Governance of Systemic Risks for Disaster Prevention and Mitigation

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Introduction

Against the backdrop of natural hazards and disaster risks, the Sendai Framework articulates the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics as well as the strengthening of disaster risk governance (UNISDR, 2015). The perspective of systemic risks contributes to these desiderata by providing a comprehensive view of disaster risks. Furthermore, the proposed concept of inclusive governance of systemic risks can improve disaster risk governance. By definition, natural hazards are natural phenomena that have negative effects on humans or the environment (cf. Burton, et al, 1993). Natural hazards encompass geophysical and biological activities. Many disasters are temporally and causally related. This is not only the case regarding geophysical hazards, i.e. earthquakes as the precursors of tsunamis, but also regarding biological hazards, i.e. climate change as contributing factor to the spread of diseases. Importantly, disasters can be provoked or affected by anthropogenic processes. While hazards are natural, disasters are not. "Social processes generate unequal exposure to risk by making some people more prone to disaster than others" (Hilhorst/Bankoff, 2004, p.2).

The interaction between natural and human-induced disaster is a more recent phenomenon that is supported by the increased settlement in disaster-prone areas, the vulnerability of technological and urban infrastructure in relation to natural forces, and the impact of natural hazard on such infrastructure and other facilities with a hazard potential, e.g. gas terminals, pipelines, and chemical factories. Natural hazards often trigger chain reactions that lead to a long sequence of technical and societal damages with disastrous outcomes. Furthermore, many so-called natural hazards are influenced or even sometimes caused (climate change) by human interventions. Thus, the interplay between natural and non-natural risks has become a prominent example of complex risk and disaster interactions.

Such complex interactions are the topic of a new field in risk analysis that deals with systemic risks. The following sections will introduce the term and the concept of systemic risks, apply this concept to natural hazards, more precisely to the combination of natural and human-induced hazards, and develop a risk governance concept for such systemic risks based on the IRGC framework. Finally, the article ends with some policy recommendations and conclusions.

The Concept of Systemic Risks

In the understanding of this article, “risk” is a situation or event where something of human value is at stake and where the outcome is uncertain (Rosa, 1998; Rosa, 2008; cf. Society for Risk Analysis Glossary, 2018). The concept of “systemic risk” bridges the gap between risk research and complexity science. It denotes properties of risk that gain momentum against the backdrop of a systems perspective. The phrase “systemic risk” is used in various scientific disciplines. Its origins stem from economics. From an economic perspective, systemic risk is defined as “the risk that (i) an economic shock triggers through panic or otherwise either the failure of a chain of markets or institutions or a chain of significant losses to financial institutions, (ii) resulting in increases in the cost of capital or decreases in its availability, often evidences by substantial financial-market volatility.” (Schwarcz, 2008, p.204) The concept assumes a systems perspective, postulating connections between elements of the system. Failure in one sub-unit or cluster of the system will lead to cascading events in other system units. These cascading events may lead to major disturbance or even complete failure of the whole system. Cascading events are caused by “trigger events”. Depending on the specific system, these triggers assume different forms, e.g. an economic shock, that will lead to systemic failure (Schwarcz, 2008, p.198). Systemic risks therefore occur, when a hazard will not only lead to negative effects in parts of the system, but also to failure of the system as a whole (Kaufmann and Scott, 2003, p.372). On the basis of these assumptions, the OECD Report Emerging Systemic Risks in the 21st Century, released in 2003, presents an interdisciplinary and coherent concept of systemic risks. The report assumes that a risk becomes systemic when a society’s essential systems, e.g. telecommunications, infrastructures, health care, are potentially threatened (OECD, 2003, p.30). This perspective focuses on the perpetuation of society and implies that contextual factors originating in the domains of demography, ecology, technology and socio-economic structures have a significant influence on systemic risks. Furthermore, these contributing factors are often related with each other, leading to interdependencies and increased complexity. These interdependencies impede comprehensive risk analysis and, consequentially, pose a major stumbling block for risk management.

Especially systemic risks are hardly predictable due to their complexity and heterogeneity. Yet some generic properties of systemic risks can be identified that set them apart from other kinds of risks (cf. Schweizer and Renn, 2019; Lucas et al., 2018; Renn et al., 2017; Renn, 2016). Systemic risks can be characterised by five major properties.

- First, systemic risks are characterized by high complexity. On the one hand, complexity stems from influencing factors that determine the emergence of systemic risks and their trajectories of development. On the other hand, systemic risks are tightly coupled with each other and traditional risks. These interdependencies influence all aspects of human life. Complexity obfuscates the workings of systemic risks and inhibits extrapolation from the past to the future. Established methods of science cannot identify the probability of occurrence or the extent of damage in any accurate fashion. Instead, science utilises models of scenario building to sketch out the stochastic nature of systemic risks.
- Second, systemic risks are transboundary and global in nature. Although systemic risks originate in one subsystem of society or the environment, the ripple effects of these risks affect all social subsystems, such as the economy, politics, and civil society. They transgress standard procedures of "divide and conquer" approaches towards analysis. Furthermore, their modes of action surpass national boundaries, thus calling for multi-level governance (cf. Hooghe, 1996) and international cooperation.
- Third, systemic risks are characterised by stochastic relationships between trigger and effects. Systemic risks are highly interconnected and complex, stochastic and non-linear in their cause-effect relationships. Deterministic relationships between cause and effect are non-existent. This poses major challenges to risk governance, especially risk communication, because identical causes can lead to diverging results.
- Fourth, systemic developments are non-linear and include tipping points. Science struggles to identify these tipping points in advance. A complex system can remain stable for an indefinite length of time. Once it reaches a tipping point, the system drastically changes its conditions of existence in a very short period of time. These changes in condition may include a complete collapse of the system. Systems often, but not always, depart from one steady-state condition to the next after going through a phase of collapse and re-organisation.
- Fifth, systemic risks are often underestimated in public policy arenas and public perception due to uncertainties of point of occurrence and extent of damage. Many systemic risks are public knowledge and perceived as highly relevant by the public. Yet very little action is taken to get to the root of the problem.

These generic properties of systemic risks shed a light on several aspects of natural hazards and disasters. When analysed in isolation, most natural hazards do not meet the characteristics of systemic risks. The damage is most often proportional to the energy or material released, the impacts are local, the relationships are deterministic and people are well aware of these hazards because they have experienced them in the past. However, over time most natural hazards have to be seen in the context of vulnerabilities of infrastructure, industrial activities, structural developments and behavioural patterns that amplify or attenuate the impact of each natural event. In particular, a natural event can trigger chains of subsequent events that may amplify and also multiply damages. The Fukushima Daiichi nuclear disaster, for instance, was triggered by an earthquake that led to a tsunami which, once it hit shore, destroyed highly critical infrastructure. The subsequent nuclear disaster was the result of the complex interactions between natural hazards and man-made infrastructure. Focusing on these combined effects, the characteristics of systemic risks are all met. First, the sequences of natural and human-induced triggers are characterised by high complexity. This also applies to contributing factors, e.g. wildfires may result from lightning strikes or human activity, and to interactions between natural hazards, e.g. an earthquake triggering a tsunami. Second, natural hazards induced or amplified by human actions tend to be cross-boundary and may be global in nature, as in the case of the release of carbon in the atmosphere. Third, natural hazards are more and more interlinked with civilizational activities and interact with human infrastructures. These relationships tend to be complex, non-linear and stochastic in nature. A multi-hazard approach seeks to identify the interactions and interrelationships between natural and human-induced hazards. Interdependencies between hazards vary in likelihood and spatial importance (Gill and Malamud, 2014). Fourth, the cascading effects throughout the chain of vulnerabilities demonstrate an abrupt change in conditions and tipping points that cause secondary effects, such as explosions. Fifth, disasters caused by natural hazards often receive wide media attention, especially when human life is put at risk. However, secondary impacts are very often left out of the picture. Most natural hazard management plans address only the direct impacts of natural hazards. Consequentially, there is a lack of attention to these interactions resulting in inadequate design and re-design of infrastructure and settlements. In a similar vein, climate change is a well-known phenomenon that receives public attention but is lacking a coherent and above all effective governance approach.

Inclusive Risk Governance of Natural Hazards: A Systemic Perspective

Governance of natural hazards needs to pay close attention to the interactions between human-induced and natural hazards. The five characteristics of systemic risks do not only challenge scientific investigation, but also, and foremost, society as a whole. Consequentially, the stakes for governance of natural hazards as triggers for systemic risks are high and inclusive strategies of governance are called for. Inclusive risk governance puts the paradigm of inclusive governance into practice for decision-making processes relating to risks. Inclusive risk governance incorporates expert, stakeholder and public involvement as a core feature. Inclusive risk governance goes beyond traditional risk analysis to include the involvement and participation of various stakeholders as well as considerations of the broader legal, political, economic, and social contexts in which a risk is evaluated and managed (Klinke and Renn, 2011). Inclusive risk governance is based on the assumption that all stakeholders have something to contribute to the process of risk governance and that mutual communication and exchange of ideas, assessments and evaluations improve the final decisions rather than impeding the decision-making process or compromising the quality of scientific input and the legitimacy of legal requirements (Renn and Schweizer, 2009, p.175). It is assumed that evidence-based risk analysis provides a nearly complete picture of all the scientific facts needed for risk characterisation and risk management. Inclusion of stakeholders and civil society is expected to make available a normative yardstick for evaluating risk characterisations and management options. In simple terms, the task of inclusive risk governance is to reconcile facts with values.

In the 2005 White Paper on Risk Governance, the International Risk Governance Council (IRGC) has put forward an innovative integrative model of inclusive risk governance. IRGC’s White Paper on Risk Governance aims at the “development of an integrated, holistic and structured approach, a framework, by which we can investigate risk issues and the governance processes and structures pertaining to them.” (IRGC, 2005, p.5) It comprises analytic research on governance structures as well as normative advice to improve governance practice. Consequentially, IRGC’s Risk Governance Framework distinguishes between understanding a risk (for which risk appraisal is the essential procedure) and deciding what to do about a risk (where risk management is the key activity) (IRGC, 2017, p.10). The Risk Governance Framework serves two purposes. First, it conceptualises good risk governance of policy issues. Second, it offers a framework for the coherent analysis of risk governance processes. The framework consists of four consecutive steps: Pre-Assessment, Appraisal, Characterisation and Evaluation, and Management. Communication and participation are cross-cutting issues that are an integral part of all these phases. Continuous feedback between the phases is assured due to the cyclical nature of the Risk Governance Framework.

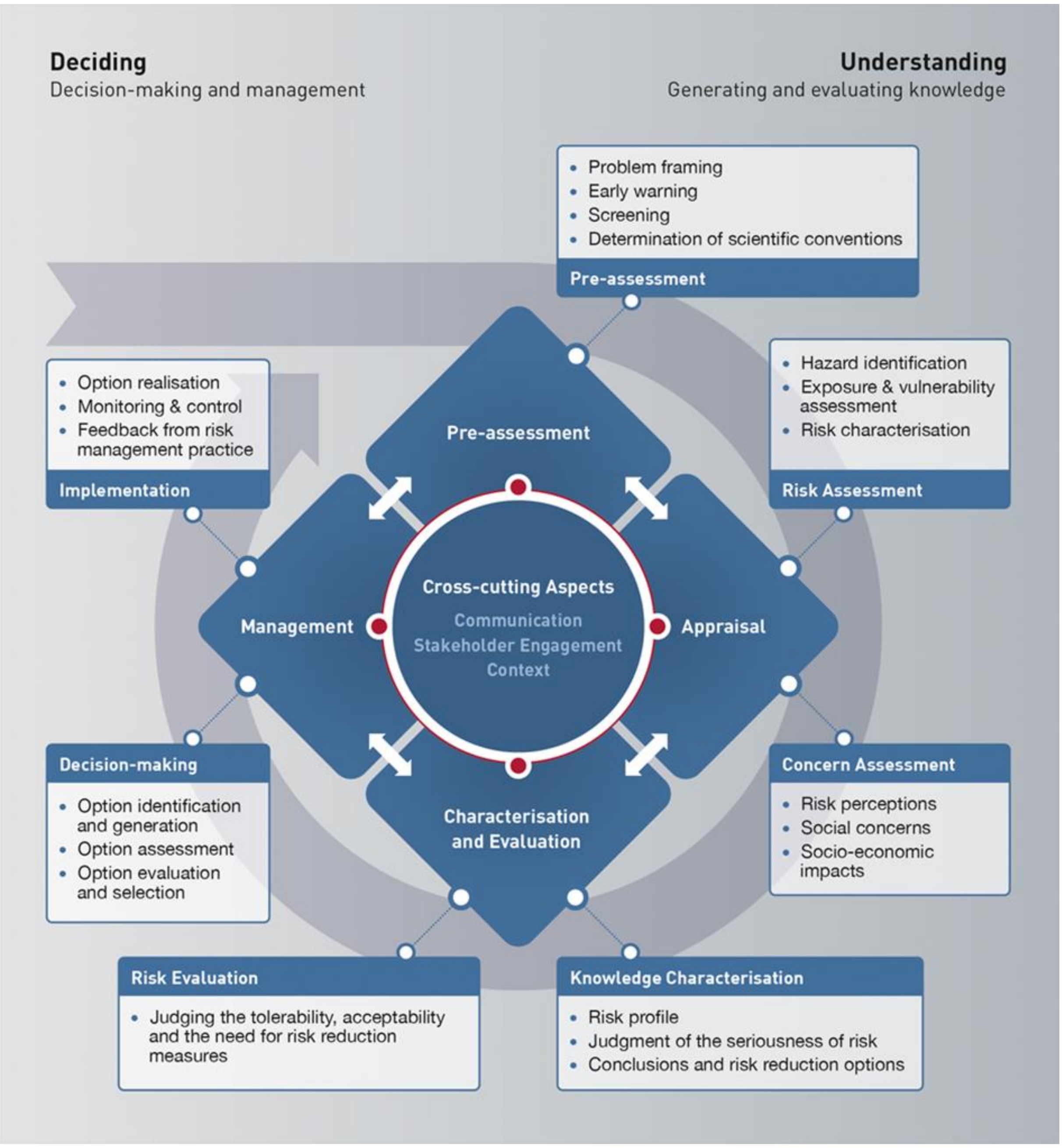

Figure 1: Revised IRGC Risk Governance Framework (IRGC, 2017, p.10)

While IRGC's White Paper offers valuable insights for governance of natural hazards in general (cf. Florin and Xu, 2014), this article focuses on the systemic aspects of natural hazards and the commonalities between natural hazards and systemic risks.

Pre-Assessment

The first part of pre-assessment consists of framing the risk issue. Problem framing analyses the reasons why a phenomenon is labelled as a risk and which concepts and images of the risks and benefits are introduced into the debate by the various actors involved. Usually major societal actors, such as governments, the scientific community, the industry, and civil society, frame risks differently. Pre-assessment therefore aims at capturing "the various perspectives on the risk, its associated opportunities, and potential strategies for addressing it." (IRGC, 2017, p.11). Pre-assessment of natural hazards needs to take into account the various interrelationships between these hazards and other kinds of risks. Problem framing in this context already requires an understanding of the intricate interdependencies that in combination constitute the systemic character of these risks. In short, the phase of pre-assessment conceptualises the dimensions and the context in which the respective risk is embedded considering various framings. Most importantly, in the case of natural hazards such as a tsunami, pre-assessment focuses on the establishment of mechanisms for detecting early-warning signals and for determining the scope as well as extension of the destructive forces, and scientific conventions for interpreting their impact.

Appraisal: Risk Assessment and Concern Assessment

Risk Appraisal includes two major components, i.e. risk assessment and concern assessment. Risk assessment establishes the scientific link between risk agent(s) and consequence(s). The final output of risk assessment is the estimation of a risk with regard to probability distributions of modelled consequences. In order to achieve this goal, three core components have to be assessed: the identification and estimation of hazard, the appraisal of exposure and vulnerability, and the estimation of risk.

Hazard identification and estimation cover the recognition of potential adverse effects and an assessment of the strength of cause-effect relationships. Sound scientific analysis is essential here. Likewise, exposure and vulnerability assessment rely on scientific examination. Scenario technique is often used for exposure and vulnerability assessment as it models the diffusion, exposure, and effects on risk targets. Risk estimation is then conducted on the basis of previous risk assessment results. Hence, risk estimation can take the form of quantitative or qualitative assessment. Concern assessment contributes an assessment of risk perceptions, social concerns and socio-political impacts to risk appraisal. Concern assessment rests in the same way as risk assessment on sound science, although here socio-political and other often called "soft" factors are analysed by employing "hard" methods of social research such as surveys, focus group research or behavioural simulation. Concern assessment equally poses challenges to risk governance. Concern assessment is not so much challenged by not yet available data but by the heterogeneity of concerns associated with natural hazards.

In conclusion, the main governance gap with regard to natural hazards is not the lack of scientific data, but their complexity and to some extent lack of agreement on these data and the uncertainty about their accuracy. Also, there is considerable variability in the extent to which secondary impacts and other interdependencies are included in current assessment approaches. Appraisal of natural hazards especially needs to address these secondary impacts and interdependencies. The importance of an integrated risk appraisal in the form of risk assessment and concern assessment becomes obvious in the case of the Fukushima Daiichi nuclear disaster. The nuclear disaster was triggered by an earthquake followed by a tsunami, a natural hazard quite common to Japan and the rest of the Pacific Rim. The transboundary effects of the natural hazard, however, were due to the complex interactions between natural hazards, man-made infrastructure and human error. Comprehensive risk appraisal of the Fukushima Daiichi Nuclear Power Plant, as proposed in this article, would have considered the vulnerability of the power plant to the disastrous potential of infrequent but not impossible earthquakes of great magnitude. Furthermore, a stress test beyond the design basis accidents could have revealed that it was not appropriate to locate the emergency electricity generator close to the levies that were constructed to protect the plant from sea water rise.

Characterisation and Evaluation

This phase of the governance process consists of knowledge characterization and risk evaluation. In this phase, the decision has to be made whether a risk is acceptable, tolerable, or intolerable. This judgment is made on the basis of the characterisation and evaluation of risk. Acceptable activities offer benefits with negligible risks. Risk reduction is therefore unnecessary. Tolerable activities are pursued for their benefits yet require additional risk reduction efforts. Intolerable activities are prohibited or substituted. This judgement on the tolerability, acceptability and the need for risk reduction measures are based on knowledge characterisation. Knowledge characterisation is an essential element of the governance process. During the whole governance process, and especially during the appraisal phase, much knowledge on the risk issue in question is accumulated. The knowledge characterisation phase entails a close examination of all acquired knowledge. Furthermore, this phase identifies the main characteristics and challenges for governance of specific natural hazard with regard to complexity, uncertainty, and ambiguity. In this context, complexity refers to the difficulties policy makers or risk managers encounter when identifying and quantifying the causal links between a multitude of potential causes and specific adverse effects. Uncertainty prevails if the strength of confidence that the risk assessor can ascribe to the proposed cause and effect chain under consideration is challenged. Put another way, uncertainty increases when complexity cannot be resolved by scientific methods. Ambiguity denotes the variability of (legitimate) interpretations and normative implications based on identical observations or data assessments. In the case of systemic risks, the phase of knowledge characterisation is an especially challenging task due to the systemic interrelations and interdependencies that distinguish these risks from other, epistemologically less puzzling risks.

Uncertainty can take many forms. One fundamental manifestation of uncertainty which challenges knowledge characterisation is time. The temporal component of risk is crucial regrading most natural hazards. For example, the beneficial aspects of frequent, yet small-scale wildfires, such as increased biodiversity, may surpass and counterbalance their negative impacts, e.g. loss of profits in forestry. If wildfires do not occur over a long time period of time, a new fire is likely to evolve into a catastrophe for the ecosystem as well as for populated areas. Thus, many small wildfires prevent a catastrophic fire in the future. Similar time dependent management issues are common in flood management or draught prevention. Management of natural hazards in the appropriate time frame is therefore an important aspect of risk evaluation. Thinking about time dependencies leads to resilience rather than risk management. Investing in resilience may increase smaller risks or include economic inefficiencies but it is an effective safe-guarding mechanism against low-probability, high-consequence events (Linkov et al., 2014).

Risk evaluation as the second component of this phase applies societal values and norms to the judgment on tolerability and acceptability. Risk evaluation also determines the need for risk reduction measures. Risk evaluation therefore relies as much on the input of scientific evidence as input of societal values. In the case of “simple” risks, such as risks of car or plane accidents, the benefits of taking regulatory action may be uncontroversial, such as compulsory seat belts in cars and flight recorders in planes. Natural hazards, however, often consist of complex, uncertain or ambiguous (in the case of climate change) risks - or a combination thereof - that require a different approach to risk assessment, evaluation and management, with respect to the perceptions and values associated with those risks (IRGC, 2017, p.17). Consequentially, the systemic aspects of natural hazards call for a more comprehensive involvement of stakeholders. Especially in the case of temporal uncertainty, stakeholder involvement can help point the way where scientific investigation only focuses on short-term gains rather than long-term resilience. Traditional knowledge is often based on century old experiences which cannot be assessed scientifically because data are incoherent and not available for long time periods. Long-term thinking opens new avenues to include and harvest different kinds of knowledge, such as indigenous and local knowledge. Stakeholder involvement thus creates possibilities to investigate the perceptions and values associated with temporal uncertainty.

Management

All the information gathered in previous phases is combined in the management sphere. Especially the results of characterisation and evaluation are the basis for designing appropriate risk management strategies. Risk management aims at the design and implementation of actions and remedies required to avoid, retain, reduce or transfer the risk. This phase consists of decision making and implementation. Decision making includes option identification and generation, option assessment, as well as option evaluation and selection. Option identification and generation discovers potential management options for risk reduction. Option assessment investigates the future impact of each management option on economic, technical, social, political, and cultural dimensions. Option evaluation then assesses these options by means of multi-criteria analysis. Based on the results of option evaluation, the best management option is selected. The second major part of the risk management phase deals with the implementation of the previously selected risk management option. Therefore, risk management implementation deals with option realisation, monitoring and control, as well as feedback from real-world risk management practice.

Management of natural hazards needs to heed the challenges posed by complexity, uncertainty, and ambiguity. First, complexity occurs when there is dissent within the expert community about causal relationships. The complexity of natural hazards mainly stems from the various interrelations between natural hazards and their various primary, secondary, and tertiary effects. Especially the secondary and tertiary effects are difficult to conceptualise due to cascading events that have far-reaching negative effects in seemingly unrelated risk domains and arenas. Therefore, governance efforts for natural hazards should include an epistemological discourse amongst experts with the aim to provide clarity with regard to causal relationships. Epistemological discourses with experts and agency staff aim at settling cognitive conflicts. Second, in those cases where the main issue is uncertainty, an epistemological discourse – even with input provided by the best experts in the field – will only go half the way. Uncertainty therefore prevails if probabilistic methods are not applicable and established scientific methodology cannot yield answers with any certainty. With regard to natural hazards, a resilience-focused management strategy will help to deal with uncertainty. Such a strategy draws attention to the level of resilience of the risk-absorbing system. Resilience targets the particular features of a system which will enable absorption of adverse effects and speedy recovery (Linkov, et al., 2014; Renn, 2008, p.39). Consequentially, this strategy relies on the comprehensive assessment of the vulnerability regarding built environments of hazards. The strategy also pays close attention to interrelations that need to be considered. Third, ambiguity may take form as interpretative or normative ambiguity. Interpretative ambiguity refers to legitimately varied interpretation of data, research results, and risk management options. Normative ambiguity occurs when diverging opinions are due to diverging normative assumptions such as ethical and moral principles (Renn et al., 2011). In both cases, inclusive risk governance is responsible for finding consensus, or at least consent on dissent. This task can be achieved by means of participative discourse which facilitates compromise and trade-offs regarding conflicting societal goals. Ambiguous risk phenomena call for a participatory discourse including civil society in order to reconcile normative conflicts. Discourse-based strategies look for an argumentative reconciliation of ambiguous risk issues by building tolerance for diverging positions and enhancing trust in decision-making institutions. Ambiguity is a major issue with regard to secondary and tertiary effects of natural hazards. The mechanisms of social construction that frame the effects of natural hazards as disasters may be highly ambiguous. Discourse-based strategies that encompass stakeholder engagement and public participation map out ambiguities that would otherwise impede governance efforts. Participatory discourse especially supports management by finding acceptable and fair solutions for dealing with uncertainties and ambiguities. For instance when considering earthquakes and their impact on critical infrastructure, participatory discourse reveals the limits of the operator's willingness-to-pay for risk reduction as well as the public's limits of acceptance. Thus, discourses involving stakeholders and the public explore the potential for trade-offs and their limits.

Communication

Risk communication is a necessary and desirable activity, which is partly mandated by governmental laws and regulations, and partly required by stakeholder demand and public pressure. In the light of new activism by consumer and environmental groups, private companies as well as governmental agencies feel obliged to provide more information and guidelines for policy makers, interested parties, the media and the public at large. This approach is embedded in the legal and political paradigm that enforces openness and the 'right to know' policy framework.

Risk communication is a vital element of the whole risk-handling chain, from framing of the risk issue to monitoring of risk management impacts. The precise form of communication needs to reflect the nature of potential disasters triggered by natural hazards. In addition, risk communication needs to address the societal context and whether the issue raises, or might raise, societal concern. Communication is a means of ensuring that:

- those who are central to risk framing, risk appraisal or risk management understand what is happening, how they are to be involved, and, where appropriate, what their responsibilities are (internal risk communication);
- and others outside the immediate risk appraisal or risk management process are informed and engaged (external risk communication).

The first task of risk communication has often been underestimated in the literature. A close communication link between risk/concern assessors and risk managers, particularly in the phases of pre-assessment and tolerability/acceptability judgment, is crucial for improving overall governance. Similarly, cooperation among experts with backgrounds in natural science, engineering, and social science, in combination with teamwork of legal and technical staff, and continuous communication between policy-makers and scientists are all important prerequisites for enhancing risk management performance. This is particularly important for the initial screening phase where the allocation of risks is performed.

The second task, communicating risk appropriately to the outside world, is also a challenging endeavour. Many representatives of stakeholder groups and, particularly, members of the affected and non-affected public are often unfamiliar with the approaches used to assess and manage risks and/or pursue a specific agenda whilst trying to promote their own viewpoints. They face difficulties when asked to differentiate between the potentially adverse effects of hazards and the risk estimates that depend upon human exposure and the vulnerability of the absorbing system.

Effective communication, or its non-existence, has a major influence on how people are prepared to cope with disaster risks. In this regard, limited knowledge of and involvement in the risk management process can lead to the misallocation of resources and misguidance of behavioural and political responses to perceived threats. Communication in this sense follows a two-way approach. The example of natural hazards and their impacts on critical infrastructure shows that beyond the communication between regulators and scientists, continuous communication with and between operators and the public is necessary. On the one hand, the public needs to be informed about potential hazards and trained in appropriate behaviour in the case of an emergency. On the other hand, the public provides local and anecdotal knowledge as well as insights in human behaviour that are crucial for successful risk governance.

Policy Implications

In the spirit of the Sendai agreement and informed by the literature on systemic risks, we would like to put forth the following recommendations for dealing with natural hazards which exhibit the characteristics of systemic risks:

1. Strive for more interdisciplinarity (natural, technical, and social sciences as well as the humanities) and transdisciplinarity (practice and science): Successful management of natural hazards requires an interdisciplinary and transdisciplinary approach. On the one hand, the different scientific disciplines must combine practical findings on the frequency, severity, and spread of natural hazards such as floods, storms, and earthquakes. On the other hand, social and communication science is needed to optimise the effectiveness of warnings, the design of settlements and others forms of land-use, as well as the effectiveness of crisis prevention and crisis management measures. Finally, the administrative and organizational sciences should be included since they can contribute to the efficient and effective pre- and post-emergence of natural hazards. Furthermore, it is essential to integrate experiential and local knowledge in

natural hazard management. This requires a transdisciplinary approach in which scientists, local and regional administrators, as well as stakeholders from the affected publics work together. So far, there is still no integrative natural hazard management in place in most parts of the world. It is an important task for the future to further expand this interdisciplinary and transdisciplinary cooperation and to support it through a network of designated management priorities. Politics should provide incentives through targeted support measures.

2. Harmonising regional, national, and international data to avoid fragmentation (general metadata bank): Throughout the world, regional and local approaches are found to improve risk prevention. At the same time, there are global frameworks and databases in place. However, a database that links the various governance levels and provides communication from the local to the global level of governance is still missing. There is a lack of an international initiative to harmonise the different databases and to offer a coherent and shared service for authorities and inhabitants. This is not a matter of centralising responsibilities, but rather of effectively networking the existing structures towards a common data collection and evaluation programme. An important goal is to standardise the communication content and warnings so that a continuous learning effect for the population can be achieved. Risk management becomes ineffective if warnings and communication strategies differ from region to region and are therefore not clearly understood by the people concerned.
3. Eliminating inconsistencies in regulation (moral hazard): Preventive and aftercare measures are still desirable goals mentioned in the Sendai agreement but not effectively implemented in most parts of the world. For instance, insurance regulations in Germany give raise to the emergence of so-called moral hazards (the uninsured receive state aid after an event yet the insured must pay high premiums). It is important to establish rules of elementary insurance to avoid such free-rider problems.
4. Create communication with those affected and share knowledge: Many people lack adequate awareness of the dangers of natural forces. In particular, they underestimate the complex interactions between natural triggers and technological and medical disasters. This is especially the case if natural hazards are accompanied by technological failures (explosions, fires, structural deficits) or behavioural responses (such as mechanisms of contagion). Most people

have little knowledge about how to behave properly when faced with natural hazards. Another contributing factor is tourism. When travelling as tourists, people are unfamiliar with the natural hazard landscape of an area and may endanger themselves because they underestimate natural hazards. To remedy this situation, communication programs are needed that provide basic information on appropriate behaviour and necessary precautions through a variety of communication channels to people in areas exposed to natural hazards. This could be done in joint actions by elementary insurers and civil protection authorities.

5. Build problem-solving competencies: Although much academic expertise exists on the topic of natural hazards, there is still a lack of interdisciplinary competence, integrated training of experts for civil protection and crisis prevention, and an efficient network of experts who exchange their knowledge and expertise, in particular for natural hazards that are embedded in larger systemic risks. In order to successfully develop such a network, resources are needed to create competence teams across countries, and to lay the foundation for competence acquisition and competence preservation through joint seminars as well as exercises and continuing education programs. These networks should be run jointly by educational institutions, such as universities, non-university research institutions, civil protection authorities, and civil society groups that act as crisis workers in emergencies.

There is no doubt that the implementation of these five recommendations would require additional resources. More importantly, it is crucial that those responsible in educational institutions, public authorities, and civil society groups recognise problems, find common ways to address them, and are motivated to integrate their programmes in cooperation with academia in order to identify the main characteristics of systemic natural risks and the best governance structures to meet them.

Conclusions

The threat of systemic natural risks is growing worldwide, despite all efforts to mitigate effects. Society needs more appropriate methods to cope with such natural risks. New approaches are necessary to monitor risks, assess them across disciplines, and manage them in an effective and efficient manner. The IRGC framework proposed in this article presents a pragmatic solution to this challenge. Due to the integrative and adaptive nature of the framework, managers can accomplish response systems that meet the criteria of an effective, efficient and sustainable disaster response.

The IRGC approach is inclusive, interdisciplinary, transdisciplinary, adaptable, and problem-oriented. It combines technical, natural, and social scientific approaches to assess, manage, and govern natural hazards. Properly implemented, the IRGC risk governance framework assists natural hazards mitigation by characterising the systemic interdependencies between natural events and other types of hazards in a built environment, and by proposing appropriate management measures. An integrated, inclusive and adaptive management approach is a good guarantee for an adequate response to systemic risks stemming from natural hazards. However, we still need more advanced models for systemic risks that link natural hazards with technological and civilisational risks. We also need to develop more effective planning tools that enable communities to organise effective risk management on the basis of self-organizing units. Economic incentives need to be linked with risk avoiding and mitigating behaviour. There is also the demand for further educational opportunities for mutual communication, training programmes and campaigns for enhancing skills locally. Finally, the time is right for the establishment of an independent institution for systemic risk assessment and governance with the aim of early detection and early warning for natural as well as technological risks because both types of risk become more and more interlinked (WBGU, 1999).

Effective risk management must find a balance between efficiency and resilience, and the solutions devised must be fair to all people affected (Renn, et al., 2009). The concept of inclusive governance seems most promising to meet the challenges of sustainable risk governance of disaster risk in all its dimensions. Risk communication and the engagement of stakeholders and civil society lie at the heart of this concept (Schweizer and Bovet, 2016). Communication and engagement are indispensable for inclusive, collaborative modelling and assessment approaches that enable systemic risk perspectives. Finally, the systemic risks approach contributes to the anticipation of adverse effects be they geophysical, technological, biological or socio-political.

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