Policy brief

Critical Infrastructure Resilience

Lessons from Insurance

International Risk
Governance Center

This publication should be cited as: Florin, M.-V. & Sachs, R. (2019).
Critical Infrastructure Resilience. Lessons from Insurance.
Lausanne: EPFL International Risk Governance Center.
DOI: 10.5075/epfl-irgc-273295

Available from irgc.epfl.ch

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Executive summary

Primarily intended for an audience interested in learning about how insurance can broadly contribute to resilience, this policy brief aims to be a source of inspiration for critical infrastructure (CI) managers and resilience researchers.

Today's risk landscape is characterized by increasing complexity, interconnectedness, fast-paced changes and the importance of systemic risks, which, among others, affect critical infrastructures (CI). New instruments have to be developed and implemented to deal with the challenges and to benefit from the opportunities in this new environment. Resilience-driven strategies are suggested and developed as a potential way forward. Resilience is generally defined as a system's ability to respond to unexpected events that can potentially lead to significant disruptions in functionality. The concept describes a state of dynamic stability of systems to deal with the sudden impact of adverse events, and to restore as quickly as possible ability to function and capacity to act.

Managing resilience complements more conventional forms of risk management to cope with the unexpected. The two different approaches address the unanticipated threat of losses, both physical and financial, both events and trends. Risk assessment and management are valuable and necessary, and can be enhanced by assessing and improving resilience.

There is a potential tension between acknowledging that resilience is being particularly useful for grappling with uncertainty and unquantifiability, and a basic principle and requirement from insurance, which is that the assessment of a critical infrastructure resilience should provide a measurable outcome. The significant difference between risk management and resilience is the shift in focus from events to the system.

The development and implementation of resilience strategies are far from trivial. In this policy brief, we suggest five factors that can guide and inspire further attempts to strengthen resilience, both methodically and operationally. The following five lessons are drawn from the development of risk management practices in the insurance industry.

1. Develop methods to measure resilience
2. Implement standards to measure and manage resilience, possibly with independent rating agencies
3. Align interests between stakeholders, to avoid asymmetry of information
4. Create incentives for continuous improvement
5. Address the issue of systemic risk

In addition to providing insights on these factors, insurance already contributes to resilience. This paper summarizes existing insurance products and services and attributes them to the resilience cycle. We conclude our analysis with the description of use cases for advancing resilience insurance and of a positive feedback mechanism between resilience, insurability and risk transfer. We consider the existence of positive feedback mechanisms a crucial success factor towards stronger resilience in critical infrastructures.

We acknowledge that other ways of improving resilience beyond insurance exist. Most importantly, advancing resilience requires multi-stakeholder dialogues between industry, academia and governments and the necessary platforms to enable that dialogue. It is essential, however, that this dialogue leads to action and creates a real impact.

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Introduction

Today's risk landscape is driven by major trends like climate change, digitalization and globalized flow of financial assets, goods and people. Formerly independent events can become connected, either directly or indirectly, and these connections typically lead to higher complexity. Critical infrastructures are interconnected, forming complex adaptive systems. They change and adapt (or not) in response to internal stresses and external shocks, and are thus generally difficult to narrowly define, which complicates any attempt to fully understand and model their behaviour (IRGC, 2018b).

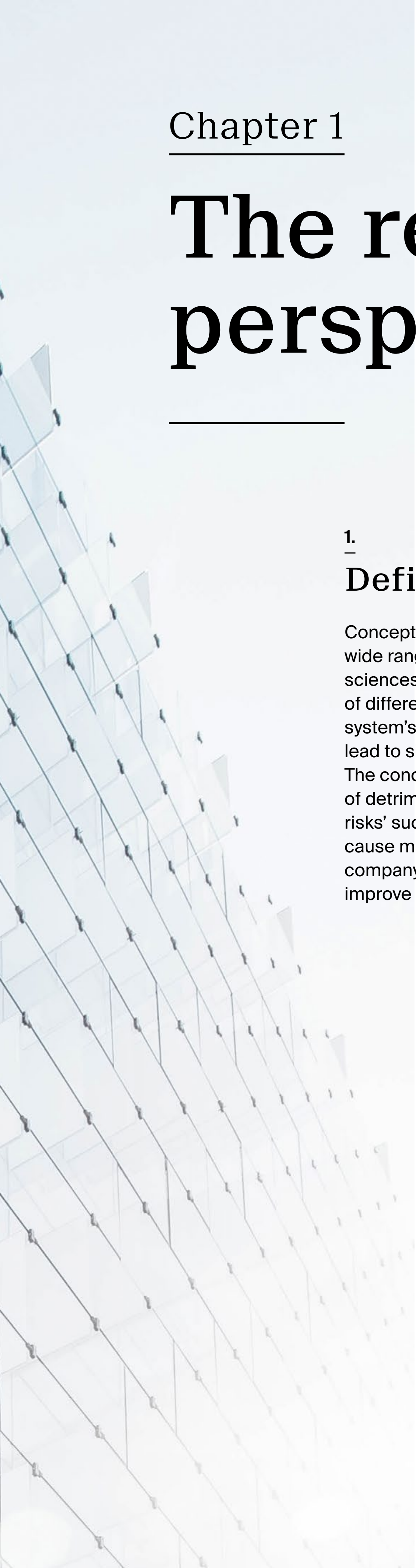
The insurance industry is increasingly requested to contribute to the resilience of critical infrastructures. So far, risk management and risk transfer have been the industry's basic instruments. However, in the light of changes in the global risk landscape and the increased importance of systemic risk, the classic methods of risk management approach their limits and insurers consider resilience as a promising approach to deal with risk and uncertainty. Insurance companies are also interested in benchmarking infrastructures and comparing their different levels of resilience.

When risks materialize between and within complex systems, the chances of cascades and ripple effect increase. Individual events are increasingly likely to lead to consequences with larger geographical and temporal reach. This is becoming a major issue of concern, which traditional risk managers are not very familiar with. Against this background, large-scale shock events such as the Wannacry cyber-attack in 2017, the Fukushima nuclear power plant meltdown in 2011, the blackout in Italy in 2003, or SARS in 2003 seem to be increasingly harder to predict because of rapid technological, environmental, political and societal developments, and have systemic impacts across borders. Their widespread consequences are impossible to assess beforehand. This is also particularly true with long-term risks such as climate change, and their impact on the natural, economic and societal environment.

To insurers, this development can be seen as a threat to diversification, one of the main cornerstones of professional risk management. Techniques and methods for the management of systemic risks in practical applications are missing. Systemic risk is a challenge to assess, monitor and manage in particular for critical infrastructure service providers and for insurers.

Supplemental to risk management, resilience seems to be an adequate approach to encounter these changes in the risk landscape towards complexity and interconnectedness, for the following reasons: First, holistic concepts such as resilience that take into account the entire system and its lifecycle may be more adequate than more targeted risk-based approaches for individual components. "Rather than focusing on asset protection alone, a system approach allows governments and infrastructure operators to address asset interdependencies and prioritise resilience measures for critical hubs and nodes whose failure would cause the most damage." (OECD, 2019). Second, resilience approaches explicitly acknowledge systems' interconnectedness including social, environmental, economic, and emergent factors (e.g., through considering multi-scale interactions, critical thresholds, and social capital; Bresch et al., 2014). Third, resilience-driven strategies aim at maintaining functionality and survival, reducing and limiting the losses resulting from unknown, uncertain and unexpected events, by considering the consequences that impact the system (Linkov et al., 2016).

In complement to the IRGC Resource Guides on Resilience (IRGC, 2016, 2018a), this policy brief elaborates from ideas developed during the EU Horizon 2020 SmartResilience project (2016-2019). It provides some guidance to improve the positive feedback between insurance and resilience.



Chapter 1

The resilience perspective

1.

Defining resilience

Concepts of resilience have been developed and applied in a wide range of different contexts (e.g., natural sciences, social sciences, engineering), and hence there is an abundance of different definitions. Resilience is generally defined as a system's ability to deal with adverse events that can potentially lead to significant disruptions in the functionality of that system. The concept of resilience aims at reducing vulnerability in case of detrimental events or trends (e.g. so-called 'slow-onset risks' such as consequences of climate change) that potentially cause major disruptions. Ideally, the system (e.g., an individual, company, society) would learn from this experience and even improve its functionality after the event.

For a structured approach to resilience it is useful to look at the functionality level of a given system and divide the temporal process into distinctive phases. Resilience usually refers to the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events (NAS, 2012). Partners in the SmartResilience project have added a first phase, "understand risk", which is particularly valuable for the specific purpose of establishing links with insurance (Øien, Bodsberg, & Jovanovic, 2018 -see Figure 1-, elaborating from NAS, 2012).

1. **Understand risk**. The objective is to identify risks and assess their impact on the system, both direct and indirect consequences. Vulnerabilities have to be assessed, also with respect to emerging risks. Understanding risk is the basis of insurability and hence an important phase for the purpose of this paper.
2. **Anticipate / prepare**. Given a thorough understanding of the risk situation, foresight techniques have proven adequate and scenarios for possible events are relevant to illustrate dynamic developments. Appropriate measures for both expected as well as extreme events need to be developed and implemented.
3. **Absorb / withstand**. Ability to absorb shock is a property of resilient systems, to avoid losses and disruption if/when a significant and sudden event happens. The protective measures need to work and to mitigate the experienced impact.
4. **Respond / recover**. There have to be prompt, well-organised emergency aid and sufficient resources available to rebuild and restore the functionality of the system as swiftly as possible.
5. **Adapt / transform**. After the system has recovered from the event, it is crucial to evaluate the loss of functionality during the event and improve the capacity and capability of the system. Results from this lessons-learnt exercise need to be used to improve the previous phases (1–4) in order to increase the overall resilience level.

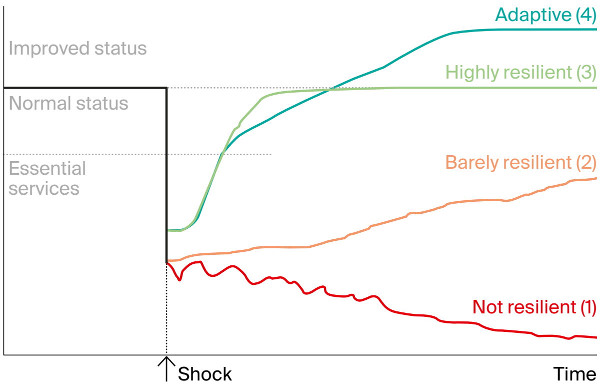


Figure 2: Functionality of four different systems according to their resilience levels. (Munich Re, 2017)

Figure 2 illustrates the functionality curve of systems that have different resilience levels, and how they respond to an adverse event (Munich Re, 2017). System 1 is not resilient and does not recover at all. Overall functionality decreases after the event and recovery efforts fail. System 2 has only little resilience. Recovery is very slow, barely reaches its pre-event functionality level and if so, possibly only with external aid. A highly resilient system (System 3) recovers faster after the event and also shows smaller losses

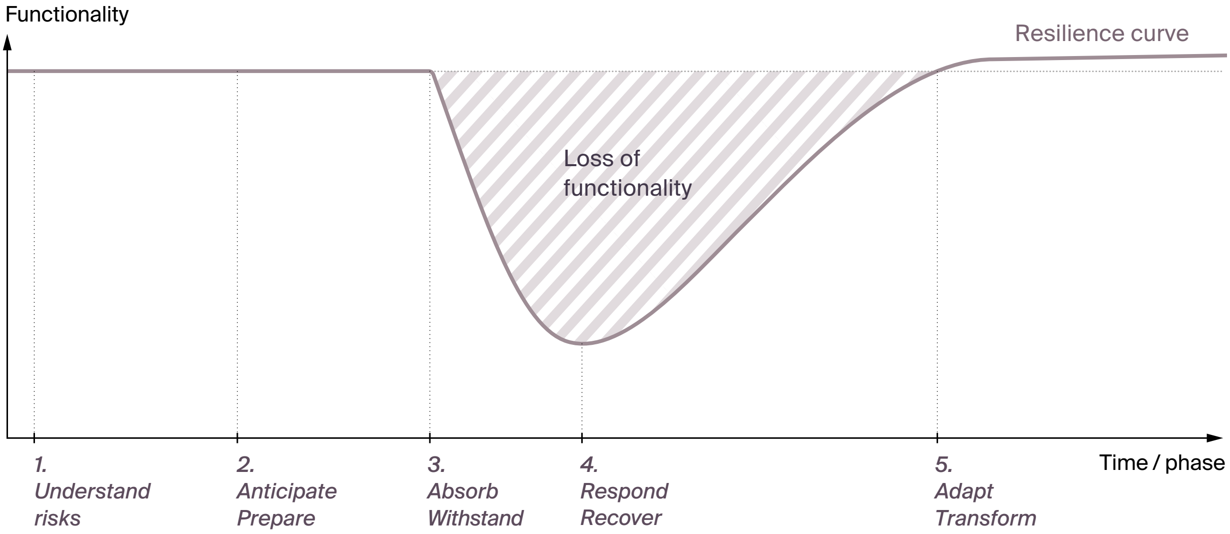


Figure 1: The five phases of functionality in a resilient system (Øien et al., 2018)

due to preventive measures. Functionality is restored after a short time due to available resources. External support is typically not required. An adaptive system (System 4) is characterized by its higher level of functionality after recovery. While overall recovery may take longer, in particular after essential services are up and running, the rectification of weaknesses and implementation of improvements lead to overall increased functionality.

2. The system view

Resilience strategies do not focus on reducing risk at source, i.e. what could lead to disruptions of an organisation, infrastructures, or environments, but rather on how a system can be strengthened in its ability to cope with and recover from shock events and to adapt to new conditions (IRGC, 2018b; Linkov et al., 2016; Linkov & Trump, 2018). Resilience can thereby be seen as the buffering capacity of a system to absorb a disturbance while retaining its most critical function (OECD, 2019). In their efforts to cope with unexpected shock events, risk managers and policymakers increasingly take a resilience perspective in addition to their usual focus on identifying, assessing, and managing particular risks (Linkov & Trump, 2019). Major stakeholders with a responsibility to manage risks, such as municipalities[1], have even focused much of their communication and efforts to resilience.

The resilience concept explicitly addresses systems holistically versus individual parts of a system, also by considering interrelations. It is thereby not limited to single threats but rather analyses the disruptions to a system regardless of the respective cause. Consequently, the quantitative aspects of individual threats are not the main focus of the analysis. The need for quantification of individual risks is embedded in a more holistic framework. Hence strengthened resilience is a possible solution to the management of non-quantifiable risks, i.e. uncertainty, and addresses the challenge of system failures, too.[2]

3. Critical infrastructure resilience

While the concept of resilience can be applied to all kinds of systems, this paper specifically considers the resilience of critical infrastructures (CI) such as energy grids, water supply, transportation networks, financial systems, and health care.[3] Infrastructure disruptions can cause serious economic, social, and environmental impacts with severe losses, including existential crises. Therefore, various stakeholders such as communities, governments, business owners, investors, and service operators, have a high interest in strengthening infrastructures in a way that disruptions can be avoided or dealt with effectively. The spectrum of specific infrastructure risks is broad and reaches from errors in design and construction over force major such as political, legal, and contractual risks, major adverse events such as terrorist attacks on airports, cyber-attacks on financial systems, or large-scale natural catastrophes such as earthquakes, floods, tsunamis, and volcanic disruptions (cf. Kunreuther, Michel-Kerjan, & Tonn, 2016).

How can critical infrastructure disruptions be kept at an acceptable level or even be avoided? A previous approach is represented by the so-called Critical Infrastructure Protection (CIP) programs. Such programs build on the comprehensive identification and mitigation of potential adverse events (e.g., extreme weather, terrorist attacks, war). However, there are so many different critical infrastructures in different geographical locations and a plethora of actual and hypothetical events, that it appears ineffective to prepare for all of them individually (i.e., following a classical risk management procedure). An additional problem is that direct and indirect consequences of individual events can show contagion and lead to cascading effects, such that CI might be affected by very remote events, which are out of scope of any economic risk assessment. The increasing complexity and interdependency of infrastructure systems make it impossible to predict and prepare for all such scenarios (see also Wadé

[1] Such as cities participating in the '100 resilient cities' project 100resilientcities.org

[2] In the context of this report, uncertainty refers to both aleatory uncertainty, and epistemic uncertainty. Research can reduce epistemic uncertainty, and techniques such as Bayesian uncertainty quantification can provide useful information. Overall, what we mean by non-quantifiable risk is that there is insufficient data or knowledge to describe the performance of a system using reliable estimates for probabilities. Furthermore, one could in theory argue that a resilient system should be able to maintain functionality even if the “unknown unknowns” happen.

[3] OECD (2019) contains an overview of CI definitions that are used in the member states.

& Sachs, 2013).[4] Therefore, and as an alternative approach, Critical Infrastructure Resilience (CIR) approaches are built on the assumption that not all threats can be anticipated (Øien et al., 2018). Improving resilience should thereby offer opportunities to reduce the potential disruptions, reduce system vulnerabilities, and/or mitigate the consequences when disruptions do occur.

4.

Risk management, uncertainty and resilience

Managing risk and managing resilience are two different yet linked approaches that address the threat of unexpected losses, both physical and financial, both events and trends (IRGC, 2016; Trump et al., 2018b). All types of risk management activities, including business continuity management, are still valuable and helpful. The existing practices can be complemented by assessing and improving resilience.

Risk management builds on the identification of specific threats. Risk can be avoided at source, prevented, or reduced. Their financial consequences (monetary losses) can be transferred to third parties such as insurance. Risk management deals with specified risks and assumes these risks are in principle known or at least knowable. Risks can be quantified in both their occurrence probability as well as their loss severity – for which a sophisticated toolkit of probabilistic methods is available (see McNeill, Frey, & Embrechts, 2005). Quantification is a typical challenge in risk management, in particular when it involves insurance as a means of risk transfer. Insurance companies require quantification for their probabilistic models.

In reality, however, only a limited subset of unexpected events can be assessed quantitatively. The vast majority of events and their consequences can be assessed only with qualitative methods, if at all. These non-quantifiable events are described with various levels of "uncertainty", a term which some experts use in contrast to "risk" (when events and losses are quantifiable). Coping with uncertainty is a major challenge for any system such as an individual, corporate or society. It may not be possible to identify and qualify uncertain events in the first place. And even if it were possible, it may not be economically feasible to prepare for any of them individually.

Insurers have always dealt with uncertainty and some have formally adopted principles of uncertainty management in their internal processes. Emerging risk management is largely based on expert judgment and has to reflect the subjectivity of probability assessments (Sachs, 2018).

There is a connection between research on resilience and uncertainty. Concerning CI, research on uncertainty has largely been driven in the context of so-called High-Reliability Organizations (HRO) such as firefighting teams, airlines or operators of critical infrastructures like nuclear power plants. The principles of coping with uncertainty (Weick & Sutcliffe, 2007) are also categorized in temporal categories, i.e. before and after the event. Before the event it is important to develop possible scenarios and apply foresight techniques. It is also recommended to avoid oversimplification because many situations are more complex than the model is designed for and can handle. Furthermore, the limitations of any model have to be transparent to all stakeholders. After the event has happened, the impact has to be contained. It is important to ensure that the system can maintain capacities for action under stressed circumstances (redundancy, diversity, modularity), also noting that decision-making in a crisis may be different from the normal process in a hierarchical organisation.

Although some scholars contrast or even oppose the concepts of risk management and resilience, this should not be the case in the context of risk of disruption of services provided by CI, with large direct and indirect negative consequences, and even more when considering the role of insurance. Insuring a CI subject to unexpected and potentially large-scale disruptions (for which a resilience-based approach is needed) requires considering also, in addition to resilience analysis, the use of established risk management concepts and methods such as risk assessment, risk mitigation or business interruption (BI) (Linkov et al, 2018). Trade-offs between efficiency (e.g. leanness) and resilience (e.g. slack and redundancy) must be made visible and addressed (Ganin, 2017).

[4] In IRGC (2018) the reasons and consequences of complexity and how this leads to systemic risks are rigorously analysed.

Chapter 2

Lessons from risk management in insurance

The pivotal factors for the successful development of risk transfer solutions, i.e. insurance products, and implementation of professional risk management practices in the insurance industry can be translated into the resilience context.[5] **There are a few basic, traditional factors that are required for any risk transfer through an insurance product. These factors remain valid even in a changing risk landscape and in the context of resilience solutions.** They proved helpful to advance risk management in insurance products and insurance companies, and they should be used to guide the development of tools and methods for strengthening resilience (Sachs, Florin & Eller, 2019):

1. Develop methods to measure resilience
2. Implement standardised methods to measure and manage resilience, possibly with independent rating agencies for CI with large and exposed communities
3. Align interests between stakeholders, to avoid asymmetry of information
4. Create incentives for continuous improvement
5. Address the issue of systemic risk

[5] We chose to focus on insurance methods and products in this policy brief. However, we acknowledge that financial products like derivatives, especially those allowing to hedge against catastrophes of different kinds, can be complement or substitutes for insurance products. Derivatives can thus be expected to have an impact on the demand for insurance aimed at mitigating the consequences of critical infrastructure outages.

This section explains these factors in more details and presents lessons learned from risk management in insurance, for the advancement of resilience. In other words, **if a CI is interested in improving its insurability thanks to resilience performance, it must consider the following five requirements.**

Factor 1: Measure resilience

There is a potential tension between acknowledging that resilience is being particularly useful for grappling with uncertainty and unquantifiability, and a basic principle and requirement from insurance, which is that the assessment of a critical infrastructure resilience should provide a measurable outcome. The significant difference between risk management and resilience is the shift in focus from events to the system. While resilience strategies do not require the quantification of the unknown, e.g. via risk scenarios, the system capacities related to resilience should be measured in quantitative terms. Although qualitative aspects are helpful too, e.g. for the identification of critical issues, quantification of resilience should lead to measurable and tangible outcomes, which are consistent across site and time.

Resilience can indeed be measured in many dimensions. The following examples provide practical approaches and are by no means comprehensive or complete.

1. **Reduced loss**: Resilience can be measured through the total loss of performance caused by a given disruption. Resilient systems are characterised by reduced total loss of performance (Moteff, 2012).
2. **Reduced expected recovery time**: Resilient systems are characterised by quick recovery (Moteff, 2012). Resilience can be measured through the amount of time needed to fully recover to normal operation. This addresses reduction in business interruption.
3. **Area under the functionality curve**: While the exact shape of the functionality curve may not always be of direct interest, it is important that the loss of functionality, integrated over time, remains small in case of adverse events. Such a measure corresponds to familiar concepts in risk management, e.g. the Global Risk Index from the Cambridge Centre for Risk Studies, who assess vulnerability and resilience of around 300 cities worldwide (Cambridge Centre for Risk Studies, 2018).
4. **Indicator-based methods**: The SmartResilience project has developed a holistic methodology based on indicators for the assessment and management of resilience of critical infrastructures, e.g., energy, water supply, and transportation networks (SmartResilience, 2019). It acknowledges potential large and systematic (e.g., environmental, geopolitical, societal, economic, and technological) threats (SmartResilience, 2019). Various indicator-based approaches have been developed for the purpose of understanding and evaluating urban resilience, including UNDRR (2017), City resilience index (2019) or Resilience Matrix (Fox-Lent & Linkov, 2018), but with less focus on quantification for insurance needs.

The question of how resilience can be measured should not only be driven by matters of feasibility (i.e. what measures are possible) but also of utility (i.e. what measures add value). In real applications, several measures of resilience will be needed. Different stakeholders (e.g., communities, administration, CI providers, insurers, regulators, policymakers) may have different requirements regarding measures of resilience. Multi-criteria decision analysis can be helpful to reflect and integrate different stakeholders' views. However, it is crucial that measurements of resilience are comparable across sites and industries (see also Factor 2: Standardised methods). Ex-post analyses are helpful to identify weak spots and areas for future improvement. For additional benefit, quantitative methods are needed to enable ex-ante measurement of resilience, e.g., scenario modelling of the functionality curves of a particular CI under specific threat scenarios (e.g., natural catastrophes, cyber attacks, terrorism).

A critical infrastructure provider will be able to decide about investments in resilience measures if the benefit/cost of the proposed measures can be calculated (Kunreuther et al., 2016). This will enable a meaningful discussion between different stakeholders, e.g. CI provider, governments, insurers and puts them into a position to form a common view of desirable and achievable resilience levels.

Factor 2: Standardised methods

Although resilience is an emerging field of interest in CI and insurance, at some point in time, market standards will have to be established for the definition of resilience, for the methods of assessment and monitoring, and for the implementation of resilience frameworks in the market. Cost-benefit analyses of investments in resilience require reliable and comparable price tags, based on some standard.

We do not advocate the view that regulation or any supervisory authority should define these standards as a starting point. On the contrary, we trust that engaging in active multi-stakeholder dialogue, involving e.g. researchers, operators, insurers, governments, will lead to a resilience framework and best practices, which are more likely to be generally accepted and practical. Regulation will then be the necessary incentive for wide implementation of resilience tools in the practice and working towards a level playing field for all actors.

Any method to assess and manage resilience needs to be transparent, objective, meaningful and applicable to a sufficiently broad and deep market. This is particularly difficult because individual stakeholders, e.g. CI operators, will have specific requirements, too. Thus, such implementation of a methodological standardization is far from being trivial.

However, it will be important that measurements of resilience are consistent, and assessments can be related to each other. Reliability, reproducibility and comparison (benchmarking) with other similar systems will be key factors for the adoption of any resilience measurement system in the market.

Factor 3: Align interests between stakeholders

Implementing resilience concepts in the industry requires the alignment of interest of the stakeholders involved, including investors, operators, regulators and insurers. The insurance industry is experienced to address this in the proper design of the insurance contract (e.g., by retentions, deductibles, etc.). Insurance contracts are designed to align the interests of policyholder and insurer. The loss needs to occur randomly and in particular without influence from the policyholder. **There should not be the possibility for the policyholder to create a loss and claim compensation from the insurer**. These ideas may be translated for the design of resilience-based strategies.

In particular, the resilience assessment should be independent of the operator of the critical infrastructure if this assessment is to be used for pricing third party investments or insurance policies. It makes sense to establish a trusted third party, independent both from operators and other stakeholders, such as insurance companies, which can model and evaluate the resilience of critical infrastructures. Such an entity could also provide a framework for balancing multi-stakeholder interests. Users of CI services, operators, investors and supervisory authorities will have different expectations regarding optimal resilience levels.

For future resilience-based solutions, there might be a need for modelling agencies with a dedicated focus on resilience assessment. In this regard, different institutions aim at providing certification for resilient infrastructures, such as the US Institute for Business and Home Safety (IBHS), the US National Institute of Standards and Technologies (NIST), and the initiative to create a European Risk and Resilience Assessment and Rating Agency (ERRA).

Concerns have been raised that risk management and mitigation may also create a false sense of security, or even a moral hazard. It may reduce the incentive to those who manage the physical assets for safety and security from investing in resilience measures. While this is certainly true, it is not new in the context of risk management. This has always been an issue since the invention of risk management, mitigation and transfer. The negative incentives of risk mitigation must be acknowledged. However, the positive aspects by far outweigh the negative ones: nobody would seriously argue that the world would be a safer place without risk management.

Factor 4: Incentivize continuous improvements

The development of risk management practices in the insurance industry has been a long journey and is still ongoing. Refining and recalibrating models and the intelligent use of data, in particular in the age of digitalisation, show the efforts in the industry to keep up with the changing risk landscape and behaviours and to adapt to new economic and regulatory environments. For example, road and car safety regularly increases in response to many factors including pressure from insurance. Likewise, insurance will expect that CIs manage their resilience as an ongoing exercise towards improvement. As the environment changes within which an infrastructure operates, so does the infrastructure itself change its methods and levels of resilience. Continuous input from own experiences and those of third parties is required and shall be used to adapt the resilience framework. As we mentioned in the introduction, the risk landscape keeps changing, and we will face a very different environment in 10 or 20 years from now.

Society has a strong interest that infrastructure providers are committed to this ongoing process. If the requirements are simply seen as one-time exercises in order to comply with some sort of standard, changes in the environment, technological degradation, and general ageing of people and infrastructure will render static resilience methods and assessments outdated and inadequate. Resilience-based strategies should also foster changes in the corporate culture and governance to enable ongoing improvements, for example via resilience monitoring requirements and regular scenario exercises.

Economic and financial constraints are, in many cases, key obstacles to resilience improvement: present-day investments need to be balanced with potential future benefits. Investors and beneficiaries may well be different parties with diverging interests. **These financial obstacles for the operators of CI have to be made transparent and mitigated, for example by creating direct or indirect incentives for investments in critical infrastructures, to engage in continuous resilience improvement**.

Factor 5: Address systemic risks

Critical infrastructures are linked to the issue of systemic risks from a system-of-systems view. Systemic risks are characterised by contagion, complexity, low predictability, cascading effects, long-term and far-reaching consequences across entire geographies and domains of the global risk landscape (IRGC, 2018b; Lucas et al, 2018). Systemic risks are caused by interdependencies and can lead to large accumulation risks (a particular problem and worrying trend in re-insurance, as illustrated in Figure 3). Any method for resilience assessment should provide a meaningful way to attribute the contribution of specific critical elements to overall resilience, i.e. what is the benefit/value of strengthening the resilience of an individual CI.

Portfolio models in the insurance industry reflect a holistic view, too, and allow the attribution of total risk to individual elements (company). However, these models are generally not well designed to deal with systemic risks properly, leaving the insurance industry with the challenge to assess, identify and mitigate systemic (accumulation) risks.

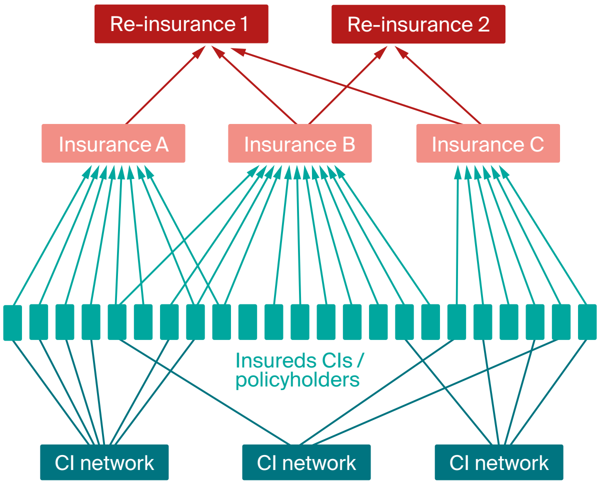


Figure 3: Accumulation risk in insurance and re-insurance, an illustration of systemic risk. A failure in any insured CI can propagate through the network of CI and insurance companies, and accumulate at the top.

The resilience approach has the potential to reduce systemic risks by creating transparency about critical parts of the system, provided this approach allows for the attribution of individual elements to overall resilience. If resilience concepts are applied in critical infrastructure, the reduction of systemic risks can be assessed, for example when critical nodes (e.g., energy supply) have been strengthened and their contribution can be quantified. This can reduce the likelihood and extent of negative consequences of failure, and improve recovery times and adaptability. Cost-benefit analyses and economic decision-making of investments in resilience require the valuation of different elements of the system and options.

The role of regulation

Regulation is often mentioned as a structuring factor for insurance, as well as for CI. Whenever there is an evidence-based risk, regulators can have a mandate to step in. If, in a deeply interconnected society, the potential harm to citizens/environment/economy from a collapse of critical infrastructure is sufficiently high to require mandatory levels of resilience throughout a CI network, regulators could build resilience and insurance requirements into the regulatory frameworks that apply to CI operators.

Chapter 3

Insurance contribution to resilience

Resilience broadens and enhances the traditional risk management toolkit in several aspects and – if properly implemented – may lead to higher safety, in particular in a complex, interconnected and dynamic risk landscape. Resilience also has important benefits for insurers and vice versa. In this section, we focus on direct and indirect, existing and potential future contributions from insurance to resilience.

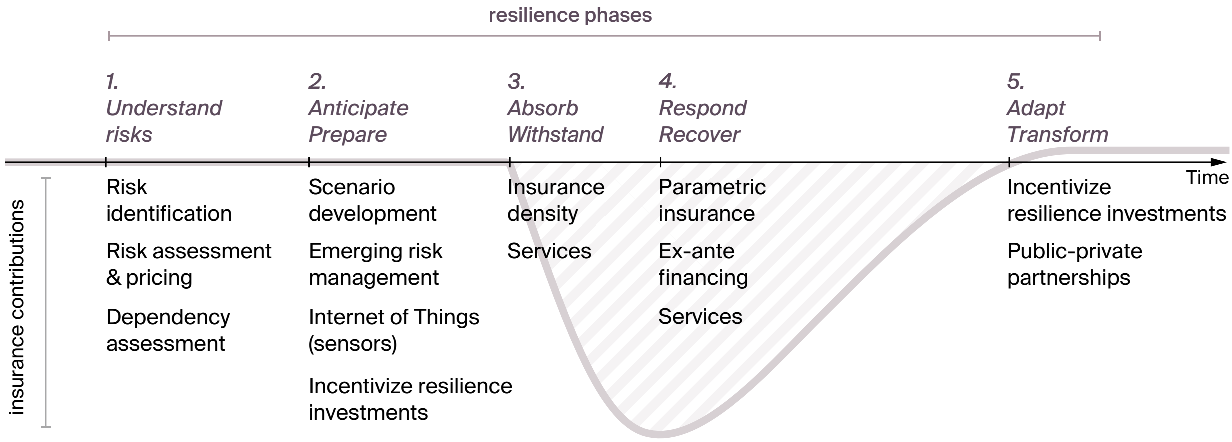


Figure 4: Insurance contributions along the resilience cycle. Traditional infrastructure insurance markets (risk-transfer) are mostly found in phase 3 (absorb/withstand), aiming to increase insurance density

1.

Resilience through insurance

The insurance industry already supports in various ways the strengthening of systems towards increased resilience in the five phases of the process:

1. Understand risk (e.g., increase transparency through risk identification, risk assessment and pricing, and dependency assessments);
2. Anticipate / prepare (e.g., enable anticipation through scenario development and emerging risk management, and avoid losses for instance through current innovations in the context of sensor technology);
3. Absorb / withstand (e.g., through increased insurance density as well as additional services);
4. Respond / recover (e.g., through innovations such as parametric insurance which accelerate payments as well as through means of ex-ante financing and forecast-based risk financing);
5. Adapt / transform (e.g., through Public-Private Partnerships as well as the incentivisation of investments in resilience) as illustrated in Figure 4. Some examples could be allocated to several phases or also allocated differently. The proposed allocation simply serves to illustrate the range of contributions.

Figure 4 intends to demonstrate how the application of lessons from insurance risk management can lead to instruments for higher resilience. The translation of these lessons could also help to advance resilience strategies beyond insurance, e.g. creating investment opportunities (make long-term capital investment more appealing) or structure the process towards market standards and regulation. This aligns with the long-term sustainability goals of the industry and society (reconcile short and long-term horizons).

2.

The resilience-insurability cycle

Insurance can contribute to stronger resilience through its existing product portfolio, but it can do more. There actually exists a positive feedback mechanism: first, higher resilience can improve insurability. For example, understanding of the risk situation, reduction of expected losses and improved recovery times will positively influence the insurer's risk assessment and increase its risk appetite. Second, risk transfer via additional insurance can strengthen resilience. Loss reduction addresses the

Figure 5: Positive feedback between insurability, risk transfer and resilience

capability to withstand and respond to critical events. The availability of additional funds through insurance pay-outs can reduce recovery times and enable adaptation. **The combination of insurance and resilience concepts thus appears to lead to win-win situations for all stakeholders, and can trigger positive feedback**.

The main objective of this cycle is to strengthen resilience in critical infrastructures. Clearly, the insurance industry is an important factor in this cycle. There is also an additional benefit for insurers: the development of resilience strategies for critical infrastructures may give rise to the development of innovative risk transfer products. Changing the perspective from risk management to resilience management can lead to business opportunities through the development of new resilience-based insurance solutions that go beyond offering pure risk transfer.

We consider the identification and use of positive feedback mechanisms a crucial success factor towards stronger resilience in critical infrastructures – and beyond. The interconnected and complex nature of the world has to be accepted and acknowledged. Rather than aiming for simplifications and reductionism, risk managers should embrace complexity and use features like feedback cycles to improve risk reduction and resilience (see also Boulton et al., 2015).

3. Use cases for advancing resilience insurance

Complementing the risk management perspective with a resilience management perspective can enhance the role of the insurance industry, which is exploring how it can strengthen infrastructure resilience as well as its own business, through the development of new resilience-based insurance solutions that go beyond offering pure risk transfer. Resilience is a positive concept that can be used by the insurance industry to consult their clients from new perspectives and to develop new products and services to enhance resilience, even if only indirectly. For illustrative purposes, we describe below five 'use cases': (1) resilience-based insurance pricing, (2) resilience bonds, (3) fast disaster response covers, (4) public-private partnerships, and (5) resilience consulting. These examples serve to illustrate existing insurance initiatives, which may be applied in other contexts, and new initiatives, where the industry is currently in the product development phase.

Use case 1: Resilience-based insurance pricing

The resilience of an infrastructure has an immediate influence on individual infrastructure risk: the deeper the infrastructure's functionality drops due to an adverse event and the longer the recovery time, the higher the expected loss will be. In theory, insurance is priced at an actuarially fair rate when the premium charged to cover a risk equals its expected loss (Kunreuther et al., 2016). Therefore, infrastructure resilience is a critical variable for the assessment of specific infrastructure risks, which potentially provides more detailed and accurate information of expected loss.

Resilience-based insurance pricing can increase an insurer's competitiveness in the traditional infrastructure insurance market. Being able to accurately reflect an infrastructure's resilience in that infrastructure's risk assessment can enable an insurer to both select and price risks as well as allocate capital and steer risk appetite more effectively. This may result in a competitive advantage for both CI and insurance.

Various implications have been suggested and realised for how **resilience can be incentivised or even financed through reduced insurance premiums**. The following examples illustrate that the resilience perspective can be a fruitful basis for joint-ventures between insurance companies and resilience-focused service providers – and offers insurers new distribution possibilities for their insurance offerings:

- US-based roof construction company My Strong Home[6] offers roof safety constructions that are directly financed through savings on home owner's insurance.
- Insurance providers have been requested to give discounts on business interruption premiums when infrastructure operators install back-up or distributed sources of energy to minimise downtime during blackouts (Kunreuther et al., 2016).

[6] mystronghome.net

- Insurance-linked loan packages were suggested for infrastructure resilience investments whereby an upfront insurance premium discount serves as an upfront dividend for the resilience investment (Centre for Global Disaster Protection & Lloyd's of London, 2018).

The main precondition for incentivising resilience through insurance discounts is a recognised procedure for assessing expected loss reductions through particular resilience investments.

Use case 2: Resilience bonds

As an alternative to traditional catastrophe insurance, **transfer to capital markets such as with cat(astrophe) bonds** is used since the mid-1990s to transfer well-defined sets of low-likelihood/high-impact risks from a sponsor (typically an insurance company) to investors. Cat bonds can cover various types of disasters, such as hurricanes, earthquakes, or floods.

Resilience bonds are an extension of such cat bonds that aim at incentivising investments in resilience. For instance, Goldman Sachs, Swiss Re, RMS, and the Rockefeller Foundation joined forces in the RE.bound programme, to structure resilience bonds for financing resilient infrastructure projects. In addition to cat bonds mentioned above, resilience bonds explicitly account for the risk reduction value of specific resilience investments on the expected loss to investors. This is done in two-steps:

1. The issuer validates if and how a specific resilience project reduces the expected loss for the investors based on financial catastrophe models. On that basis, the value of a resilience rebate is set from the reduced cost of coupon payments to investors.
2. Cost savings from the reduction in coupons paid to investors is captured and distributed to bond sponsor(s) in the form of a resilience rebate which can be used to finance risk reduction investments.

On that basis, resilience investments such as coastal protection systems to reduce physical and financial damage from storms and floods might be incentivised through lower potential losses passed up the chain to state and federal disaster budgets (RE.bound, 2017).

The technical bottleneck of such resilience bonds is the modelling of the reduction of the investors' expected loss due to a specific infrastructure project (similar to use case 1). Typically, such models need to be tailored to a specific infrastructure in order to allow for sufficient accuracy. Standardisation of methods and transferability as outlined previously in this paper is therefore limited.

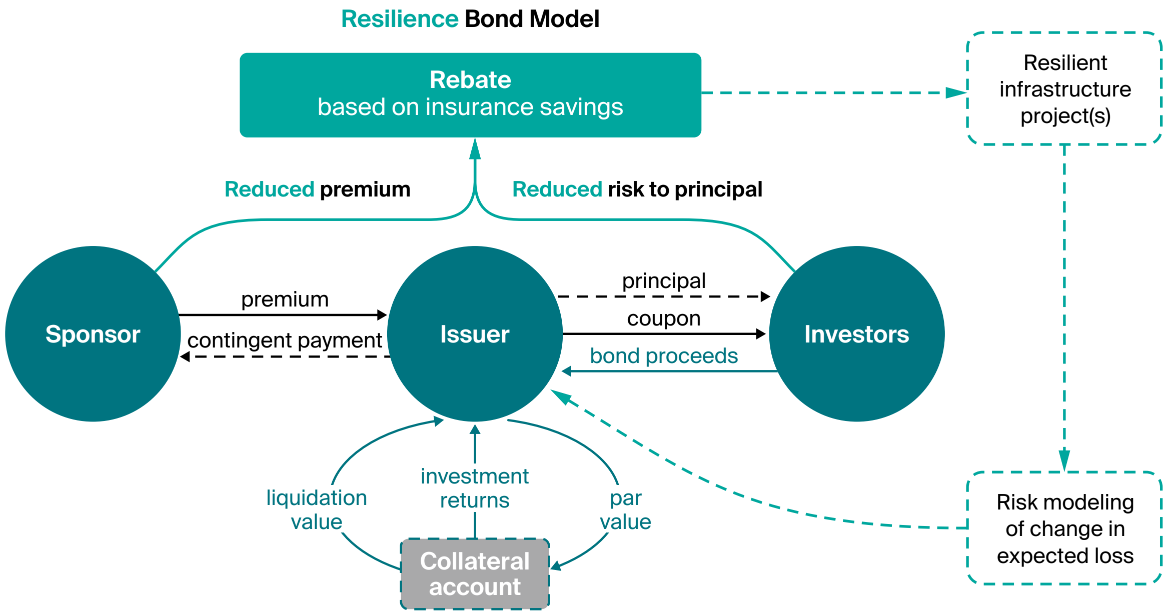


Figure 6: Illustration of a resilience bond structure

Use case 3:
Fast disaster response covers

Mechanisms of ex-ante disaster financing address a system's capability to respond and recover (i.e., phase 4 of the resilience cycle) because key challenges of post-disaster finance are 1) availability of funding and 2) too slow timing to support critical needs. Various possibilities of ex-ante financing exist for disaster response measures (Hammett & Mixter, 2017). For example, the Pandemic Emergency Financing Facility (PEF; a joint venture by the World Bank, Munich Re, Swiss Re, GC Securities) offers a solution for ex-ante financing of response and recovery measures for pandemic outbreaks. Emergency response funding is thereby accelerated by a combination of insurance payouts and pandemic bonds (Munich Re, 2018).

In this context, **parametric insurance is a major innovation** of the past decade. Parametric policies use indicators that are related to a hazard (e.g. wind speed, amount of rain, the intensity of seismic activity) rather than actual damage as insurance triggers. This reduces the cost of insurance and settlement can be very quick. The main effect of such fast disaster response covers is early cash flows that can facilitate recovery speed. In times of crisis, it is often the speed of an insurance payout that adds more value compared to government or humanitarian aid, which can often take several months (World Bank, 2017). Basis risk, i.e. the difference between the parametric trigger and the actual loss, needs to be addressed properly, however.

Use case 4:
Public-private partnerships

Large-scale infrastructure resilience projects require, in many cases, partnerships of multiple, both public and private stakeholders, i.e., so-called public-private partnerships (PPPs). Such PPPs are generally an opportunity for the insurance industry to extend the limits of insurability and thereby open new fields of business. There are already examples:

- The City of New Orleans, Veolia, and Swiss Re joined forces in the aftermath of Hurricane Katrina for sophisticated analysis and detailed planning of an efficient resilience strategy.
- The Terrorism Risk Insurance Act (TRIA) is a loss-sharing arrangement between insurers and the government for losses in a future terrorism scenario. It specifies that commercial losses that result from a terrorist attack will be paid by insurers (and uninsured firms) until they exceed 60 bn USD. Beyond that threshold, losses are paid by the government (Kunreuther et al., 2016).

Large-scale infrastructure resilience PPPs involve three key challenges (World Bank, 2017):

1. Contractual allocation of risks between different public and private stakeholders
2. Management of long-time contracts in changing environments
3. Commercial uncertainty in the costs of resilience investments

We argue that the insurance industry can contribute to each of these three challenges through its experience with both long-time and multiple-stakeholder contracts. In addition, **insurers might be able to provide transparency to PPPs**, via risk-based premiums both for individual and complex infrastructure systems.

Use case 5:
Resilience consulting

As mentioned previously, resilience is a truly complementary perspective to risk management, and insurers can offer advice to their client to reduce their vulnerability to risk and disruption in addition to cooperation around specific risks. Some insurers or brokers (e.g. Marsh 2018) explicitly offer resilience consulting to their corporate clients.

The resilience concept might also offer new possibilities to structure risk transfer. The effectivity of an insurance cover largely depends on the relevance of the selected triggers and compensation mechanisms. We argue that if insurance is used to increase a system's resilience, the selection of triggers and compensation should ideally be based on the system's functionality level (i.e., a predefined drop of the functionality level triggers an insurance payment that helps to recover in a predefined time).

Much of the resilience consulting currently serves to develop Business Interruption Insurance as well as contingent BI cover – for which losses have increased dramatically (Mizgier, Kocsis & Wagner, 2018). It will be challenging to advance the resilience concepts in practical applications, but as we have argued before we consider resilience-based strategies as an answer to systemic risk in a complex risk landscape.

Conclusion

In this policy brief, we summarized the concept of resilience, its relevance for critical infrastructures and the role of insurance. Resilience enhances the risk management toolkit in several aspects and may lead to higher safety and security, in particular in a complex, interconnected risk landscape. We consider resilience-based strategies as an answer to systemic risk in a complex risk landscape.

The implementation of resilience concepts in insurance is challenging. Many of the key factors that helped the insurance industry to develop and implement their current risk management practices will be difficult to implement in a resilience context. While risk management and resilience management differ, lessons can be drawn from the insurance industry, which can help to guide further development and successful implementation of resilience in the context of critical infrastructures.

Insurance has a positive impact on resilience by providing instruments of risk transfer and mitigation. There even exists a positive feedback mechanism, whereby higher resilience can improve insurability and indirect positive consequences of insurance, and additional or better insurance can strengthen resilience. The combination of insurance and resilience concepts appears to lead to win-win situations for all stakeholders. We consider the identification and use of positive feedback mechanisms a crucial success factor towards stronger resilience in critical infrastructures – and beyond. We are convinced there exist other cycles as well. We would like to encourage researchers and practitioners to look for them and make them applicable in the resilience context.

It is obvious that insurance is not the only solution to higher resilience, and there are other ways forward beyond the lessons that we have drawn. The OECD (2019) also stresses the importance of building partnerships to develop a common vision and agree on achievable resilience objectives. Comprehensive and practical governance structures and policy instruments that address the transboundary dimension of infrastructure systems and the issue of cost-benefit analysis and allocation in a multi-stakeholder situation with diverging interests have to be developed and implemented.

Advancing resilience requires multi-stakeholder dialogues between industry, academia and governments and the necessary platforms to enable that dialogue. Dialogue is necessary and is the first step towards action and real change. Risk and resilience managers should be careful that dialogue is not detached from real-world problems. Solutions have to be implemented that really impact the resilience of critical infrastructures.

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Acknowledgements

This policy brief elaborates from insights developed during the Horizon 2020 SmartResilience project (2016-2019) including at a workshop with experts in insurance, hosted by the Swiss Re Institute on 18 and 19 February 2019.

We are grateful for the input and feedback provided by various members of the SmartResilience project.

An external peer-review was coordinated by Ortwin Renn, with Igor Linkov, Reinhard Madlener and Bernd Schürmann, who provided thoughtful comments and suggestions. Copy-editing: Anca G. Rusu. Graphic design: Anne-Sylvie Borter.

The research leading to these results has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under the Grant Agreement No 700621.

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The International Risk Governance Center at EPFL (Ecole polytechnique fédérale de Lausanne) helps to improve the understanding and governance of systemic risks that have impacts on human health and safety, the environment, the economy and society at large. IRGC's mission includes developing risk governance concepts and providing risk governance policy advice to decision-makers in the private and public sectors on key emerging or neglected issues. It emphasises the role of risk governance for issues marked by complexity, uncertainty and ambiguity, and the need for appropriate policy and regulatory environments for new technologies where risk issues may be important.

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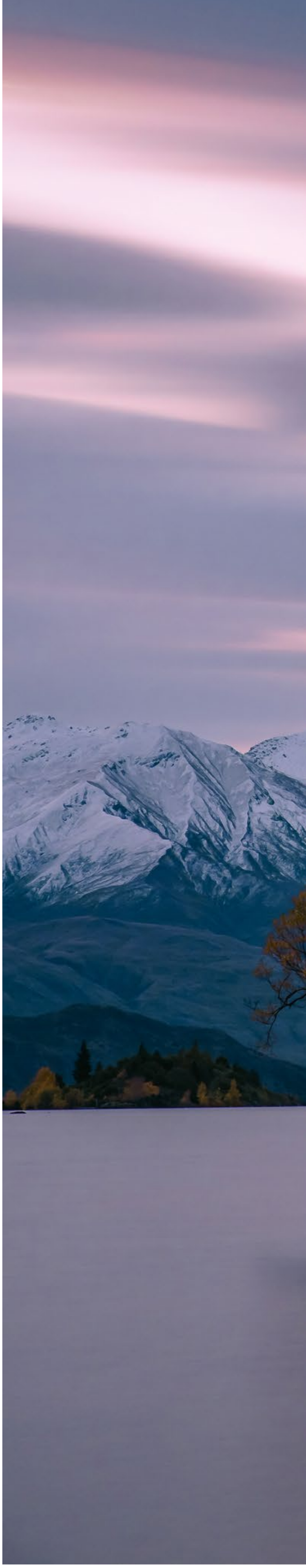

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