchronous time signature of dynamic systems and the occurrence of risks; the second refers to the temporal evolution of how systemic risks build up and unfold, involving feedback loops of asynchronous operations of system components.

2.2.1

Polysynchronous time signatures of dynamic systems

Polysynchronous events refer to simultaneous disruptions (events) in a system or systems. If a single extreme event such as a drought occurs, the system is usually buffered, reducing the consequences. For example, trade mitigates price shocks resulting from crop losses in one of the world's breadbaskets. However, if multiple extreme events happen simultaneously (see section 2.3.1), the system may cross a threshold where negative impacts increase in a non-linear fashion with every additional event. Studies have shown that disasters – such as floods – often exhibit a higher spatial correlation in the extremes, a so-called tail-dependency.[57] In Central and Eastern Europe, for instance, river basins show strong positive cross-correlation in peak discharges owing to atmospheric circulation patterns. Those interdependencies across regions are not yet sufficiently included in probabilistic risk modelling, which is crucial, for example, for the development of robust insurance schemes. Risks of extreme events in complex systems will be underestimated as long as risk projections ignore geographic risk patterns.

One useful method to better account for interdependencies in risk modelling is the copulas method.[58] This is a statistical tool to account explicitly for non-linear dependencies in complex, multivariate models. It has been applied in the fields of finance, medicine and catastrophe modelling so far.

Further innovations in risk modelling are needed to better understand polysynchronous events.[59] For example, the risks of current and future hazard events such as wildfires, droughts or extreme precipitation, as well as their knock-on effects on agricultural production, food prices and food security need to be understood, especially in the context of rapid climatic change. See section 2.1.1 and the risks and consequences of MBBF.

2.2.2

Feedback loops of asynchronous operations of system components

An adverse event affecting the functioning of an individual system component can cause reverberations or ripples within the larger system and lead to a breakdown of related system components and potentially the complete system.

Box 2.4. Systems reverberations – global navigation satellite system

In supply chains and traffic systems, applications using global navigation satellite systems – notably the global positioning system (GPS) – have been expanding exponentially, delivering innovative and efficiency-enhancing capabilities, revolutionizing the operations across entire supply chains. Efficiency gains through just-in-time delivery systems have been remarkable in the logistics sector and also in related sectors such as financial services (e.g. settlement systems), food systems and health (e.g. manufacturing).* A failure in a GPS will cause deliveries to be delayed. Order and delivery jams could cause, through positive feedback loops, the simultaneous failure of many services that are likely otherwise assumed to be independent of each other. It is entirely plausible that the malfunctioning of a relatively small service delivery system, originally designed to assure the synchronization of business operations reaping efficiency gains, could cause large-scale breakdown of food and health systems at local or even national or global scale.

* Beneficial efficiency gains must be measured against new risks posed; for example, the potential deleterious effect of just-in-time food delivery programmes on the resilience of communities.

The most prominent macroscopic example for asynchronous feedback is the disturbance of the climate system. The fast extraction of fossil fuels due to short-term economic incentives leads to a steadily increasing stock of GHGs in the atmosphere. The unprecedented speed of the transfer of carbon from the ground to the atmosphere is not scaled to match with the regenerative dynamics of the natural carbon cycle causing alterations in the functioning of the Earth system. These alterations are predicted to cause new, more-frequent and intensive disasters ranging from drought and flooding all the way to changes in seismic activity.[60]

Some of these disturbances lead to feedback loops such as increased frequency of forest and savannah burning, and permafrost thawing, which further accelerate the build-up of carbon stocks in the atmosphere and cause increased warming, potentially triggering even more catastrophic abrupt climate change phenomena. Evidently, a synchronization of the rate of extraction of carbon from the ground with the rate of natural carbon sequestration would have been a more robust development strategy for humankind and is currently envisaged as an element of a possible future emissions trajectory to be implemented under UNFCCC.

Box 2.5. High-mountain Asia

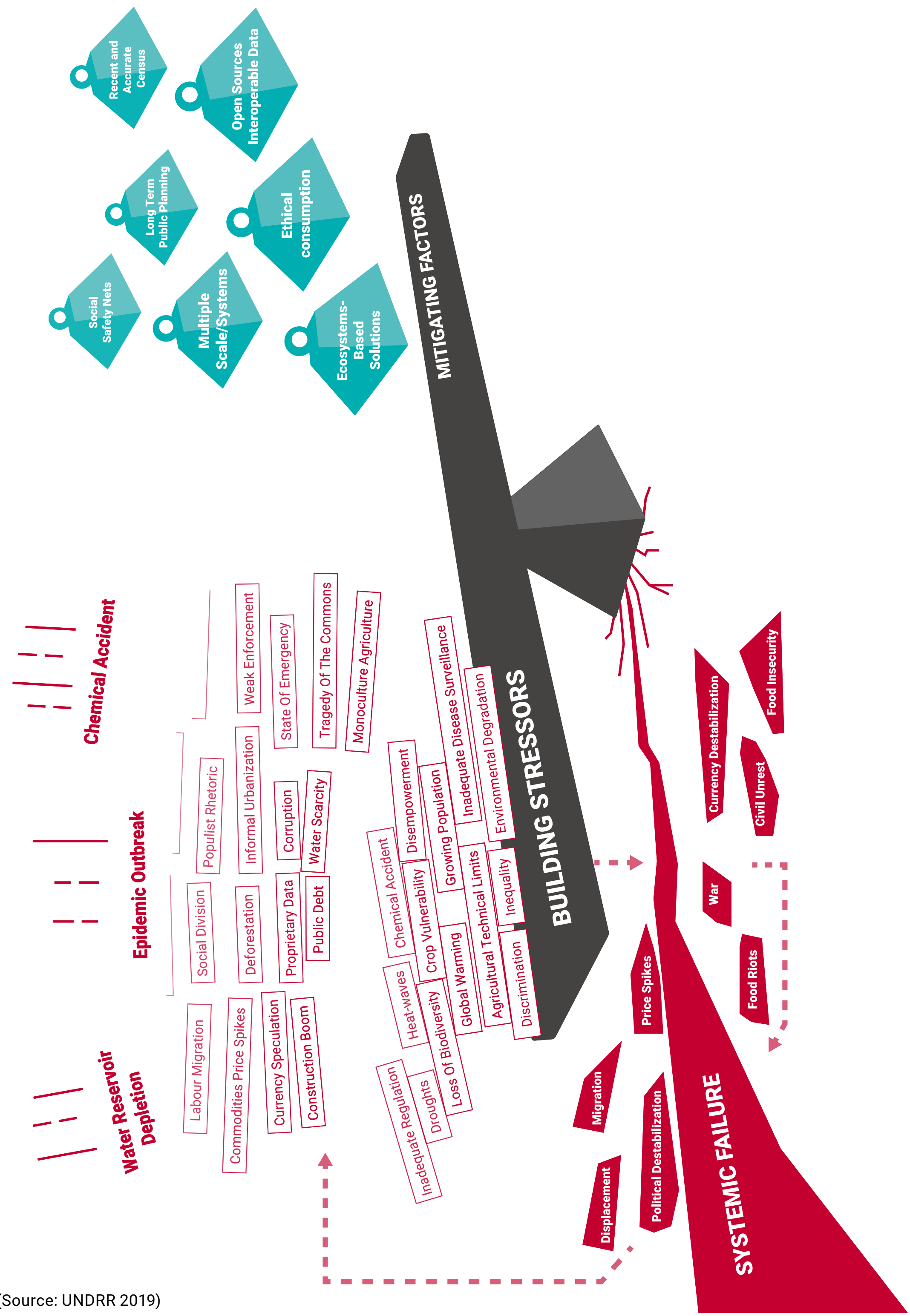
Cascading hazard processes refer to a primary impact (trigger) such as heavy rainfall, seismic activity or unexpectedly rapid snow melt, followed by a chain of consequences that can cause secondary impacts. These result in a complex array of vulnerabilities that interact in interdependent and unpredictable ways and can have tremendous impacts on populations downstream of the initial triggers. High-mountain Asia is highly vulnerable to cascading hazard processes given the tectonic, geomorphologic and climatic setting of the region, particularly as it relates to glacial lake outburst floods.

It is expected that the occurrences of glacial lake outburst floods will increase in the future due to permafrost thaw and glacial retreat exposing mountain slopes and destabilizing the environment. This will increase the potential of landslides, avalanches and debris flow hazards, which can hit the glacial lake and trigger an outburst flood.

(Source: Nussbaumer et al. 2014)

57 (Timonina et al. 2015)
58 (Aas 2004); (Aas et al. 2009)
59 (Golnaraghi et al. 2018)
60 (Masih 2018)

Figure 2.4. Systemic risk stressors and mitigating factors



(Source: UNDRR 2019)

Box 2.6. For the curious – modelling asynchronous feedback

Stochastic risk management models have been developed to help understand and quantify the dynamics of systemic risk in general and of asynchronous feedback events in particular. Numerical models can either be non-structural time-series models (e.g. vector autoregressive models), structural models (e.g. system dynamics models) or combinations where scenarios are generated by a structural model to specify a non-structural emulator model. The latter approach then allows for the use of stochastic optimization models to calculate robust prevention or response strategies.

For assessment of the systemic risk dynamics of large integrated systems, it is necessary that the resolution in timescales of the system components are matched with the relevant dynamics. Fine spatial scale processes might be measured in seconds while processes on planetary scales can be measured in decades or centuries. When the whole of the system endogenously adjusts itself or gets triggered through an exogenous shock to a transition to a new equilibrium by feedback loops, an asynchronous operation of temporal scales might render the system unstable. In attempting to understand disruption and collapse of functioning in natural and human systems, it is likely that such dynamic mismatches are core drivers.

2.2.3

Multiple spatial scales of systemic risks

HFA primarily focused on risk at the national scale, to inform public policy and provide guidance to national governments on DRR. However, risk is interconnected across larger and smaller geographic scales. One example of the smaller spatial scale is urban areas, which are central sites where people, economic activity and built assets are concentrated, and which are increasingly considered as being the front line for DRR.[61] Disasters in urban areas affect local residents and livelihoods, and also transfer shocks through supply chains and resource networks to other locations.

Primary risks to urban areas

Previous Global Assessment Reports (GARs) have divided risk into multiple classes: everyday risk (which includes food insecurity, disease, crime, accidents, pollution, and lack of sanitation and clean water), extensive risk (which includes death, injury, illness and impoverishment from smaller intensity hazards) and intensive risk (which includes major disasters causing death to 25 people or 600 houses or more).[62] By including these multiple classes of risk, the need for urban specialists to work alongside disaster specialists to understand how risk accumulates in urban areas had become abundantly apparent by 2015.

The Sendai Framework takes this further by establishing the need to understand and manage the interdependent, multidimensional variables of risk that are created by, and magnified among, different systems as they interact, across different geographic or spatial scales. Considerations of urban risk must embody the multitude of decisions that interact with the underlying hazards and conditions that are constantly present in an urban environment, such as infectious disease outbreaks, fires and crime. It must also consider risks that are occasional or exceptional, such as flooding, earthquakes, landslides, extreme weather events and

61 (IFRC 2010)
62 (UNISDR 2009); (UNISDR 2011b); (UNISDR 2013b); (UNISDR 2015a)

sea-level rise, to build a more representative understanding of systemic risks.

While systemic risks also affect rural areas, they are particularly relevant to urban areas because of the unique characteristics of city regions as complex systems of systems. For example, sea-level rise and coastal flood risks are critical concerns for urban areas. Most of the world's megacities are located within low-elevation coastal zones without adequate structural measures or behaviour adjustments to avoid either the initial trigger events or the cascading hazard processes.[63] Many small- and medium-sized urban areas are similarly situated and growing rapidly. The need to understand and manage systemic risk associated with infectious epidemics is multiplied in the urban context as a result of urban population densities.

To reduce or prevent the creation of risk, a better understanding of the interactions and interdependencies between urban and rural areas is essential. This requires a functioning urban/rural (city region) data metabolism to process information at appropriate scales to understand the systems implications. City regions are collecting and processing progressively more sophisticated data – increasingly in systems models – including through approaches already tested in urban health observatories.[64] This serves to build collective urban intelligence (see section 2.4.1) among informed groups of people in city regions across sectors and disciplines, to make better decisions together.

Drivers of risk and change in the vulnerability of urban areas

The nature and scale of urban risks continue to increase due to the confluence of multiple contemporary trends, including rapid urbanization, climate change and rising inequalities. Increased urban development pressure can cause settlement growth in hazard-prone areas, such as the informal settlements on the natural flood drainage areas of Cape Town, or the landslide-prone gullies and ridges around Guatemala City. Such settlements can also destroy natural protective ecosystems that have historically mitigated the risks of landslides, flooding and storms, such as absorbent wetlands and binding vegetation cover on steep land. Often, the areas most affected by these hazards are informal settlements occupied by populations with the lowest adaptive capacity, including residents without land tenure, and recent migrants.

Box 2.7. Risk and interacting urban subsystems – Lagos, Nigeria

In Lagos, Nigeria, between 1986 and 2002, urbanization resulted in a 13% increase in developed land, and an 11% decrease in mangrove, swamp thickets and other natural vegetation useful for buffering against coastal floods. Subsequent flooding affected several slum communities, which had developed on sand infill land that could not support solid structures, and that therefore had a low market value.

(Sources: Okude and Ademiluyi 2006; Adelekan 2010)

With the increased prevalence of hazardous events due to climate change, and dynamic and evolving vulnerability and exposure, such corrosive impacts in urban areas are predicted to increase in coming decades.

Transfer of disaster impacts from urban areas to other distant locations

Disaster risk in urban areas has commonly been studied from the perspective of individual cities. However, as urban areas are part of a global social and economic network, impacts in one urban area can cascade to other distant regions.

Box 2.8. Latent systemic risk – Puerto Rico

After Hurricane Maria struck Puerto Rico in 2017, a major wholesale medical supply company in San Juan was unable to maintain production. As a result, hospitals across the globe faced a critical shortage and a 600% increase in the cost of intravenous bags. Moreover, Puerto Rican pharmaceutical manufacturers were unable to manufacture drugs needed to treat diabetes, cancer and heart conditions. This was not an isolated instance of significant business interruption. The secretary of Puerto Rico's Department of Economic Development and Commerce considered "the lack of power is the root of everything", when referring to the chronic underinvestment in the electricity grid in the decades leading up to Hurricane Maria as a major driver of the prolonged and extensive impacts of what was the largest blackout in the history of the United States of America.

(Sources: Alvarez 2017; Conrad 2018; Wong 2018)

Recent research has shown that the global urban-industrial network is more vulnerable to multiple simultaneous hazards than to singular impacts in wealthy, large urban areas.[65] Therefore, as climate impacts become more prevalent, impacts capable of interrupting urban economic flows and creating social instability may become more severe.

63 (Brown et al. 2013)
64 (International Science Council 2018)
65 (Shughrue and Seto 2018)

2.3

Systemic risk governance

Governance generally refers to actions, processes, traditions and institutions (formal and informal) by which collective decisions are reached and implemented.[66] Risk governance can be defined as "the totality of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken."[67] It is usually associated with the question of how to enable societies to benefit from change, so-called "upside risk", or opportunity, while minimizing downside risk, or losses. In contrast, systemic risk is usually seen as downside risk. The realization of systemic risk by definition leads to a breakdown, or at least a major dysfunction, of the system as a whole.[68] Assessing, communicating and managing – in short, governing – systemic risk is compounded by the potential for losses to cascade across interconnected socioeconomic systems, to cross political borders (including municipal and Member State boundaries or regional mandates), to irreversibly breach system boundaries and to impose intolerable burdens on entire countries. Risk governance is also confounded by almost intractable difficulties in identifying causal agents and assigning liability.

What needs to be set up so that institutions can govern systemic risk? Like any emerging phenomena, systemic risk cannot be measured by separately quantifying the contributing parts. This means that effective governance should consider the interconnected elements and interdependencies among individual risks. For this purpose, a network perspective, with attention to interconnected nodes or agents, can be useful, as well as greater accountability and responsibility on the part of individual and institutional decision makers, for example, through the establishment of the principle of collective responsibility.[69]

Some of the characteristics of such institutions at the global scale can be explored through examples from the global financial system and international climate change institutions (see Chapter 13).

2.3.1

Global financial crisis in 2008

Systemic risk governance requires new institutional structures, as was recognized after the global financial crisis in 2008. Before the crisis, early warning systems (EWSs) were in place to identify precursor signals and anomalies in the overall performance of the complex financial system. Yet they failed to detect what are now understood to be clear signals. The probability of a financial crisis occurring in the United States of America in 2007 was calculated to be between 0.6% and 1%. For the United Kingdom of Great Britain and Northern Ireland, the results were similar, with the probability of a financial crisis calculated at between 0.6% and 3.4% in 2007. Financial systems operated in a siloed fashion with constituents operating rationally from their perspective and within their mandates. However, such systems often become corrupted or behave in a way that is suboptimal or procyclical at a systems level – namely reinforcing of underlying dynamics. Few organizations have the wherewithal to investigate at a system level, let alone a system-of-systems level, and so ownership of the problem is often lost.[70]

The global financial crisis prompted the development of new – or reshaping of old – institutions and mechanisms to identify, and ideally prevent, future systemic risks in the financial system. The inclusion of key developing economies (such as Brazil, China and India) in global economic decision-making processes was a central development – notably through the G20 group of globally important industrialized and developing economies plus the European Union (EU). This was accompanied by a more important role of the International Monetary Fund in the surveillance of major economics.[71] New financial mechanisms were also set in place; for example, the European Stability Mechanism is an international financial institution designed to help the euro area countries in case of severe financial distress.[72] A systemic risk tax has also been proposed to decrease the number of banks that are too central to fail.[73] However, post-crisis governance structures are considered by many analysts to be insufficient to prevent a further financial crises.[74,75]

2.3.2

Climate change

While the global financial crisis focused attention on global interdependencies and cascading risks with potentially catastrophic consequences, there are a worrying number of other potential triggers. These include extreme climate events, armed conflict, forced migration, food and water shortages, unregulated digitalization, pandemics and loss of biodiversity. Climate change is increasingly recognized as a systemic risk with potentially catastrophic impacts cascading through financial, ecological and social systems. Climate change also perhaps has the most developed global governance regime.

Box 2.9. Systemic risk governance – global climate change governance

Initiated by the United Nations, global climate governance took the form of multilateral agreements beginning with UNFCCC in 1992. The 2012 Doha Amendment to the Kyoto Protocol extends UNFCCC until 2020. As of February 2019, 126 of the 144 Member States required for the amendment to enter into force had deposited their instrument of acceptance. Negotiations held in the context of UNFCCC resulted in the adoption of the Paris Agreement in 2015, which has been ratified by 185 of the 197 Parties to the Convention. As a hybrid of legally binding and non-binding provisions, under this agreement, 183 countries have outlined their post-2020 climate actions (through NDCs). Beyond the evolution in official global climate governance, alternative political narratives have emerged that include market entrepreneurship and lifestyle changes that will encompass more flexible and participatory approaches to addressing the multifarious problems of climate change. These include adopting "climate-friendly food" or eco-driving and car-sharing.

(Sources: de Boer, de Witt and Aiking 2016; Barkenbus 2010)

While neither the governance of the financial system nor the climate system can claim full success (note IPCC warnings that NDCs of the Paris Agreement entail a potential global warming trajectory of between 2.9°C and 3.4°C above pre-industrial temperatures),[76] both have raised awareness of the necessity, and spatio-temporal complexity, of governance regimes to address systemic risks at

66 (Renn 2008)
67 (IRGC 2018)
68 (Kovacevic, Pflug and Pichler 2015)
69 (Helbing 2013b)
70 (Agathangelou 2018)
71 (Kahler 2013)
72 (Bank for International Settlements 2018)
73 (Poledna and Thurner 2016)
74 (Agathangelou 2018)
75 (Goldin and Vogel 2010)
76 (IPCC 2018)

the global scale. Moreover, the financial and climate governance regimes have brought attention to the complex web of challenges. One major challenge is establishing causal attribution of systemic losses as the basis for assigning accountabilities and responsibilities so essential for risk governance.

The attribution of climate change has been established by accounting for past GHG emissions. Commitments and accountabilities could be tackled via GHG projections into the future.[77] However, attribution in other areas of systemic risk may be less clear, where large uncertainties exist in determining the causal effects across complex geospatial regions, across stakeholders and across sectors. For example, experts generally agree that the risk of extreme droughts and floods in some regions is increased by climate change,[78] but attributing losses from any event to human-induced climate change is still unachievable. Attribution is complicated further as systemic risk can evolve up to the global macroscopic scale through disruptions at the microscopic scale, so-called "scale-free properties",[79] or through behaviour that is indirectly linked to the disruption it causes in a specific system. Consequently, the difficulty of attributing accountability bounds the solution space for the reduction of systemic risks; it also hampers the development of a joint vision defining clear targets for its management.

Another challenge, although not unique to systemic risk, is the often deep uncertainty surrounding the triggers, exposure and cascading consequences, which are all the nodes of the network. One way of tackling uncertainties, albeit not suggested for nodes with catastrophic potential, is trial and error through an iterative risk management approach.[80] Uncertainties can be hedged by combining systemic risks with other types of risks so they can be tackled together.[81] Taking a systems approach that takes account of network dynamics and social processes can form a basis for designing risk governance approaches.

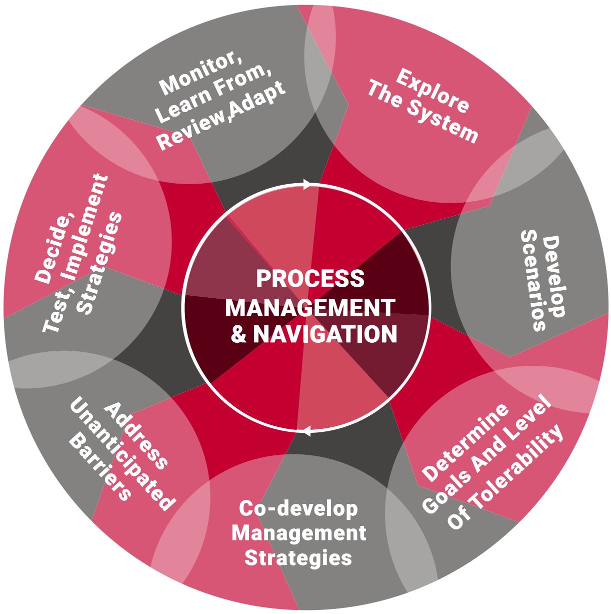
Beyond uncertainty, a more daunting challenge is a lack of understanding of the systemic nature of many risk contexts.[82] One suggestion taken from the climate risk community is to use a triple-loop learning process, from reacting to reframing and finally to transformation.[83] This is also in line with suggestions made towards an increasingly adaptive risk management framework with a focus on solutions with multiple benefits.[84]

At the core of any risk governance framework, including systemic risk, is the need for inclusive stakeholder expert processes for co-designing and co-generating solutions. While the importance of stakeholder buy-in has become increasingly apparent, there are special challenges for systemic risks.[85] For one, the cascading and uncertain nature of the losses means that stakeholder communities are ill defined and often span political borders. Because of the uncertainty, the issues will likely be characterized by varied views on the nature of the problem and its solution, as well as different "risk constructs" on the part of the stakeholder communities.[86] For the "realists" the risks can be objectively assessed in terms of their likelihood and impact, whereas for the "constructivists", the existence and nature of risk derives from its political, historical and social context, that is, it is constructed. The two divergent views can have a significant impact with regard to policy implementation.[87] Modernity reflexively relies on increasing complexity to manage the very risks it creates, which, in turn, causes disasters that are often embedded in the construction of social organizations and institutions.[88] Consequently, iterative approaches are better able to determine potential conflicts and possible solutions by identifying precursor signals or anomalies in system performance at the earliest possible point in time.[89] Human agency may play a less-important role in some systemic risk considerations (e.g. in supply chain risks) than in others (e.g. political disruption), which is important for the corresponding governance approaches. The question is related to the optimal complexity to govern systemic risk, that is, how detailed the approach should be, given limited resources.

It can be argued that in the case of complex systems and systemic risks, current measures and approaches represent a collection of failed attempts.[90] Nevertheless, the approaches are raising awareness and addressing challenges that can shed light onto critical aspects of what is itself a complex issue – systemic risk governance.

Emerging approaches (e.g. International Risk Governance Center (IRGC) systemic risk governance guidelines; see Figure 2.5) seek to address the difficult problem of assessing or measuring systemic risk, of modelling cascading consequences, of applying different management instruments,[91] and of implementing participatory processes.[92]

Figure 2.5. Flexible elements of systemic risk governance



(Source: IRGC 2018)

Successful implementation of such systemic risk governance approaches assumes flexibility and (continuous) adaptation to context (an iterative process in IPCC parlance). It is contingent upon strong leadership with mid- to long-term focus, the willingness to adapt or revise often non-linear, non-sequential processes, and the willingness to accept and resolve trade-offs.[93] Insights from more conventional risk analysis,[94] risk communication and risk management can be applied fruitfully to connect systemic risk with more traditional risk governance approaches.

77 (IPCC 2001)
78 (IPCC 2012)
79 (Poledna and Thurner 2016)
80 (Schinko and Mechler 2017)
81 (Timonina et al. 2015)
82 (IRGC 2018); (Timonina et al. 2015)
83 (Tosey, Visser and Saunders 2012)
84 (Frank et al. 2014); (Helbing 2013b)
85 (IRGC 2018)
86 (Centeno et al. 2015)
87 (Yazdanpanah et al. 2016)
88 (Beck 1999)
89 (Linnerooth-Bayer et al. 2016)
90 (Page 2015)
91 (Poledna and Thurner 2016)
92 (Linnerooth-Bayer et al. 2016)
93 (IRGC 2018)
94 (Timonina et al. 2015)

2.4

Collective intelligence, contextual data and collaboration

Risk is ultimately a human construct, created in language and meaning to describe the felt or feared volatility and uncertainty of human life – in other words, the experience of complexity and of complex systemic effects. Humans in many societies have become accustomed and attached to the illusion of control that the construct of risk has given us. But as it becomes apparent that the effects of interdependent, globally connected systems and vulnerabilities may be beyond human measurement or management, the limits of that illusion must be acknowledged. So too must the limits of present systems of governance and organization of human knowledge. This requires a new paradigm for understanding and living with uncertainty and complexity – one that activates the power of human social and contextual intelligence, and where possible, leverages it through appropriately designed artificial intelligence.

Developing the capability for contextual understanding and decision-making is a far more effective way of dealing with uncertainty and complexity than the present reliance on extrinsic frames of reference and categorical technical expertise, siloed into disciplines. In part, such capability can be built using a lifelong learning approach, so as to grow an aware, internalized ability to notice the relevance of context and the role of self; and in so doing, recognize and anticipate interdependencies and nonlinear effects.

Human decision-making is emotional, not rational, and is therefore more successfully activated by mental models based on meaning attached to values and beliefs.[95] Over time, use of narrative and meaning to negotiate the constantly changing relationship between identity and context has proven to be an effective mechanism to build resilience, to enable rapid sensing, understanding and sensemaking. In this way, collective intelligence becomes possible as an essential precondition for collective responsibility, which is at the core of systemic risk governance. Collaboration with and through that intelligence holds the key to building systemic resilience.

2.4.1

Collective intelligence

"Collective intelligence" is the powerful combination of human intelligence, artificial or machine intelligence and processing capacity.

Building resilience is necessary to adequately respond to, and reduce, risks and prevent disasters. Resilience requires: planning and preparation based on assessments to avoid or minimize risk creation and reduce the existing stock of risk; the development of capacity to restore functions quickly and effectively in the face of disruptions; and the capacity to adapt and change after a shock.

By addressing these complex systems challenges, every individual, organization or group involved in resilience building could thrive more successfully if they tapped into a "bigger mind" through collective intelligence. This could be by drawing on the brain power of other people with diverse cultural experience, chronological age, education or occupation and gender, combined with the processing power of machines.

While needed for processing big data about the functioning of complex systems, machine learning and artificial intelligence do not help people to solve more complex coordination and governance problems that require trust between people. They cannot decide on how people want to live human lives, for example in cities. Blockchain, a distributed network solution for coordinating interactions and exchanges, likewise cannot alone solve this complex human dynamic problem.

Truly global collective intelligence is a long way short of being able to solve global problems. It is now important to assemble new combinations of tools that can help the world think and act at a pace, as well as at the scale commensurate with the complex problems we face. In too many fields, the most important data and knowledge remain flawed, fragmented or closed, lacking the context and organization required for them to be accessible and useful for decisions; as yet, no one has the means or capacity to bring them together.

The critical interdependence among human health and well-being, ecology and technology is highly complex – both in the nature of connections and in responses in time and space.[96] Achievement of an improved understanding of human–ecological–technological system interactions is essential, just as is starting to be achieved in climate science through the application of sophisticated computer modelling.

This revolution in systems modelling has reached the point where it is now possible to begin modelling the interlinkages and interdependencies among the economic (values), societal (health, welfare and productivity) and environmental impacts of decisions and investments driven by the live interactions between weather, Earth crust shifts, soils, land, ocean ecology and human activity.[97] Geodata at multiple scales is available to support this approach to better understand the interactive nature of the drivers of risk and for long-term risk reduction.

In many cases, models of complex ecological systems used to make projections of future trends, use data derived statistically from putative causal associations, but these associations can change under novel conditions, and thus predictions might be questionable. Novel models that are based on an understanding of the underlying processes that cause a system to behave in particular ways are increasingly needed, spanning and interacting from global to local levels. They can be used to create a resilience compass to enable communities to steer towards a more resilient future.

Such novel models, supported by artificial intelligence and machine learning, can then build collective intelligence among communities through independent regional or national transitional super-laboratories[98] – or collaborative laboratories (discussed further in section 2.4.2). These comprise leading experts from across sectors, including academic, government, private sector and community.

Recent advances in computing power, availability of data and new algorithms have led to major breakthroughs in artificial intelligence and machine learning in the last six or seven years. Many applications are entering everyday lives, from machine translations, to voice and image recognition, to geospatial optimizations, all of which are increasingly exploited in industry, government and commerce. Increasingly constructive deployment of artificial intelligence combined with developing collective intelligence in the field of DRR will have a positive impact on saving lives, reducing injuries, minimizing damage to property and improving economic systems. At all times, these promote social equality through enhanced decision-making capabilities. To do this successfully will require strong evaluation frameworks that can assess the performance and the quality of artificial intelligence, and build trust in this disruptive technology.[99]

Further research is needed to understand fairness in the context of automated decision-making. An algorithm or decision is fair when it does not discriminate against people because of their membership in a specific group (e.g. as gender, race or sexual orientation). In the emerging field of

95 (Gatzweiler et al. 2017)
96 (Whitmee et al. 2015)
97 (Whitmee et al. 2015)
98 (EU, Directorate-General for Research and Innovation, Directorate I - Climate Action and Resource Efficiency 2018)
99 (Craglia et al. 2018)

explainable artificial intelligence (i.e. techniques in artificial intelligence that can be trusted and easily understood by humans, and which contrast with the concept of the black box in machine learning where it is often difficult to explain why the artificial intelligence arrived at a specific decision[100]), there is considerable work in progress to address these complex issues and replace the black-box approaches of conventional artificial intelligence, so as to reduce bias and increase the understandability for decision makers.

When it comes to cybersecurity, artificial intelligence is a double-edged sword. It can be greatly beneficial to increase the security of devices, systems and applications, but it can also empower those who seek to attack systems and networks and thus become an advanced tool in the arsenal for cyberattacks. The Sendai Framework takes into account the need to address risks that arise from technological innovations and their application (see Chapter 3 of this GAR). Moreover, the robustness of artificial intelligence against malicious action becomes an issue, posing the most immediate danger for the security of cyberphysical systems, in which artificial intelligence will be increasingly deployed.

Therefore, technology-based solutions to coordination problems need to be combined with human-based solutions (solutions that are made by or involving humans for solutions at a human scale). Unlike machines, which need to operate with probabilities, humans – within a social network of trust – can make decisions under radical uncertainty by attaching values to decisions. This ability in healthy human beings is due to emotional responses to highly complex decision situations to which there are no solutions from purely calculative and value-free accounting of costs and benefits.

Purely technological solutions that build on objectivity and value-neutrality detach the human being from being intrinsically connected to the environment. Humans can (or should) decide on changing deeply embedded values that define higher level rules, and shape attitude, choices and behaviour. Otherwise, societies may continue to create wealth at the expense of declining ecological life support functions in a positive spiralling feedback loop, which creates systemic risks with cascading effects and makes overarching economic, ecological and social systems increasingly susceptible to collapse.

2.4.2

Contextual data, innovative collaboration and transdisciplinarity

Complexity vexes the traditional problem-solving model of separating problems into singularly defined parts and solving for the symptoms. None of the “wicked problems”,[101] as described by IPCC[102] and multiple other scientific bodies,[103] that are currently pressuring policymakers to try new approaches to meet today’s challenges, can be understood with reductionist approaches. In other words, the deliberate simplification of a problem and its causes by removing it from its context renders the understanding and ensuing solution obsolete. The issues with which we are confronted are wrapped in contextual interdependencies that require an entirely different approach in assessment and action.

Most current scientific research tools and methodologies pull “subjects” from their contexts in order to derive detailed, specialized, quantifiable information. A wider practice of science in the future may develop ways to fully use information derived from detail and interdependency. For now, the cultural habit of de-contextualizing information, or reductionism, is the standardized, authorized and empirical norm. To make more appropriate assessments of risks arising out of multi-causal circumstances, observations that can appropriately address this complexity are urgently needed. The decisions on what actions to take, by whom and with what resources, are decisions based upon information of the situation or event. If that information cannot hold the appropriate complexity, the decisions will be founded on inadequate knowledge.

Transdisciplinary research and response

Risk creation and realization in complex systems do not remain in one sector at a time. Yet, current institutional structures mitigate these complex issues through the protocols of attending only to what is within their specific jurisdiction. Health crises remain in the realm of health ministries, while economic issues are under the separate attention of ministries of finance or employment. Likewise, ecological risks overlapping with cultural or political risks are still, in most cases, considered in parallel, but must be researched and understood better in terms of their relational interdependence.

Research bridges and increased communication across societal systems need to be developed. This is particularly true of public service systems. Lack of communication and contextual perspective among systems such as education, health, transportation and communication can increase community-level vulnerability. Connection and increased contact between such sectors will make communities more robust and resilient to long-term risks and sudden onset emergencies. The development of warm data approaches can cultivate the relationship among sectors to strengthen inter-system interaction and collaboration.

Warm data and contextual information

"Warm data" is a specific kind of information about the way parts of a complex system (e.g. members of a family, organisms in the oceans, institutions in a society or departments of an organization) come together to give vitality to that system.

By contrast, other data will describe only the parts, while warm data describes their interplay in context. Warm data illustrates vital relationships among many parts of a system. For example, to understand a family, it is not enough to understand each family member, the relationships among them must also be understood – this is the warm data. This warm data is used to better understand interdependencies and improve responses to issues that are located in relational ways. This includes understanding systemic risks in health, ecology, economic systems, education systems and many more. De-contextualizing gives specific information that can generate mistakes, while warm data promotes coherent understanding of living systems.

Box 2.10. Warm data enquiry

Systemic consequences (and consequences of consequences) are easily disconnected from their networks of causation and the importance of the relationships among contexts can be lost. For example, the caravan of asylum seekers moving north through Central America in the latter part of 2018 was viewed by the media as fleeing either violence or poverty (the "obvious" drivers of such desperate behaviour). In fact, historic drought conditions over multiple years, exacerbated by climate-induced shifts in weather patterns without accompanying shifts in human behaviour, policy or infrastructure development, were an underlying risk driver. This would be the focus of a warm data approach to understanding the complex, interdependent set of factors leading to large-scale migration.

100 (Sample 2017)
101 (Rittel and Webber 1973)
102 (IPCC et al. 2018)
103 (Rockström et al. 2009); (Whitmee et al. 2015); (World Wide Fund for Nature 2018)

Context includes the relational processes that come together to produce a given situation. In fact, most complex situations or systems are “trans-contextual”, that is, there is more than one context in play. Trans-contextual information brings together multiple forms of observation, from multiple perspectives. In recognition that information comes in many forms, a warm data research team would look for on-the-ground “wisdom” of locals, art and culture, personal stories and the voices of many generations. The task of warm data is not only to incorporate details and data points, but the relationship among details as well, at many scales.

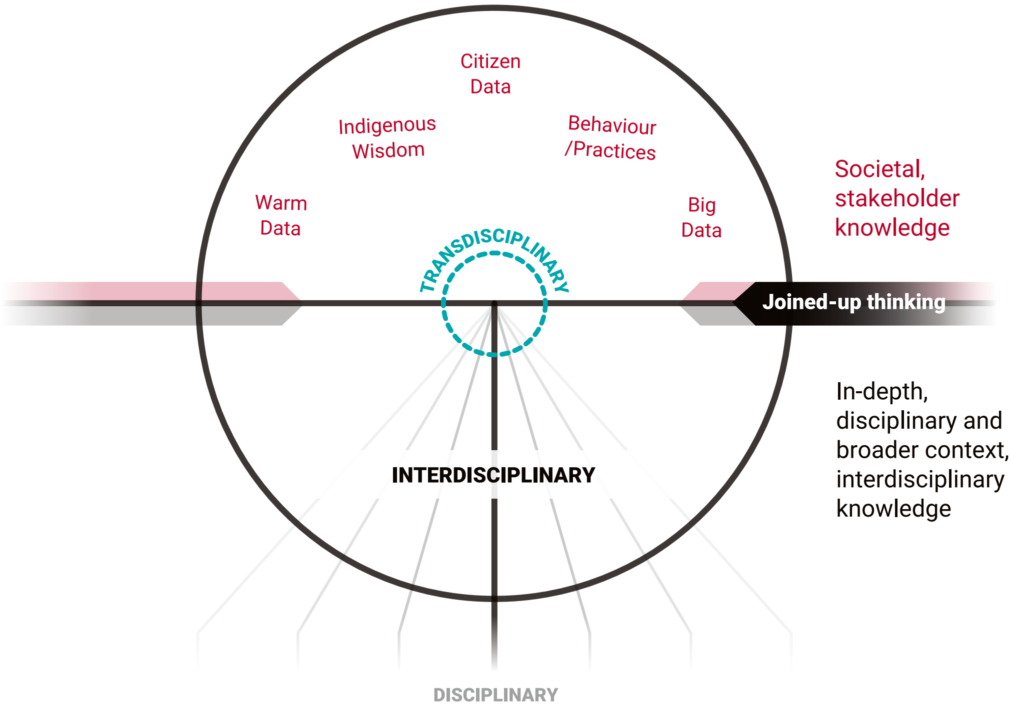
Contextual information in the form of warm data has begun to be used by researchers, governments, and public service professionals. They use it to assess complex situations and identify preventive approaches or responses to complex community (or ecological) crises, necessitating expertise that spans a breadth of contextual conditions.

When applied to specific local contexts and fields, scenarios using warm data can be useful to involve local stakeholders and decision makers in an trans-disciplinary environment – a collaborative laboratory or “collaboratory” – to produce alternative futures that are robust to the relevant uncertainties and complexities.[104] A set of scenario exercises conducted within an agreed set of parameters across scales (from smallholder farmers to globally collaborative institutions) help to identify stakeholder preferences, motivations, scale-specific trends and drivers, and most importantly, add the local contexts needed for the modelling exercises.

Changing patterns of interaction at local levels using trans-contextual knowledge processes

The natural extension of the above process is bridge-building across systems. This is a step towards forming collaborative decision-making bodies at local levels (“collaboratories”). In doing so, there is the possibility to bring together people from different, but interdependent fields, to explore and energize or regenerate local community vitality. As these community groups form and exchange trans-contextual knowledge, new communication patterns begin to form, linking otherwise separated sectors of experience. The place-based solutions that emerge from the collaborative development of contextual warm data lend themselves to self-organizing around actions that are co-created, with local ownership of data, risks and solutions. By providing context, warm data is a metashift that generates connection, communication and action, which is able to address complexity in new ways. Local capacity can be increased significantly by drawing from collective intelligence and mutual learning, .

Figure 2.6. **Transdisciplinary knowledge generation**



(Source: adapted from Brown et al. 2015)

When research is done in this way (i.e. across contexts), the interdependency becomes apparent. For example, food cannot be separated from the economic, nor even political, systems; neither can it be separated from culture nor medicine. Food is also an important catalyst for strong bonds among generations. In this sense the work of supporting food initiatives is not simply to distribute nutrition, but to also knit relationships among the diverse contexts into projects and actions that involve the whole community. The solutions lie in the recognition of collective response. No single response is enough to address a complex problem.

Warm data is the overlap across systems and is produced by teams whose enquiry is practised in crossing contextual frames, sense-making and finding patterns. The lens of contextual enquiry and trans-contextual research is one that not only brings disciplines together but many other forms of knowledge also, including the place-based wisdom of local practitioners, as well as cultural and indigenous sensitivities.

When superficial solutions are implemented to provide answers to problems in complex systems, the problems proliferate. Developing the capability for contextual understanding and decision-making is far more effective, and the benefits are felt across multiple sectors simultaneously. Structures and approaches are needed that can bring forward information that presents the contextual interlinking of the potential systemic risk impacts as they are felt at the individual, microscopic level within larger global, macroscopic contexts.

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104 (Vervoort et al. 2014)

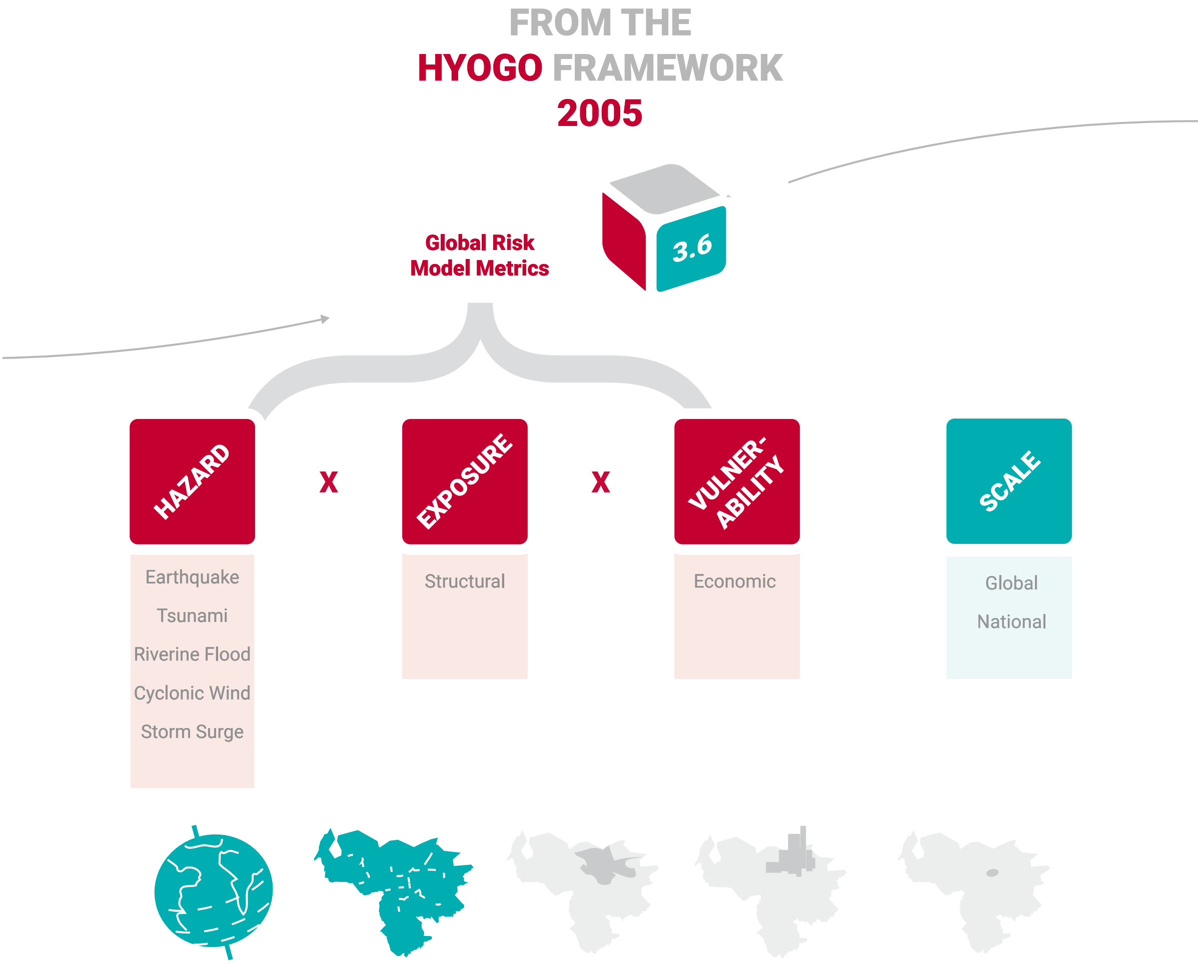
2.5

Shifting the paradigm – introducing the Global Risk Assessment Framework

Paradigms are not corrigible by normal science, paradigm change is a value change.[105]

Our global society has come to realize that the systemic risks we create can induce situations of large-scale instability and even uncontrollability.[106] There is therefore an urgent and growing need to better understand and manage uncertainties and to mobilize people, innovation and finance. The imperative to extend standard risk management frameworks or even to heed the call for a paradigm shift on

Figure 2.7. From global risk assessment to GRAF

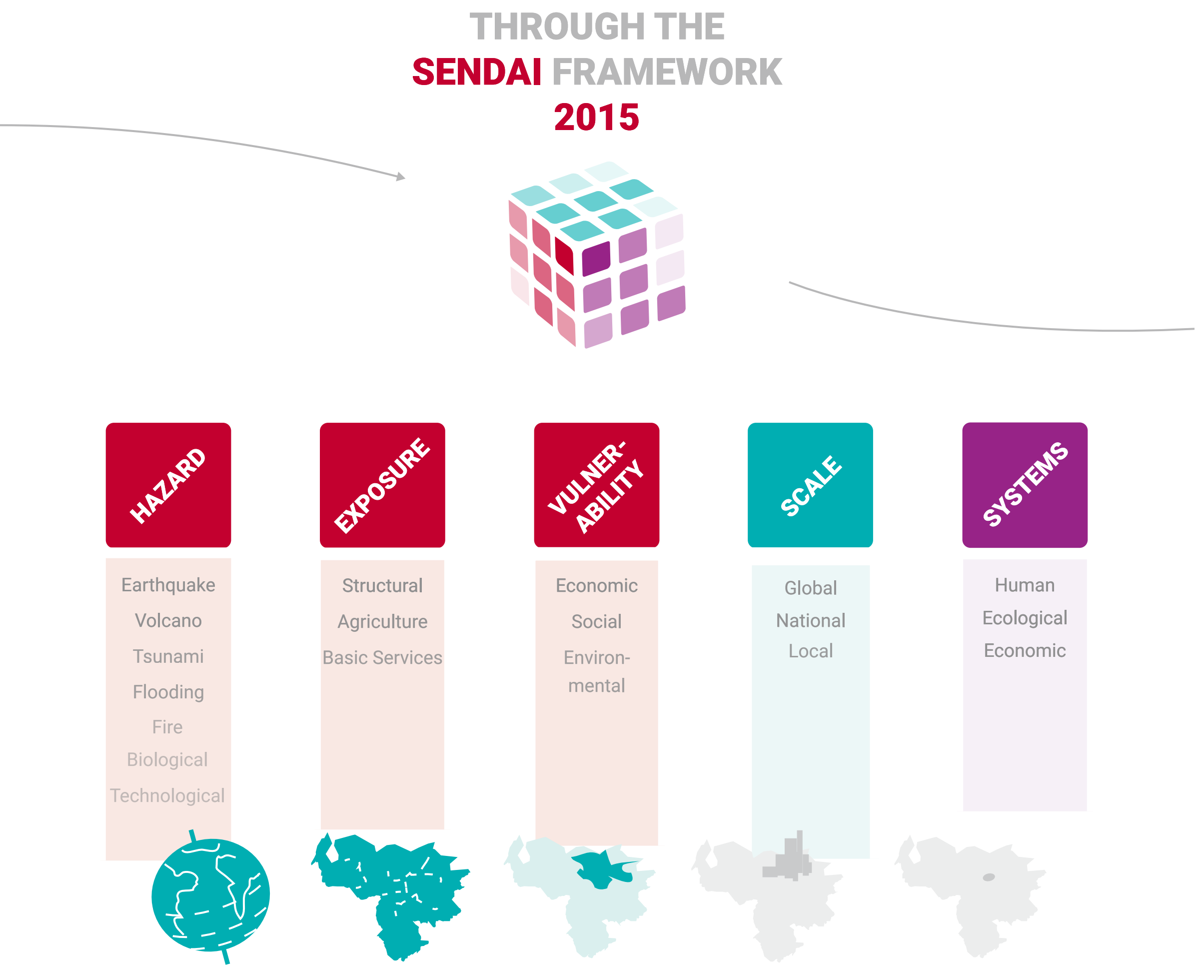


(Source: UNDRR 2019)

how to deal with both controllable and uncontrollable risks – the sort of change that the Sendai Framework exhorts – is undeniable. A transition is needed from one paradigm to another – from managing disasters to managing risk – and from managing "conventional" hazards to engineering an improved understanding of the dynamic interactions with systemic risks. Exploring the facilitation of a "new system of relations" that allows future theories and solutions to emerge that are "wider in scope, more accurate in prediction, and solve more problems".[107]

Major renovations of approaches to risk assessment and analysis are needed to fully realize the challenge and call of the Sendai Framework. As has been noted, methods today are tuned to the largest and most historically obvious and tractable "peaks" of risks for human beings rather than the interdependencies among them.

In recent decades, we have both created and recognized many other types of risks of the greatest consequences for humankind. Understanding



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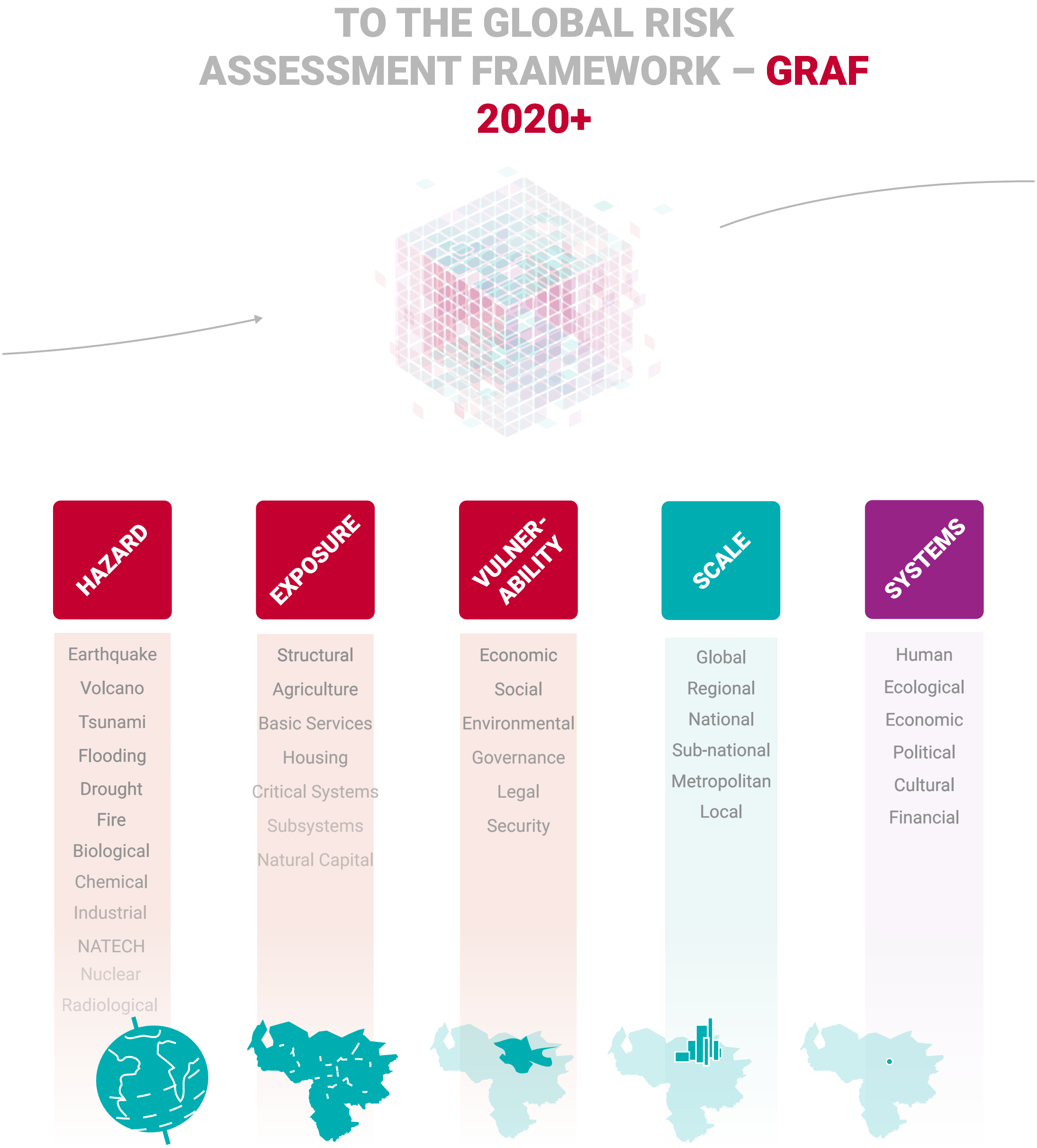
105 (Kuhn 1962)
106 (Helbing 2013b)
107 (Butterfield 2007)

Figure 2.8. GRAF 2020–2030



(Source: UNDRR 2019)

the systemic nature of risks, and the opportunities afforded by new approaches and new concepts of risk, will be the central challenge of the first half of the twenty-first century.

If I had to select one sentence to describe the state of the world, I would say we are in a world in which global challenges are more and more integrated, and the responses are more and more fragmented, and if this is not reversed, it's a recipe for disaster.[108]

In response to this challenge, UNDRR – mandated to support the achievement of the outcome and goals of the Sendai Framework and the 2030 Agenda – was called upon by experts to establish a process to co-design and develop a Global Risk Assessment Framework (GRAF) to inform decision-making and transform behaviour, specifically with respect to systemic risks.

This will explicitly support national and subnational governments, as well as non-State actors including private sector businesses and financial institutions referred to in paragraph 36(c) of the Sendai Framework, to recognize new patterns of vulnerability and risk formation within efforts to achieve the targets of all the 2015 intergovernmental agreements, and assist in measuring progress in reducing risk. GRAF is also intended to be a crucial component of a comprehensive United Nations risk assessment and analysis framework in support of the 2030 Agenda. It will contribute to the vision of the Secretary-General of the United Nations to support decision-making for an Integrated Platform on Prevention as well as within the United Nations Resilience Framework.

GRAF is designed to inform and focus action within and across sectors and geographies by decision makers at local, national, regional and global levels on the outcomes, goals and priorities for action set out in the Sendai Framework and the 2030 Agenda. It addresses multiple issues such as assessing systemic vulnerabilities of agricultural systems, or strengthening the resilience of electricity generation and distribution systems in hurricane-prone locations, or business continuity planning for public and private sector actors for basic service delivery in rapidly growing metropolitan areas.

The goal for GRAF is to improve the understanding and management of current and future risks, at all spatial and temporal scales. It aims to better manage uncertainties and mobilize people, innovation and finance by fostering interdisciplinary systems thinking and enabling identification of anomalies and precursor signals. It seeks to reveal the interlinkages, relationships, correlations and dependencies of multiple risks and actors across systems to build a shared understanding and enable decision makers to act.The design and development of GRAF is led by the GRAF Expert Group, GRAF Working Groups and UNDRR. Driven by a user-centric design process, GRAF will work with all stakeholders to create a framework and community of practice for the understanding and sharing of risk contexts, data, information, models, metrics, risk communication modalities and decision support.

> *Paradigm change has been described as "handling the same bundle of data as before, but placing them in a new system of relations with one another by giving them a different framework"*.[109]

Through approaches such as ensemble modelling and intercomparison, GRAF will improve understanding of the multidimensional nature and dynamic interactions of risks, so as to prevent or adapt discontinuities in critical systems (including human health, ecosystem functioning and economic development) and create the potential to transform behaviours. GRAF seeks to enable self-organization and learning focused on local processing of information by relevant stakeholders on the impacts and consequences of decisions. Recognizing that major reductions in risk will be achieved through understanding and addressing patterns of vulnerability and exposure, and acknowledging that data on vulnerability (social and environmental) are severely underdeveloped, experts recommended this as a priority area for GRAF.

The GRAF Theory of Change sets out early thinking about the development and implementation of key elements of GRAF. It includes causal pathways (people, science and systems), which are intended to clearly and explicitly define questions to be addressed and elements to be tested and established. The co-design and development of GRAF will continue in three broad phases of activity: Phase 1 – design and set up; Phase 2 – building the framework; and Phase 3 – scaling implementation.

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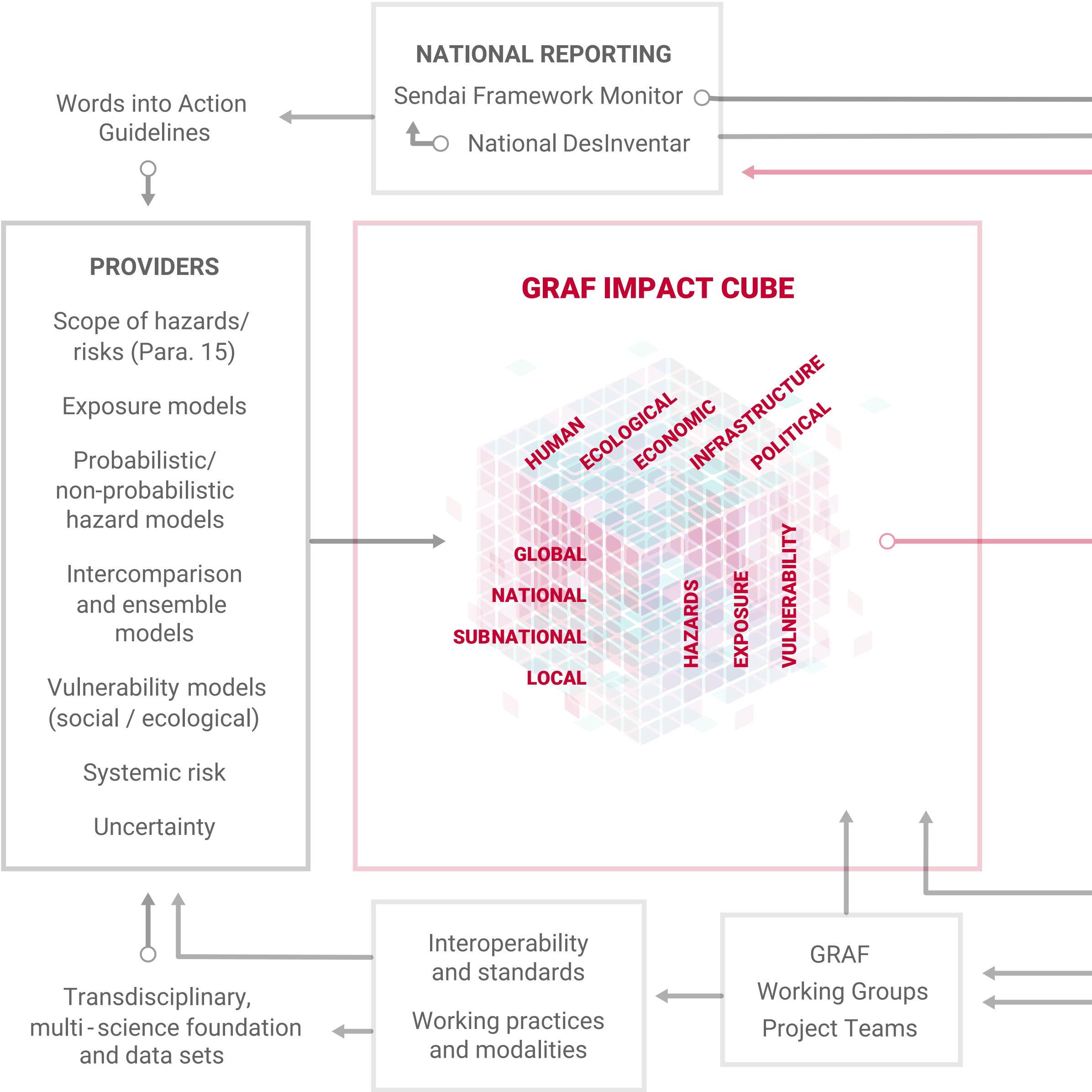
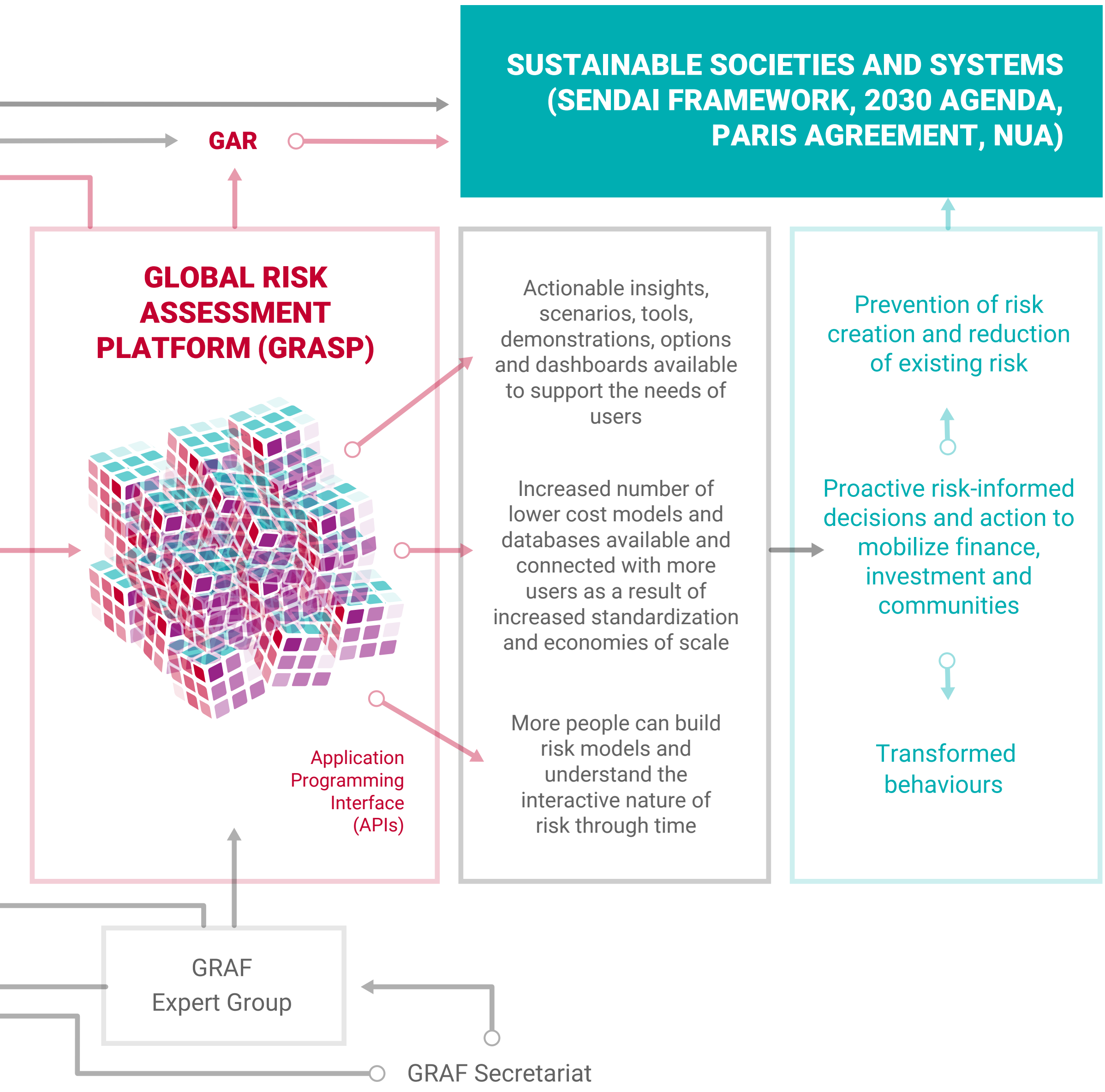
108 (António Gutteres, United Nations Secretary-General, January 2019)
109 (Butterfield 2007)

Figure 2.9. **Schematic representation of GRAF**



(Source: UNDRR 2019)

By providing insights, tools and practical demonstrations to decision makers at relevant scales through the development of multi-user, open and inclusive, collaborative and shared methodologies for stakeholders on a timely basis, GRAF can stimulate interdisciplinary systems behaviours that will support transformative action. This will enable warm data research, establishment of collaboratories and the accelerated development of collective intelligence about systemic risk to



create a culture of risk-informed decision-making, to transform behaviours and to ultimately increase the resilience of societies and systems.

Chapter 2
Conclusions and recommendations

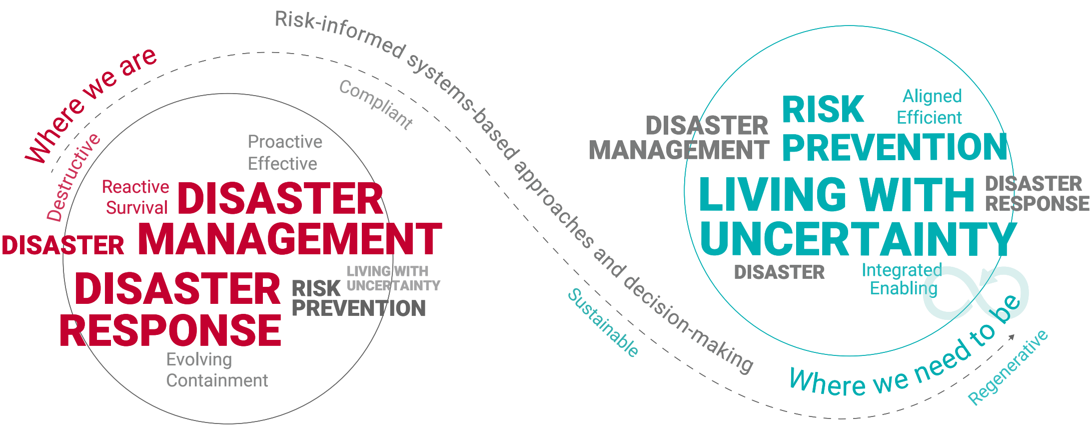
The solutions lie in the recognition of collective response. No single response is enough to address a complex problem.[110]

Conclusions

With the certainty of near-term non-linear changes, the critical assumption of the relationship between past and future risk must be revisited.

The regenerative potential of the social and natural systems envisaged in the aligned intergovernmental agendas will be better understood, and progress will be accelerated, by incorporating systemic risk and systemic opportunity into the design of policies and investments across all scales. Similarity of the characteristics of systemic risks in different domains suggests that as attempts are made to understand the effects of endogenous triggers and critical transitions, there will be more patterns apparent in different domains, which will allow the development of a consistent understanding of the fundamental characteristics of systemic risks.

Figure 2.10. "Innovation curve" – from destructive to regenerative approaches



(Source: UNDRR 2019)

Systemic risks might be easy to mitigate early on. However, failure or even intentional ignorance to capture the role of underlying drivers of systemic risk will allow small risks to grow into major problems, increasing the opportunity costs of failed interventions and missed opportunities. Developing and implementing multidisciplinary approaches to identify and act on precursor signals and systems anomalies are critical to minimizing or avoiding discontinuities in complex systems.

Most prevailing risk management tools assume underlying systems are complicated, rather than complex. Understanding sensitivities to change and system reverberations is far more important and challenging in the context of complex systems. Simulations of such systems show that small changes can produce initial ripples, which can be amplified by non-linear effects and associated path dependencies, causing changes that lead to significant and potentially irreversible consequences.

To allow humankind to embark on a development trajectory that is at least manageable, and at best sustainable and regenerative consistent with the 2030 Agenda, a fundamental rethink and redesign of how to deal with systemic risk is essential. Improved understanding of system components, including precursor signals and anomalies, systems reverberations, feedback loops and sensitivities to change, will be imperative.

The global urban–industrial network is more vulnerable to multiple simultaneous hazards than to singular impacts in wealthy, large urban areas. Therefore, as climate impacts become more prevalent, impacts capable of interrupting urban economic flows and creating social instability may become more severe.

Systemic risk governance is confounded by difficulties in identifying causal agents and assigning liability. While neither the governance of the financial system nor the climate system can claim full success, both have raised awareness of the necessity and spatio-temporal complexity of governance regimes to address systemic risks at the global scale.

While needed for processing big data about the functioning of complex systems, machine learning and artificial intelligence are limited in their capability to help people solve more complex coordination and governance problems that require trust among people. Unlike machines, which need to operate with probabilities, humans – within a social network of trust – can make decisions under radical uncertainty by attaching values to decisions.

Complexity vexes the traditional problem-solving model of separating problems into singularly defined parts and solving for the symptoms. Such issues are wrapped in contextual interdependencies that require an entirely different approach in assessment and action. Warm data is the overlap across systems. The lens of contextual enquiry and transcontextual research is one that brings together disciplines and many other forms of knowledge, including the place-based wisdom of local practitioners and cultural and indigenous sensitivities.

Realizing the systemic nature of risks, and the opportunities afforded by new approaches and new concepts of risk will be the central challenge of the first half of the twenty-first century. GRAF seeks to improve understanding of the multidimensional nature and dynamic interactions of risks, so as to prevent or adapt to discontinuities in critical systems and enable local processing of information by relevant stakeholders on the impacts and consequences of decisions. GRAF can stimulate interdisciplinary systems behaviours that will support transformative action, enabling accelerated development of collective intelligence about systemic risk to create a culture of risk-informed decision-making, transform behaviours and ultimately increase resilience of societies and systems. It is intended to contribute to a comprehensive United Nations risk assessment and analysis framework in support of the 2030 Agenda and the Sendai Framework.

110 (Bateson 2018)

Recommendations

- **Accelerated action and ambition** is needed to transition from one paradigm to another – from managing disasters to managing risk – and from managing "conventional" hazards to engineering an improved understanding of the dynamic interactions with systemic risks.
- Humans can (or should) decide on **changing deeply embedded values** that define higher level rules of operation and interaction. If not, societies may continue to create wealth at the expense of declining ecological life support functions in a positive spiralling feedback loop that creates systemic risks with cascading effects and makes overarching economic, ecological and social systems increasingly susceptible to collapse.
- To fully realize the challenge and call of the Sendai Framework, **major renovations of approaches to risk assessment and analysis** are needed. Methods today are tuned to the largest and most historically obvious and tractable risks for human beings rather than on the full topography of risks.
- **Scenario building and stochastic simulation** need to be included in risk modelling to facilitate thinking and decision-making in complex systems.
- A new paradigm for **understanding and living with uncertainty and complexity** is required – one that activates the power of human social and contextual intelligence, and where possible, leverages it through appropriately designed artificial intelligence.
- Developing the **capability for contextual understanding and decision-making** can prove a more effective way of dealing with uncertainty and complexity than the present reliance on extrinsic frames of reference and categorical technical expertise, siloed into disciplines.
- Greater focus is required on **place-based solutions** that emerge from the **collaborative development** of contextual warm data based on self-organizing around actions that are co-created, with local ownership of data, risks and solutions. Local capacity can be significantly increased by drawing from collective intelligence and mutual learning.
- A better understanding of the **interactions and interdependencies between urban and rural areas** is essential to reduce or prevent the creation of risk. This requires a functioning urban/rural (city region) data metabolism to process information at appropriate scales to understand the systems implications.
- Private sector financial institutions need to **integrate DRM** into their business models and practices through disaster risk-informed investments.
- **Structures and approaches** to bringing forward information are needed that present the contextual interlinking of the potential systemic risk impacts as they are felt at the individual, microscopic level within larger global, macroscopic contexts.