PUBLIC DELIVERABLE

H2020 Project: Smart Resilience Indicators for Smart Critical Infrastructure

D6.7 - Views from Insurance about the SmartResilience Project

Coordinator: Aleksandar Jovanovic EU-VRi

Project Manager: Bastien Caillard EU-VRi

European Virtual Institute for Integrated Risk Management

Haus der Wirtschaft, Willi-Bleicher-Straße 19, 70174 Stuttgart

Contact: smartResilience-CORE@eu-vri.eu

Views from Insurance about the SmartResilience Project

Report Title:	*Views from Insurance about the SmartResilience Project*		
Author(s):	Sachs R., Florin M.-V., Eller E.		
Responsible Project Partner:	EPFL	Contributing Project Partners:	

Document data:	Filename / Release:	SmartResilience - A discussion of Project Outcomes from an Insurance Perspective		Release No.: 2
	Pages:	42	No. of annexes:	3
	Status:	Final	Dissemination level:	PU
Project title:	Views from Insurance about the SmartResilience Project		Grant Agreement No.:	700621
			Project No.:	12135
WP title:	WP6: Dissemination and Exploitation		Deliverable No:	D6.7
Date:	Due date:	February 28, 2019	Submission date:	March 29, 2019
Keywords:	Insurance, resilience, critical infrastructure (CI)			
Reviewed by:	M. Bruch		Review date:	April 15, 2019
	R. Schneider		Review date:	April 15, 2019
Approved by Coordinator:	A. Jovanovic		Approval date:	April 16, 2019

April 16, 2019

Release History

Release No.	Date	Change
1	March 29, 2019	Revision after comments from workshop participants. Draft was sent to them for review and comments on March 15, with request to provide review by March 25
2	April 16, 2019	After peer review

Project Contact

EU-VRi – European Virtual Institute for Integrated Risk Management
Haus der Wirtschaft, Willi-Bleicher-Straße 19, 70174 Stuttgart, Germany
Visiting/Mailing address: Lange Str. 54, 70174 Stuttgart, Germany
Tel: +49 711 410041 27, Fax: +49 711 410041 24 – www.eu-vri.eu – info@eu-vri.eu
Registered in Stuttgart, Germany under HRA 720578

SmartResilience Project

Modern Critical Infrastructures are becoming increasingly smarter (e.g. the smart cities). Making the infrastructures smarter usually means making them smarter in the normal operation and use: more adaptive, more intelligent etc. But will these smart Critical Infrastructures (SCIs) behave smartly and be smartly resilient also when exposed to extreme threats, such as extreme weather disasters or terrorist attacks? If making existing infrastructure smarter is achieved by making it more complex, would it also make it more vulnerable? Would this affect resilience of an SCI as its ability to anticipate, prepare for, adapt and withstand, respond to, and recover? What are the resilience indicators (RIs) which one has to look at?

These are the main questions tackled by SmartResilience project.

The project envisages answering the above questions in several steps (#1) By identifying existing indicators suitable for assessing resilience of SCIs (#2) By identifying new smart resilience indicators including those from Big Data (#3) By developing, a new advanced resilience assessment methodology based on smart RIs and the resilience indicators cube, including the resilience matrix (#4) By developing the interactive SCI Dashboard tool (#5) By applying the methodology/tools in 8 case studies, integrated under one virtual, smart-city-like, European case study. The SCIs considered (in 8 European countries!) deal with energy, transportation, health, and water.

This approach will allow benchmarking the best-practice solutions and identifying the early warnings, improving resilience of SCIs against new threats and cascading and ripple effects. The benefits/savings to be achieved by the project will be assessed by the reinsurance company participant. The consortium involves seven leading end users/industries in the area, seven leading research organizations, supported by academia and lead by a dedicated European organization. External world leading resilience experts will be included in the Advisory Board.

Executive Summary

On 18-19 February 2019, EPFL organised a workshop of the SmartResilience project, hosted by the Swiss Re Institute in Zurich. The workshop gathered representatives from insurance and insurance experts. After providing some general considerations about insurance, resilience and critical infrastructure (CI) to describe the context in which the methodologies developed by the SmartResilience project can be used in an insurance setting, this report provides an analysis of the contribution of SmartResilience to insurance. The analysis elaborates from research made prior to the workshop, presentations made by partners of SmartResilience, and discussion among participants. While analysis and testing of ResilienceTool is still on-going among workshop participants, and it is thus premature to draw final conclusions, the interim observations and recommendations made at the workshop include that:

- SmartResilience is a timely and relevant initiative for insurance, which is truly interested in the methods developed and type of assessment that the ResilienceTool can provide for critical infrastructure
- Potential applications for CI operators include to get better i.e. more efficient and broader insurance coverage
- Potential applications for insurance companies include to develop new insurance products, based on a better understanding of CI resilience
- Insurers would welcome a method for comparing resilience across CIs (benchmarking)
- Potential advantages beyond the insurance industry include facilitating access to capital investment, an issue which is always important for CI
- Key recommendations for action include to:
  - Form a user group (community of practice)
  - Focus on key vulnerabilities of CI networks, including potential societal implications
  - Continue the conversation about the creation of an independent rating agency
  - Continue the conversation about standardisation

Table of Contents

List of Figures

List of Boxes

List of Acronyms

Acronyms	Definition
BI	Business interruption
CI	Critical Infrastructure
CIRAM	Critical Infrastructure Resilience Assessment Method
EPFL	École Polytechnique Fédérale de Lausanne
ERRA	European Risk and Resilience Assessment and Rating Agency
EU-VRi	European Virtual Institute for Integrated Risk Management
IBHS	US Institute for Business and Home Safety
IoT	Internet of Things
IRGC	International Risk Governance Center
KPI	Key Performance Indicator
PEF	Pandemic Emergency Financing Facility
PPPs	Public-private partnerships
NIST	US National Institute of Standards and Technologies
TRIA	Terrorism Risk Insurance Act

1 Introduction

This introduction sets the scene about the context in which the methodologies developed by the SmartResilience project have been evaluated by experts in insurance and representatives from the insurance industry. The evaluation was made during a workshop hosted by the Swiss Re Institute, on 18 and 19 February 2019. Specific evaluation in user groups continued after the workshop. The insurance industry is familiar with the concepts of risk analysis, business continuity, business impact analysis and recovery planning, and resilience assessment can be seen as part of this type of methodologies.

This report adopts the definitions of key terms used throughout the SmartResilience project. Resilience is generally defined as a system's ability to cope with possible adverse events that can potentially lead to significant disruptions in its functionality (EU-VRi, 2018; Jovanovic et al., 2016). It describes a state of dynamic stability of systems to deal with the sudden impact of adverse events, and to restore as quickly as possible their ability to function and their capacity to act. Critical infrastructures are those infrastructures that provide critical products and services to society and the economy.

- Risk and resilience must be 'articulated'. Managing resilience complements and includes risk management. They are considered two different approaches that address the unexpected threat of losses, both physical and financial, both events and trends. Risk management is still valuable and helpful and can be enhanced by assessing and improving resilience. Resilience is perceived as a more positive perspective, in contrast to risk that is negatively associated. The resilience perspective has thereby the power to convene people around a common goal. It is thus not surprising that both scholars and industry practitioners speak of a resilience hype in recent years.
- Although the two concepts are often contrasted, or even opposed, in the context of risk of disruption of services provided by CI, and direct and indirect negative consequences, insuring a CI subject to unexpected and potentially large-scale disruptions (for which a resilience-based approach is needed) often brings back to established concepts and methods such as those for risk assessment and management, business interruption (BI) or trade-offs between efficiency (e.g. leanness) and resilience (e.g. slack and redundancy).
- Resilience is for systems, not individual risks. Resilience is a property of systems that describes the capacity of a system to recover from disruption.
- CI are interconnected, complex systems. They increasingly form networks with adaptive features. 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.
- Interconnection in systems trigger the development of so-called 'systemic risks'. There is extensive description and characterisation of systemic risk, but few practical 'solutions' exist on how to manage them. For example, the Global Risk Report of the World Economic Forum describes and raises awareness to many global and interconnected risks, but does not propose 'solutions'. The International Risk Governance Center at EPFL (IRGC) suggests governance guidelines for systemic risks (IRGC, 2018), but reminds that there is insufficient knowledge about how to understand both the causes and the full extent of consequences of systemic risks, thus how to deal with them and cascading failures between systems, and generally poor collaboration between 'owners' of complex adaptive systems.
- Two examples provide relevant illustrations of global systemic risks. First, climate change does and will increasingly affect many CIs. Climate change is a global problem with local effects. Risks from climate change are not probabilistic and may materialise with sudden catastrophic events, which

calls for resilience-based approaches for their assessment and management. Because insurance provides compensation in case of specific damage following specific 'events', which are not probabilistic, like those deriving from climate change, insurance is interested in solutions based on better understanding of resilience levels and ways to increase it. Second, the increasing interconnectivity through the Internet of Things (IoT) is both a factor of resilience through modularity and diversity, and a source of new exposure and vulnerability. Risks resulting from the IoT entail multiple causes and consequences, and are not probabilistic either.

- Resilience must be a dynamic process that is adaptive to change. Engaging in building resilience involves engaging in a continuous process of change monitoring and adaptation, with the goal to improve performance (i.e. the performance of the system to deliver the critical services it is expected to deliver).
- Insuring a system is a challenge. Insurance needs a 'policyholder', which is normally a company or an institution, not a 'system' of CI, in which several entities participate. Going beyond insuring a 'risk owner', innovative models of cooperation and attribution of risk and resilience within the system need to be explored. Critical nodes have to be clearly identified.
- In the case of CI, the risk owner and the beneficiaries may not align. Similar to the management of systemic risks, for which recommendations include to focus on exposure and tolerability (because of the uncertainty about the risk source or the event leading to the risk), one may have to look at the beneficiaries of the services provided by the CI to develop effective insurance and other solutions to improve resilience.
- The insurance industry already contributes to resilience through conventional risk transfer solutions. For example, basic fire or flood insurance enable quick recovery after disruptions. However, those insurance solutions are better suited to protect individual, local policyholders. They do not address the need to cover entire systems, especially when those are affected by cascading disruptions between systems or CI. This raises a particular challenge called 'accumulation'. Systemic risk can lead to the accumulation of losses in an insurance portfolio or, more generally, to system failure. Based on the current structure of insurance products and financial strength of insurance companies most insurance products do not explicitly account for systemic risks with accumulation potential. It must be noted that accumulation primarily materialises in re-insurance (insurers' insurance), where non-systemic accumulation risk is properly addressed. Currently, (re-)insurance companies assess diversification and monitor and manage their accumulation risk through correlation assumptions and consideration of systematic vs. idiosyncratic risk. The development of systemic risk can be seen as a threat to diversification, one of the main cornerstones of insurance.

There is a common viewpoint that resilience-based insurance solutions can serve as a meaningful add-on to pure risk-based methods (defined as probability x consequences), and SmartResilience can make a useful contribution.

2 The basics of insurance and their requirements

The insurance industry is the centre of risk expertise and has therefore both the ability and the mandate to contribute to infrastructure resilience. Traditional infrastructure insurance products cover property damage, business interruption, and third-party liability. In addition, examples for modern insurance products include financial income protection (e.g., protecting energy companies against the negative financial effects of a warm winter) and cyber insurance (e.g., in terms of both physical damage and third-party liability). Beyond providing these risk-based solutions, it makes sense that insurance should also participate in improving the resilience of organisations and societies in general and critical infrastructures in particular (IRGC, in prep.).

There are a few basic, traditional principles that are required for any risk transfer through an insurance product. These principles remain valid even in a changing risk landscape and in the context of resilience solutions. They need to be considered in any attempt to use insurance as a tool for strengthening resilience. On-going approaches to resilience and contribution from the SmartResilience project are promising in the development of new solutions.

To enter into consideration for the development of insurance products (traditionally risk-based), insurance has certain requirements or needs, which we describe below, focusing on what that would mean for resilience-based insurance:

1. To measure and quantify resilience, as well as associated losses
2. To assess diversification in the portfolio and to address the issue of systemic risk or accumulation
3. To develop and implement standardised methods in the insurance market
4. To align interests between all stakeholders
5. To create incentives for continuous improvement

This section explains these needs in more details, to present conditions under which the indicators and methodologies developed by SmartResilience can be relevant to the insurance industry.

2.1 Insurance Need 1: Measure resilience / Quantification

Insurance provides compensation for experienced losses. The loss has to be measurable in financial terms. Loss frequency and severity need to be quantified, e.g. through probabilistic models and risk or resilience maps. If higher resilience leads to lower losses and fewer disruptions, this effect needs to be quantified as well. Only then resilience will lead to a benefit for the policyholders, which some of them may expect in terms of premium reduction, although it is not clear whether that is possible at all, and whether the economic incentive would be enough.

The assessment of critical infrastructure resilience must lead to quantitative results. Although qualitative aspects are helpful too, e.g. for the identification of critical issues, the use of insurance in an effort to improve resilience requires measurable and tangible outcomes, which are consistent across site and time. Amongst others, the following three approaches are practicable for quantifying resilience.

1. Quantification of resilience as reduced loss or expected losses. Resilience can be operationalised through the total loss of performance caused by a given disruption. Resilient systems are characterised by reduced total loss of performance (Moteff, 2012). This addresses also a reduction in expected loss.
2. Quantification of resilience as reduced expected recovery time (i.e., one of many "macro indicators", see Figure 4). Resilience can be operationalised through the amount of time needed to fully recover to normal operation. Resilient systems are characterised by quick recovery (Moteff, 2012). This addresses reduction in business interruption.

3. Quantification of resilience as the area under the functionality curve. The larger the area, the higher is overall resilience. While the exact shape may not 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 other 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).

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 desirability (i.e. what measures add value). Different stakeholders (e.g., communities, administration, CI providers, insurers, regulators, policymakers), as well as different infrastructures (e.g., energy providers, hospitals, water supply, telecommunication networks, gas stations), may have different requirements regarding measures of resilience. In the insurance context, the exact measure will depend on the definitions in a specific insurance contract (e.g., property damage, business interruption).

In real applications, several measures of resilience will be needed. It will be important, that these measures are consistent, are based on the same methods, or assessments can be related to each other. Any quantitative method needs to allow for ex-ante measurement of resilience, e.g., scenario modelling of the functionality curves of a particular CI under specific threat scenarios (e.g., NatCat, cyber, 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 providers and the insurers, possibly also involving society. Whereas ex-post analyses are helpful to identify weak spots and areas for future improvement (post mortem analyses), insurers have to be able to measure resilience already ex-ante.

2.2 Insurance Need 2: Diversification, pooling and need to address systemic risks

Risks in the insurance portfolio need to be independent from each other to a certain degree to create the pooling effect (law of large numbers). In the insurance portfolio, there has to be a diversification benefit. The expected loss in the portfolio is smaller than the total sum insured. Likewise, accumulations in the insurance (and particularly the re-insurance) portfolio need to be identified and managed. Accumulation risks can lead to large losses that may be threatening also for the (re)-insurance company, especially as risks are increasingly interconnected in long and complex value chains. Accumulation risks can occur, if a single risk driver causes many otherwise independent losses, e.g. the landfall of a hurricane leads to destruction of property along the coast. This is called systematic risk, and there are well-established methods for its management.

In contrast and addition to this, critical infrastructures are linked to the issue of systemic risks, both from a system-of-systems view and in the context of an insurance portfolio. 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, 2018). Whereas systemic risks are by definition caused by interdependencies and can lead to large accumulation risks, insurance is based on the principles of diversification and risk pooling, both presuming independency of a group of risks (IRGC, in prep.). This is why there is generally limited appetite for systemic risks in the insurance industry.

The resilience approach has the potential to reduce systemic risks by creating transparency about critical parts of the system, reducing the likelihood and extent of negative consequences of failure, and improving recovery times and adaptability. If resilience concepts are applied in critical infrastructure and the reduction of systemic risks can be assessed, e.g. via strengthening of critical nodes (e.g., energy supply), there would be a higher interest in the insurance industry to provide protection to operators of critical infrastructures. Any method for resilience assessment should provide a meaningful way to attribute the contribution of specific nodes to overall resilience, i.e. what is the benefit/value of strengthening the resilience of an individual CI. This would allow insurance to provide a tool for allocating costs and creating financial incentives.

2.3 Insurance Need 3: Standardised methods

Although resilience is clearly an emerging field, at some point in time, market standards have to be established for both the definition of resilience, for the methods of assessment and monitoring, and for the implementation of resilience frameworks in the market. In order to attach a price tag to resilience, there

needs to be a common understanding and market practice of what exactly is measured and how this translates into a price.

We do not advocate the view that regulation or any supervisory authority should define these standards. On the contrary, we trust that active knowledge exchange between all stakeholders involved, e.g. researchers, operators, insurers, governments, will lead to a generally accepted resilience framework and best practices. However, regulation can be a necessary incentive for wide implementation of resilience tools in the practice.

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 these requirements can be contradicting. For example, the more specific and tailor-made resilience indicators are defined for a particular infrastructure, the more meaningful the indicator will appear. At the same time, such specificity may hamper comparability (i.e., not being suitable for other infrastructures) as well as objectivity and transparency (e.g., if it is not self-evident how the specification has been done). Thus, such implementation of a methodological standardization is far from being trivial.

The definition and measure of loss also need to be standardised. Loss defined in the context of potential resilience-based insurance and measured after an event should be expected to coincide with loss defined in a traditional risk-based insurance.

2.4 Insurance Need 4: Aligning interests between stakeholders

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. Even though, the policyholder should be incentivised to avoid losses (e.g., through a retention).

Concerns have been raised that insurance may also create a false sense of security. It may reduce the incentive to those who manage the physical assets for safety and security from investing in resilience measures. In other words, insurance may also contribute to distracting from improving risk and resilience management. While this is certainly true, it is nothing new in the context of resilience management. This has always been an issue since the invention of risk management, mitigation and transfer.

The negative incentives of risk mitigation are certainly acknowledged. However, the positive aspects by far outweigh the negative ones. The moral hazard needs to be addressed. The insurance industry is experienced to address this in the proper design of the insurance contract (e.g., by retentions, deductibles, etc.).

Linking assessments of resilience to insurance protection requires that such assessment of resilience is independent of the operator of the critical infrastructure and of the insurer, in order to avoid conflicts of interest. It makes sense to establish a trusted third party, independent both from operators and individual insurance companies, which can model and evaluate the resilience of critical infrastructures. This will allow the development of standardised and comparable resilience assessments, and empower insurance market participants to develop and use standardized tools and KPIs and codes.

Who is best suited for such a role of an independent and trusted assessor of resilience? For the assessment of NatCat bonds, investors typically demand a risk modelling agency that is independent of the issuing (re)-insurer. For future resilience insurance 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).

2.5 Insurance Need 5: Incentivise continuous improvements

Managing resilience is an ongoing exercise. It does start with a first assessment and remains a learning, adapting and improving exercise. 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.

The insurance industry has a strong interest that their policyholders (i.e., infrastructure providers) are committed to this ongoing process. Outdated resilience methods and assessments will not reflect the current status of resilience adequately, mainly due to changes in the environment, technological degradation, and

general ageing of people and infrastructure. Prescriptive approaches and methods to resilience-building can lead to false incentives if the requirements are simply seen as one-time exercises in order to comply with some sort of standard or checklist as part of the insurance contract. The industry would rather look for methods that also foster changes in the corporate culture to enable ongoing improvements, for example via monitoring requirements and regular scenario exercises.

Economic and financial aspects are in many cases key obstacles to resilience improvement. Who pays for investments in resilience and how are costs attributed? Based on its risk expertise, the insurance industry might help reduce such financial obstacles, for example by creating direct or indirect incentives for investments in critical infrastructures to engage in continuous resilience improvement. Moreover, valid quantification and comparability of resilience are major stumbling blocks on the way forward. Results from the SmartResilience project can be a helpful starting point.

3 Existing contributions regarding resilience

This section contains examples of how insurance already contributes to resilience. Resilience 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. There exists a positive feedback mechanism: higher resilience can improve insurability, and additional insurance can strengthen resilience. The combination of insurance and resilience concepts appears to lead to win-win situations for all stakeholders.

For a structured approach, it is useful to look at the functionality level of a given system and divide the temporal process into five distinct phases that compose the resilience 'curve' (National Academy of Sciences, 2012; Øien, Bodsberg, & Jovanovic, 2018a), described below and illustrated in Figure 1.

1. *Understand risks.* The objective is to identify risk and assess their impact on the system, both direct and indirect consequences. Vulnerabilities have to be assessed.
2. *Anticipate/prepare.* Given a thorough understanding of the risk situation, foresight techniques have to be used, and scenarios for possible events should be analyzed. Appropriate measures for both expected as well as extreme events need to be developed and implemented.
3. *Absorb/withstand.* Try to avoid losses and disruption if/when a significant and relevant 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 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.

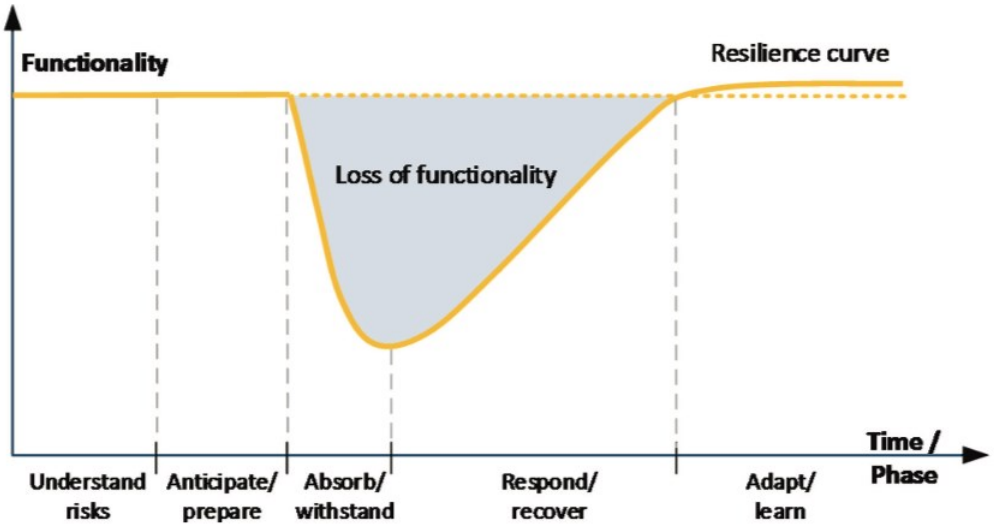

Figure 1: The five phases of functionality in a resilient system (Øien at al., 2018a)

The insurance industry supports in various ways the strengthening of systems towards increased resilience regarding all of the five resilience phases: 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 5) adapt/transform (e.g., through Public-Private Partnerships as well as the incentivisation of investments in resilience) as illustrated in Figure 2. Some examples could be allocated to several phases or also allocated differently. The proposed allocation simply serves to illustrate the range of contributions.

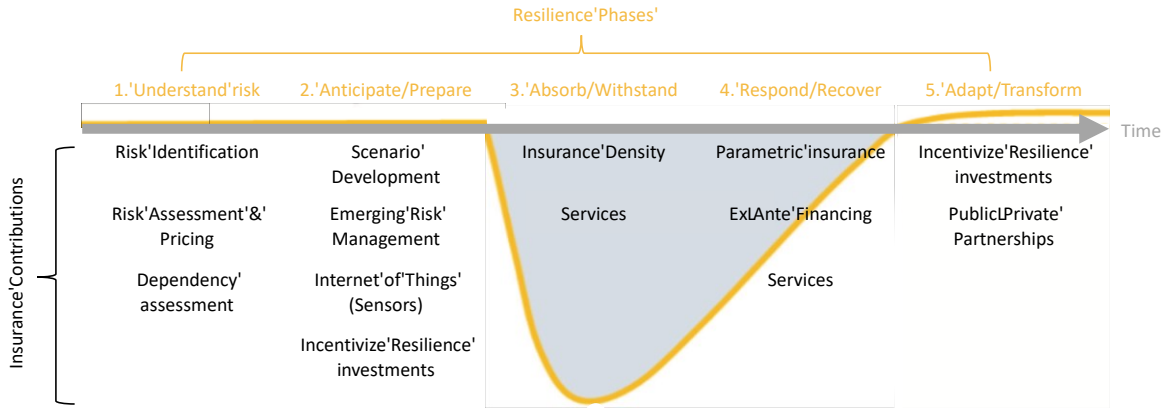

Figure 2: Insurance contributions along the resilience cycle

4 Challenges faced by the insurance industry / Where SmartResilience comes in

In this section, we summarise the challenges faced by the insurance industry concerning critical infrastructure. The purpose is to identify as clearly as possible where outcomes of the SmartResilience project should make a valuable contribution to the question of insurability of CIs based on their resilience level.

4.1 Risk identification

In the context of interconnected Cis, it is difficult to identify the individual risks and weakest points in the chain. SmartResilience can create the required transparency of CI resilience levels and lead to a better, i.e. more complete, understanding of the CI risk situation. SmartResilience can provide a framework to improve understanding of the risks, leading to the identification of new risks, rank-ordering the risks and enabling the design of specific insurance solutions that optimise the cost-benefit ratio. This is relevant because traditional risk-based insurance that simply increases overall insurance density only has a general effect on resilience. There are several reasons to this:

First, insurance only covers damage from loss events, and only when those have been anticipated and therefore covered in the insurance contract. Second, the individual nodes of a system must be relatively independent of each other. Third, insurance reduces individual risks by providing financial compensation for loss of or damage to physical assets. There is only an indirect protection by rewarding investments in physical protection measures via specific clauses in the insurance contract. Forth, insurance contracts are typically limited to named perils.

Comprehensive and complete understanding of the CI risks and resilience is, therefore, a prerequisite for any insurance solution. Comparability between risk and resilience assessments of different CI is essential and has to be enforced in the implementation. Any assessment method must produce reproducible results and be widely adopted (perhaps even standardised).

The SmartResilience method for identifying relevant 'indicators' for assessing the resilience of a CI is well-designed to address the challenge of risk identification.

4.2 Risk quantification

Complexity, uncertainty and quantification is and will remain a challenge. Insurers generally anticipate that quantifying resilience will remain a challenge, and their preference may be for solutions that do not require precise quantification (e.g. probability x severity), such as with parametric insurance.

The SmartResilience methodology provides two possibilities to analyze interdependencies within infrastructure systems. First, interdependencies can be described on the level of issues and indicators (e.g., what issues may arise in a particular phase due to dependency on another infrastructure). Going beyond that interdependency-as-issue approach, the methodology suggests assessing interdependencies at an "infrastructures-of-infrastructures" level. Thereby, one could analyze the effect of an incident on several infrastructures by using agent-based-models.

The extent to which insurers can leverage these approaches to take into account specific dependencies in their pricing needs to be determined.

4.3 Identifying critical nodes in interconnected systems

The critical role of risk quantification for resilience becomes even more apparent when considering entire systems. Strengthening a system's resilience requires to consider the dependencies between the individual components.

As seen in "insurance need #2", CI managers strive to know what are the critical nodes and associated vulnerabilities that they need to strengthen to improve the resilience of the entire system. For example, cities around the world need support in identifying and addressing critical weaknesses their systems, and ensuring sufficient level of strength in those nodes.

Identifying and investing in the robustness of a few systemically critical nodes is often more effective than homogeneously strengthening all of the system's nodes. A convincing concept is required to allocate the cost of improving overall resilience to individual stakeholders in such a setting.

SmartResilience provides a mean to assess interconnectedness, essentially via common issues and indicators. So far we have not seen a real focus on nodes and how the SmartResilience method can be used to identify critical nodes in a network of infrastructures.

4.4 Incentivising investments

Investments in resilience are generally difficult to sell: High present-day expenses are faced with only potential future advantages. In addition, networks of CIs do not have clear one or several risk owners and are thus not obvious policyholders (customers) of insurance. So solutions similar to community insurance may have to be developed, despite the possible heterogeneity in CIs that are linked in a network of CIs. For example, health care systems are composed of various types of actors such as hospitals and independent doctors, some public some private.

The main precondition for incentivising resilience through insurance discounts is a recognised procedure for assessing expected loss reductions through particular resilience investments. Thus, reliable measures of resilience that allow for conclusions on individual risks and insurance premiums are required to exploit the high potential of insurance for strengthening system resilience.

SmartResilience suggests measuring resilience using an indicator-based approach either indirectly (i.e., resilience level assessment) or directly (i.e., functionality level assessment). SmartResilience has the potential to be developed into a market standard. It has to be verified how such infrastructure resilience measures can be translated into specific expected loss assessments and thus insurance conditions to create investment incentives.

4.5 Regulation

Regulation is important and lacking for the overall improvement of resilience levels in critical infrastructures. The role of regulation to set principles or minimum legal requirement is important to constrain and incentivise the pursuit of socially desirable goals. Otherwise, incentives to develop insurance solutions and to buy insurance products around resilience may be low.

In order to manage and transfer risk to insurance, CI managers and risk owners must define their acceptable risk level and their desirable resilience level. This is not an easy task. There may be a misalignment between policyholders, beneficiaries of critical services, and insurance. Further, there is no such thing as an optimal resilience level that one can work towards. On the contrary, improving resilience is an ongoing effort that requires continuous investments.

SmartResilience could be the tool to track and compare resilience levels both across CIs and time. Hence, it could be the required transparency both for supervisory authorities and CI operators for learning from others and improving.

5 Solutions offered by SmartResilience

The SmartResilience project has developed a new and promising holistic methodology for the assessment and management of resilience of critical infrastructures, e.g., energy, water supply, and transportation networks (EU-VRi, 2018). It acknowledges potential large and systematic (e.g., environmental, geopolitical, societal, economic, and technological) threats (Jovanovic & Auerkari, 2016).

The project has

- Formalised five phases of the resilience curve
- Identified existing and new indicators suitable for assessing the resilience of critical infrastructures
- Developed a new advanced resilience assessment methodology based on smart resilience indicators
- Developed an interactive tool to assess and manage the resilience of critical infrastructures
- Applied the methodology and tools in several case studies involving energy, transportation, health, and water infrastructures

This section describes more specifically those aspects that are most relevant to insurance needs:

1. The five phases of the resilience curve
2. The indicators
3. The two methods for assessing resilience
4. Main expected benefits for a CI insurance

5.1 The resilience curve

The resilience curve or cycle (National Academy of Sciences, 2012; Øien et al., 2018) introduced in section 3 has been widely described elsewhere than in SmartResilience, but SmartResilience has specifically emphasised that the process starts with 'understand risk', which is particularly attractive to insurance. The resilience curve is a valuable tool for the structuring of insurance product development and the identification of business opportunities.

1. Understand risk

   This is the phase where the industry has the largest experience, yet struggles to cope with risks in complex adaptive systems. So this is the first and main phase where SmartResilience can make a valuable contribution to insurance. SmartResilience indicators (see below) and tools can increase transparency through risk identification, risk assessment and pricing, and dependency assessments.

2. Anticipate/prepare

   Using the SmartResilience assessment methods (see below) provides insights that enable anticipation through scenario development and emerging risk management.

3. Absorb/withstand

   The subscription by the policyholder of resilience-based insurance solutions will increase insurance density and coverage.

4. Respond/recover

   As explained in Box 1 below, innovations such as parametric insurance can accelerate payments. Ex-ante financing provides financial support to build resilience. These are typical insurance products that SmartResilience could target when it refines its fields of application.

5. Adapt/transform

SmartResilience could also be used to (a) inform Public-Private Partnerships and (b) incentivise investments in resilience.

5.2 Indicators: Three groups:

For each phase of the resilience curve, SmartResilience identifies the most important issues (i.e., a relevant factor, condition, action, or capacity that is critical for resilience in the respective phase). An issue is a very general term referring to anything (factors, conditions, functions, actions, capacities, capabilities, etc.) that is important in order to be resilient against severe threats such as terror attacks, cyber threats and extreme weather. It is what is important, and it is allocated to one of the five phases in the resilience cycle (e.g., it can be "training" performed in the anticipate/prepare phase).

An indicator is a description of how to measure an issue. Indicators can have logical values or numerical (e.g., it can be "percentage of personnel in a certain response team taken a certain course"; Øien et al., 2018a). It is crucial to have indicators, which are clear, realistic, unambiguous, measurable, tangible, standardised, harmonised and performing. The users will have a pivotal role in defining, selecting and assessing the value of the indicators.

SmartResilience organises indicators in three groups. All together they compose a 'customised dynamic checklist'.

- A 'core' group of indicators that are the same for all CIs and enable comparability across sectors. This core group is complemented by a set of 'recommended' indicators.
- A group of 'sectoral' indicators, that depend on the sector of activity (e.g. health, energy) and allow comparability within a sector
- 'Specific' indicators that each CI selects because they are relevant and important in its specific case

The assessment is made by 'experts' who know well the CI. The CI is given a score on each indicator, which altogether provide the quantified assessment, as will be seen below.

5.3 Methods for assessing resilience

Resilience is measured in two different ways in the SmartResilience project. The first method measures each phase indirectly through the selected indicators, without considering the shape of the resilience curve. The second method measures the loss of critical functionality directly, considering resilience as inversely proportional to the loss of critical functionality. In this case, the shape of the resilience curve is modelled. For both methods, the hierarchical indicator approach is used for assessing and managing resilience.

5.3.1 Method 1: Resilience Level Assessment

The suggested resilience indicators for Method 1 refer to the system's capacities along the phases of the resilience cycle (understand risks, anticipate/prepare, absorb/withstand, respond/recover, adapt/transform). More specifically, Method 1 is based on the most important issues for the CI and relevant indicators (see above).

On that basis, the identified indicators are assessed and aggregated by means of the Critical Infrastructure Resilience Assessment Method (CIRAM). CIRAM is a scale approach which applies across critical infrastructures, and it is using standardised indicator values and weighted averages across levels. The evaluated indicators sum up to an overall resilience level that can be used to benchmark and monitor the resilience of a critical infrastructure as well as to optimise investments in infrastructure resilience (Øien et al., 2018a, Øien et al 2017b; see Figure 3).

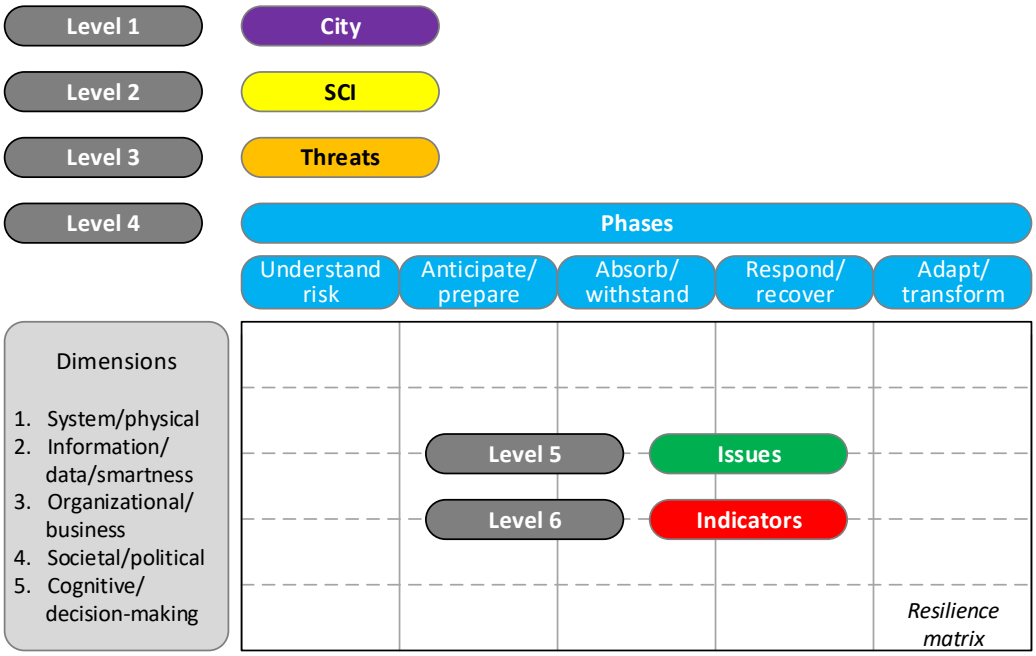

Figure 3: Illustration of Method 1 (CIRAM)

Regarding the quantification of resilience, Method 1 (CIRAM) does not consider the exact shape, size or area of the functionality curve directly. The critical infrastructure functionality curve as a function of time, before, during and after an adverse event is treated as a conceptual model within the SmartResilience methodology (see Figure 1). CIRAM is an indirect assessment within each of the five resilience phases. This provides a baseline resilience assessment of specific critical infrastructures under certain threats at a certain point in time. (Øien et al. 2017a). The outcome of CIRAM allows for relative assessments of resilience (e.g., across time, within a city), provided the individual assessments are based on comparable indicators and are evaluated according to comparable standards (e.g. user training or independent assessment agency).

5.3.2 Method 2: Functionality Level Assessment

Method 2 attempts to model the critical functionality curve directly. The main purpose of this assessment is to provide an understanding of how a disruptive event affects the critical functionality of an infrastructure. Assessment is performed by measuring so-called macro indicators like robustness, disruption time, absorption time, downtime, recovery time, recovery rate, improvement/adaptation/transformation, and loss of functionality (see Figure 4, Jovanovic et al., 2018a).

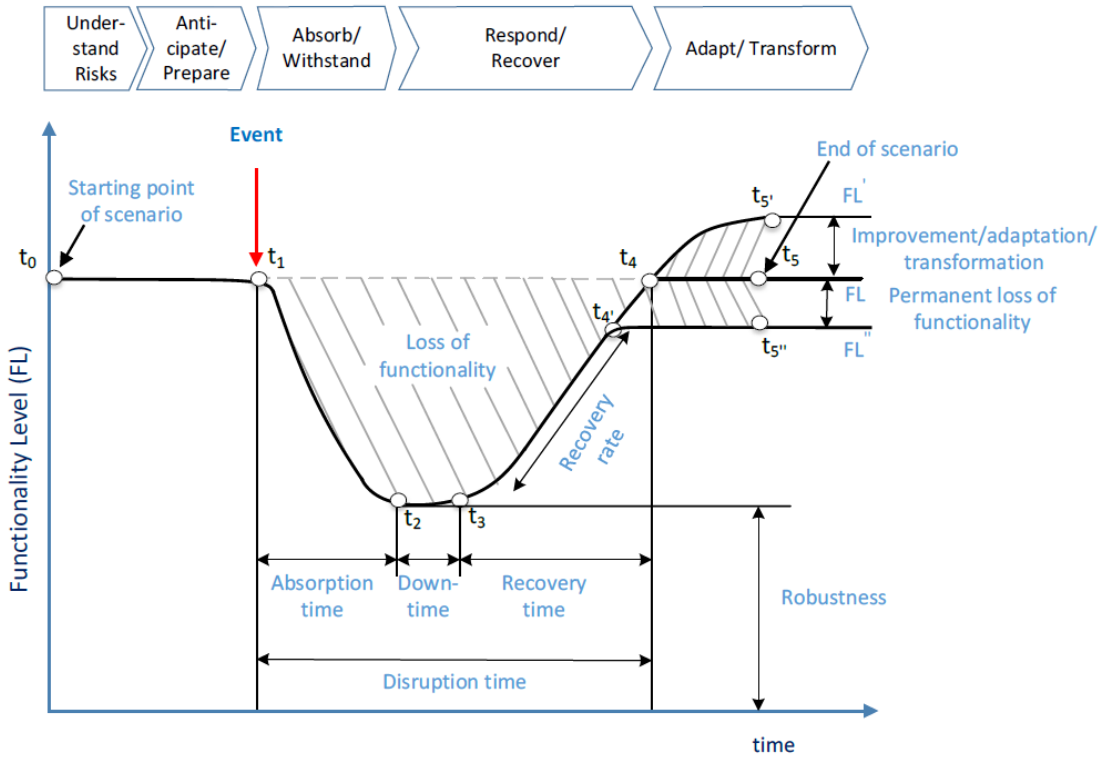

Figure 4: Illustration of Method 2

Hence, instead of resilience issues and indicators, Method 2 uses functionality elements and functionality indicators. For the obtained curve, individual thresholds can be defined (e.g. minimum remaining robustness, maximum disruption time (being aware that recovery times may vary according to business cycles) or maximum loss of functionality). Using Method 2, the critical functionality curve can then be used for stress-testing and assess whether, in a given specific threat situation, the infrastructure will be resilient enough to be able to continue functioning within prescribed limits. On that basis, the methodology can also be used for benchmarking, i.e. comparing the functionality levels of two or more infrastructures (see Figure 5; Øien et al., 2018b).

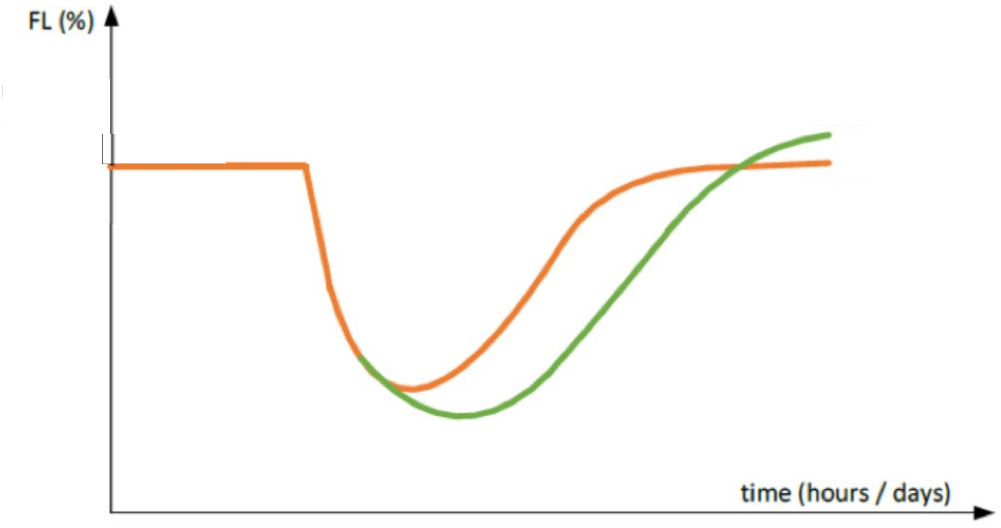

Figure 5: Benchmarking of two infrastructures based on Method 2

5.4 *Using SmartResilience assessment*

The main benefit for a CI to run a SmartResilience assessment exercise is to provide information about its capacity to understand its risks, prepare for, absorb and recover from disruptions. In particular, it provides a

measure of consequences of interconnectedness and vulnerabilities, in terms of disruption of critical services. This has been tested in case studies based on full-scale exercises.

The SmartResilience methodology was applied in several case studies that also served to model interconnectedness and interdependencies. Issues and indicators that are shared by different infrastructures indicate “lines of interconnectedness and interdependency”. The infrastructures involved and the issues/indicators form thus the logical network that can be analysed in order to model the propagation of influences from one infrastructure to another. Thus, the cascading and ripple effects can be modelled, and the dynamic behaviour of the network (“infrastructure-of-infrastructures”) analysed. Eventually, the 'ResilienceTool' (one of the product of SmartResilience) provides a user-friendly interface with a set of flexible tools that enables users to assess their level of resilience and benchmark their results against others, define optimal improvement measures, and perform stress-testing. The ResilienceTool aims to support authorities and critical infrastructure operators and owners in improving the disaster resilience of respective critical infrastructures through indicator-based assessment of their resilience capabilities (Jovanovic et al., 2019).

Besides using this information for its own needs, such as maintenance, development or investment, a CI can use this information in negotiations with insurance, to get better coverage. We are using the term 'negotiation' to indicate that there is no silver bullet and that the CI and the insurance should engage *together* into such evaluation, which should be performed collaboratively, over time, in a learning process.

Central to actual use is the fact that SmartResilience assessment must be consistent, accurate, reliable and able to predict ex-ante the resilience of a CI. As will be discussed below, reliability and other conditions will be required for wide adoption of SmartResilience methodologies in insurance.

6 Critique, recommendations and open issues

After presentations of the SmartResilience methodologies, workshop participants discussed and emphasised various aspects, strengths, opportunities for improvements and some specific recommendations:

6.1 SmartResilience is a timely and relevant initiative

After a decade of uncertainty and surprises, there is increasing awareness in the insurance industry that the risk management toolkit has to be enhanced. Two types of risks are particularly linked to the topic of resilience: non-quantifiable risks and systemic risk. Hence the SmartResilience initiative meets a topical and relevant demand. Insurance is collectively exploring how it can benefit from the current interest for resilience. It offers a flexible space for

- developing a robust method to assess the resilience and interconnectedness of CI
- testing and experimentation with new risk mitigating solutions, new product development
- demonstrating a commitment to progress, by CI operators (e.g. improve from 'score x')
- comparing different CI and share best practices

Interest was demonstrated by the participants in the workshop (whose views are summarized in this report) and can be illustrated by quoting some insurance representatives who were invited to the workshop but could not come (see Box 2 below)

6.2 Potential applications for CI operators, to get better insurance coverage

Creating transparency about the own risk situation is an obvious advantage for CI operators. In the context of the workshop, an important potential application was mentioned: The learning from a SmartResilience assessment can be used to get better insurance coverage and for insurance to calculate its risk exposure better. “Better” can mean “more tailored”, “more economical”, “more realistic”, etc. Buying risk protection is, in general, a better-informed decision.

Investments in resilience are generally difficult to sell because high present-day expenses are faced with (only) potential future advantages. By providing insurance discounts for increased infrastructure resilience, risk-based priced insurance can thus turn potential future advantages into immediate financial incentives for resilience investments.

However, several conditions need to be considered here:

- 'Better' insurance can be provided if the assessment made by SmartResilience is accurate, reliable, reproducible and comparable. This implies much testing, experimentation, monitoring, feedback from events, and learning over time to refine the methodology. There is sufficient conceptual groundwork to do now empirical analyses and implementation.
- ‘Better’ insurance may not imply premium rate reduction. Under current insurance conditions, premium discounts can only be given under two conditions: First, an investment in risk reduction reduces the risk covered by the insurance policy in terms of probability or severity. Second, this risk reduction is measurable. Thus, reliable measures of resilience that allow for conclusions on individual risks and insurance premiums are required to exploit the high potential of insurance for strengthening system resilience.
- The monetary value of the reduction in insurance premium will most probably remain very low compared to the cost of investing in resilience. Workshop participants do not expect that a discount in premium (if at all possible) would create a strong financial incentive.

- Practical implementation will be challenging with respect to comparability and information sharing outside the CI boundaries.

6.3 Potential applications for insurance companies, to develop new or improved insurance products

Resilience can be an opportunity for the insurance industry to offer new products and services to its clients. Today, the insurance industry already provides services that improve resilience based on risk management advice and risk transfer products. Changing the perspective to resilience management can even improve the role of the insurance industry. However, the insurance industry has several lines of business, and more work needs to be done to identify where specifically SmartResilience can be used as a robust tool that would have to be shared and used across the industry.

Some specific advantages were mentioned during the workshop:

- Strengthening resilience may increase the insurability of risks and create new business potential.
- SmartResilience can be used to improve the performance of various existing types of insurance solutions relevant to CI.

As has been already pointed out elsewhere in the report, a key success factor for the adoption and application of SmartResilience is not only a robust, reliable and objective method for resilience assessment, but also its implementation in the market (issues around trust, alignment of interest, comparability, etc.)

For illustrative purposes, five 'use cases' are described in Box 1 below, including (1) resilience-based insurance pricing, (2) resilience bonds, (3) fast disaster response covers, (4) public-private partnerships, and (5) resilience consulting. Each of these use-cases describes how SmartResilience could make a valuable contribution to the insurance industry to approach resilience.

Box 1: Use cases

The insurance industry is currently working on new contributions to strengthening infrastructure resilience. Clearly, the resilience perspective can stimulate new insurance solutions that go beyond offering pure risk transfer.

Use Case 1: Resilience-Based Insurance Pricing

Insurance is priced at an actuarially fair rate when the premium charged to cover a risk equals its expected loss (Kunreuther et al., 2016). In reality, there will be more components in pricing but, for the purpose of this report, this simplified relation is sufficient. An infrastructure's resilience, as a function of a system`s functionality level, 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. 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. The more accurately an insurer is able to assess the expected loss of covered risks, the more competitive its offers. Being able to take into account an infrastructure's resilience in that infrastructure's risk assessment can thereby enable an insurer to both select and price risks as well as allocate capital and steer risk appetite more effectively all resulting in a competitive advantage.
Various implications have been suggested and realised for how resilience can be incentivised or even financed through reduced insurance premiums. For instance, the US-based roof construction company My Strong Home offers roof safety constructions that are directly financed through savings on home owner's insurance. In the context of critical infrastructures, 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). As the last example, 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). These 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.

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

>>> SmartResilience suggests measuring resilience using an indicator-based approach either indirectly (i.e., resilience level assessment) or directly (i.e., functionality level assessment). This provides a conceptual basis for resilience measurement and a possible way towards implementation. It has to be verified how such infrastructure resilience measures can be translated into specific expected loss assessments and thus insurance premium.

Use Case 2: Resilience Bonds

As an alternative to traditional catastrophe insurance, transfer to capital markets such as with cat(astrophe) bonds are 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. Technically, the sponsor issues bonds through an issuer (an investment bank) that are sold to investors for a defined period of time (usually 3-5 years). At the end of the period, the sponsor pays a coupon to the investors if no catastrophe has occurred. However, in case of a catastrophe of a predefined magnitude (e.g., 1 bn € of losses for a surge height of 10 m) the sponsor uses the full value of the bond to pay claims. The bond principal is partially or fully lost for the investors. On that basis, 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, the RE.bound program is a prominent joint-venture between Goldman Sachs, Swiss Re, RMS, and the Rockefeller Foundation that structures resilience bonds for financing resilient infrastructure projects. The basic relationship between the sponsor, issuer, and investors is similar to normal cat bonds. In addition, however, resilience bonds explicitly take into account the risk reduction value of specific resilience investments on the expected loss to investors. This is done in a two-step process. First, the issuer validates if and how specific resilience project reduces the expected loss taken by 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. Second, the 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, 2018).

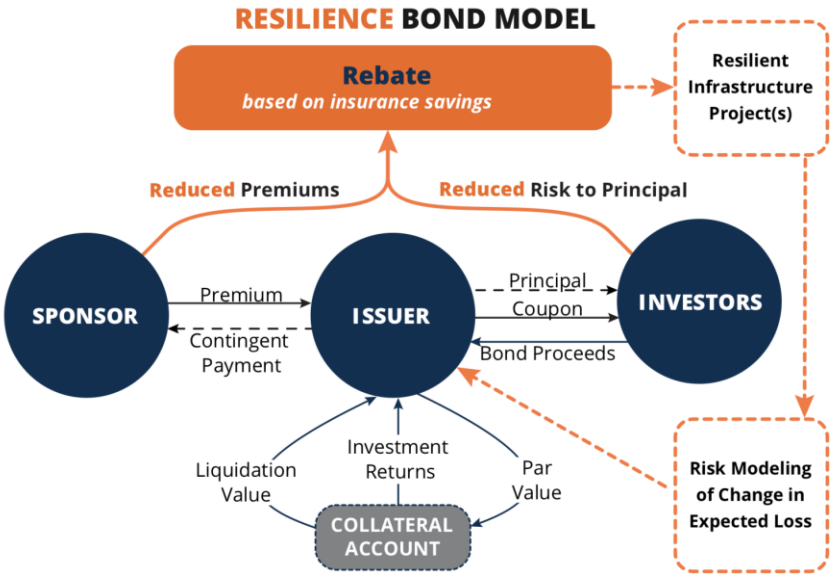

Figure 6: Illustration of a resilience bond structure

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. Therefore, the transferability of such structures on other contexts is limited.

>>> SmartResilience suggests a new methodology to measure infrastructure resilience based on a predefined list of indicators. It needs to be verified whether and how the effect of specific resilience investments on expected losses can be measured through that approach in the context of resilience bonds. Resilience bonds require trusted third parties who (1) have the credibility to make such assessments and (2) are politically and economically independent from sponsors and investors. An independent Resilience Rating Agency such as the one considered by the SmartResilience project in Europe could in principle act as such a third party auditor. Workshop participants pointed out the challenges in the realisation of such an agency in terms of data rights and privacy, financing, and in particular standardisation of method and application. The flexibility of the current method may make rating-type application difficult, so the set of common core indicators are very important for comparability, consistency and rating.

Use Case 3: Fast Disaster Response Covers

Use-cases 1 and 2 focus on facilitating investments in an infrastructure's ability to absorb or withstand losses or disruption (i.e., phase 3 of the resilience cycle). An alternative strategy that addresses a system's capability to respond and recover (i.e., phase 4) are mechanisms of ex-ante disaster financing. The key challenges of post-disaster finance are 1) availability of funding and 2) timing (which is often too slow 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 last years that can dramatically accelerate insurance payments. Parametric policies use indicators that are related to a hazard (e.g. wind speed, amount of rain, intensity of seismic activity) rather than actual damage as insurance triggers. This reduces the cost of insurance and settlement can be very quickly. In contrast to indemnity-based insurance, which requires a loss adjuster to assess individual damage, parametric insurance can pay out almost immediately. 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).

>>> A conceivable contribution of the SmartResilience methodology, in this case, is based on its assessment of a system's resilience ex-ante, especially regarding its expected capability to respond and recover to threats (recovery time, recovery rate, etc.). In other words, the insurance contract could use the resilience level as parameter and based on its value trigger pay-outs. On that basis, financial needs could be identified that can be addressed with ex-ante disaster financing mechanisms. However, the definition and design of parametric triggers are far from trivial and, among others, require highly reliable methods and data and independent assessments.

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). For example, the City of New Orleans, Veolia, and Swiss Re joined forces in the aftermath of Hurricane Katrina to increase resilience by sophisticated analysis and detailed planning of an efficient resilience strategy. As a second example, 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).
Such PPPs are generally an opportunity for the insurance industry to extend the limits of insurability and thereby open new fields of business. As per the World Bank (2017) such large-scale infrastructure resilience PPPs involve three key challenges:

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. We have highlighted that risk-based premiums can provide accurate and easy-to-understand information on infrastructure risks and resilience. This applies not only for individual infrastructures but likewise to complex infrastructure systems. In such systems, individual risk is heavily dependent on external variables. For instance, a logistics company's business continuity relies on the availability of gas stations which rely on the availability of electricity and so forth.

>>> The SmartResilience methodology provides for two possibilities to analyze interdependencies within infrastructure systems. First, interdependencies can be described on the level of issues and indicators (e.g., what issues may arise in a particular phase due to dependency on another infrastructure). Going beyond that interdependency-as-issue approach, the methodology suggests assessing interdependencies at an "infrastructures-of-infrastructures" level. Thereby, one could, in theory, analyse the effect of an incident on several infrastructures by using agent-based-models. The extent to which insurers can leverage these approaches to take into account specific dependencies in their pricing is currently not clear. Participants also acknowledged that the challenge of managing systemic risks is beyond the scope of the SmartResilience project.

Use Case 5: Resilience Consulting

Both risk management and insurance build on the identification of specific threats that are then tried to be prevented or transferred. Thus, the discussion and cooperation between an insured and an insurer circulate mostly around specific risks so far. In contrast, resilience is a truly alternative perspective. Resilience can be an opportunity for the insurance industry to consult their clients from new perspectives and to identify new mechanisms to strengthen infrastructures by developing new products and services to enhance resilience. For instance, some insurers or brokers (e.g. Marsh 2018) explicitly offer resilience consulting to its 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. For instance, business interruption covers are typically triggered by a physical loss caused by one of several defined events (e.g., fire, flood) and compensates for resulting losses of income or profit. We argue that if insurance is used to increase a system's resilience, the selection of triggers and consequences 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 recovering 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. It is challenging to understand the complex risk landscape and to move to the organisational and systemic perspective.

>>> SmartResilience offers an approach to quantify overall resilience levels and specific features of the resilience curve. This approach for ex-ante assessment of functionality in case of disruption can be a valuable support to consulting, which insurance can provide to those interested in resilience insurance. It can help the structuring of resilience insurance consulting. Participants mentioned that CI operators have their own resilience assessment tools. SmartResilience could provide an advantage if its results are comparable to market best-practises, and the impact of insurance on resilience levels could clearly be quantified.

6.4 Potential advantages beyond the insurance business

The insurance industry is a well-established and respected centre of risk expertise. Therefore, it has both the ability and the mandate to constructively contribute to increasing resilience through the support of innovations, tests, including through trials and errors.

For insurers, the outcome of SmartResilience can be used for other purposes than assessing the resilience of their customers or developing insurance products.

Insurance companies could use SmartResilience to test their own resilience. Insurance companies need to understand the direct and indirect impacts of particular loss events on their portfolio. This is already extremely difficult and will be more so in a future with complexity and interconnectedness. In addition to pursuing the strategy “more of the same” (understand risk, create transparency, provide protection), insurance can use SmartResilience for their own purposes.

It also makes perfect sense for insurers to adopt a methodology for resilience assessment and work on resilience solutions from a reputational perspective. Resilience is perceived as something positive, in contrast to risk that is perceived negatively. Resilience has the power to convene people around a common goal. If the insurance industry succeeds to develop and sell additional products and services to enhance resilience its reputation will be affected positively.

Facilitating capital investment in CI. For CI and capital investors, the external benefits of insurance to provide coverage around 'resilience' should not be underestimated. For example, the SmartResilience assessments (1 or 2) can be valuable methods for facilitating investment selection and access to capital market (insurance is a useful but not the primarily vehicle to invest in resilience).

Improving the capacity of CI to attract investments (problem of ageing and maintenance, long-term sustainability) is a common critical need. Investments can be from external investors, for example, insurance companies themselves. Insurers are among the largest investors globally. Even if their asset management role is not the focus of this report, insurers are generally interested in long-term investment opportunities. Resilience methods may allow the measurement and mitigation of risks in long-term infrastructure projects and hence make these investments more attractive and sometimes even accessible for insurers. Quite often, long-term risks in infrastructure investments prevent regulated investors like insurance companies to provide funding.

So one way for the insurance industry to move towards a more resilience-based approach is to provide value beyond financial protection. This aligns with the long-term sustainability goals of the industry (reconcile short and long-term).

6.5 Key recommendations for action

Overall, there is strong wish and recommendation to pursue the conversation and to use in practice the SmartResilience indicators and assessment tools. The main concrete recommendations that were clearly expressed during the workshop can be summarised along the following points.

6.5.1 Form a user group (community of practice)

Most workshop participants were unfamiliar with the details of the SmartResilience tools before the workshop. A majority of them was interested in forming a user group on the SmartResilience platform, to test and share data and feedback. Together with SmartResilience partners, this user group can evolve in a community of practice, to share and shape the future of resilience and SmartResilience in insurance. Some invitees to the workshop were unable to attend but had expressed interest in the outcome, and in being involved in future activities (see box 2 below).

Action points:

- Create a shared database that a group of users can use to store data that they accept to share with others, and which they can access, for the purpose of learning
- Provide training to the user group and explain the methodology along the case studies and/or user specific cases
- Test the SmartResilience methodology and share insights.
- Consider also the further evolution of the Smart Resilience method
- Clarify the roles of the different stakeholders

6.5.2 Focus on key vulnerabilities of CI networks

One key challenge in the management of complex interconnected systems is to model and understand interdependencies and to identify critical nodes. The weak links in the chain and their vulnerabilities are

potential triggers for systemic crises. If SmartResilience could help identify those and assess where investments are most needed to remedy fragilities, this would make a very useful contribution.

Action points:

- Provide examples of network analysis using the SmartResilience methods
- Survey the user group for real-world examples, that really hurt in the past
- Identify critical nodes and interdependencies in real-world examples and back-test the model results.

6.5.3 Continue the conversation about the creation of an independent rating agency

As mentioned above, it is critically important that assessment outcomes provided by SmartResilience are reliable, reproducible and comparable, and that the interests of all stakeholders align. This likely requires the formation of an independent rating agency that would certify the quality of assessment outcome. The following principles may be considered, some of which are consistent with current thinking in ISO, which tends to develop principles or guidelines that are able to evolve as technology develops and as performance improves, rather than fixed standards that do not evolve and may be used as checklists.

It may be worth noting though that various types of CI may need various types of rating agencies or systems. For private corporations, who do not provide critical services, market standards and their own reputation are important, and an independent agencies may thus not be seen as necessary. For public CI and resilience in a public and societal context, an independent rating authority may be relevant and needed to provide benchmarking and encourage continuous improvement. Regulators and supervisory authorities will most likely be involved in this process. Finally, would insurance rely on a rating agency to evaluate the resilience level of a CI before providing a resilience-based insurance, this would require that the rating agency focuses on the specific needs of the insurance business.

Action points:

- Elaborate a formal proposal for an independent rating agency, including details around data privacy and sharing, financing, and legal structure
- Ask future clients (e.g. insurance companies) for their feedback already in the early stages of the development process.

6.5.4 Continue the conversation about standardization

Use SmartResilience as a starting point for developing standardised methods for evaluating the resilience of a CI that would be used by the insurance industry

Action points:

- Provide an overview of existing alternative methods and market best-practices (if available)
- Engage in discussion with standardizing bodies, e.g. ISO

Box 2: Specific comments from insurance representatives

… from workshop invitees who were unable to attend:

- The … Chairmanship has discussed your invite but sadly cannot participate. However, we would be very interested to see any communications that come out of the project. Is this something which can be shared with the …?

- Thank you so much for this kind invitation to what looks like an excellent event. Very regretfully I will be in Asia that week and unable to attend. However, we would like to support … this important meeting….

- I have been trying to clear my calendar to allow me to attend the meeting; however, I regret that this has not been successful. This is of considerable regret – as I am very interested in the agenda; would it be

possible to get a report from the meeting afterwards?

- I am very sorry to be missing this event but I hope there might be an opportunity to join even for a sharing of our work.

- … learning about your approach towards the relation between unexpected developments and the required strategic answers of those events would definitely be interesting and relevant for me…

… from some workshop participants / ResilienceTool* users (as per 29 March 2019)

ResilienceTool: https://resiliencetool.eu-vri.eu/RunningApp/RIdb/Welcome.aspx

Feedback survey: http://www.smartresilience2.eu-vri.eu/Survey_Run.aspx?ID=978

User #1: "*I work on smart cities. I am planning to use the SmartResilience methodology. It will be key to building sustainable cities. The interconnectedness of risk and helping cities in transformation are core to my work.*"

User #2: "*I have a very good impression of the SmartResilience project results, but I have not yet assessed the tools. I got the impression of a multifunctional systematic approach based on profound research. I consider using the methodology. I recommend reducing complexity of information for marketing activities, if possible. E-Learning applications or other descriptive visual guided tours into the tool might be a mean for the first handling impression*".

7 Conclusion

The SmartResilience project has produced new types of analyses that are welcome by the insurance industry. This will be useful to its effort to embrace the field of resilience, with a view to overall improving its capacity to help critical infrastructure prepare for and recover quickly from disruptions. The field is on a path to progress and SmartResilience is certainly part of this.

8 References

All SmartResilience public deliverables are available from http://www.smartresilience.eu-vri.eu/Results

[1] Cambridge Centre for Risk Studies (2018), *Cambridge Global Risk Index 2018 Methodology*. Retrieved from https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/risk/downloads/crs-cambridge-global-risk-index-exec-summary-2018.pdf

[2] Centre for Global Disaster Protection & Lloyd's of London (2018). *Innovative finance for resilient infrastructure.* Retrieved from https://www.lloyds.com/news-and-risk-insight/risk-reports/library/society-and-security/resilient_infrastructure

[3] EU-VRi (2018). *Resilience Assessment workflow in the SmartResilience project.*

[4] Hammett, L. M., & Mixter, K. (2017). *Adaptive Finance to Support Post-Disaster Recovery.* Yale Center for Business and the Environment.

[5] IRCG (2018). *Guidelines for the Governance of Systemic Risks.* EPFL, Lausanne.

[6] IRGC (in prep.). *The Importance of Insurance for Stronger Resilience in an Interconnected Risk Landscape.* EPFL, Lausanne.

[7] Jovanovic, A. & Auerkari, P. (2016). *EU project SmartResilience: The concept and its application on critical energy infrastructure in Finland*. CRS Report for Congress.

[8] Jovanović A., Øien K. , Jelic M., Choudhary A., Tetlak K., Auerkari P., Macika S., Rosen T. (2018a). *SmartResilience D3.3: Modelling the impact of an adverse event on the "absorb" and "recover" capacity of a smart critical infrastructure, based on resilience indicators,* EU project SmartResilience, Project No. 700621 (2016–2019). EU-VRi, Stuttgart. Retrieved from http://www.smartresilience.eu-vri.eu/sites/default/files/publications/SmartResD3.3.pdf

[9] Jovanović A., Jelic M., Rosen T., Macika S., Øien K. (2019). *SmartResilience D3.7: The "resilienceTool" of the SmartResilience poroject,* EU project SmartResilience, Project No. 700621 (2016–2019). EU-VRi, Stuttgart. Retrieved from http://www.smartresilience.eu-vri.eu/sites/default/files/publications/SmartResD3.7.pdf

[10] Kunreuther, H., Michel-Kerjan, E., & Tonn, G. (2016). *Insurance, Economic Incentives and other Policy Tools for Strengthening Critical Infrastructure Resilience: 20 Proposals for Action.* The Wharton School, University of Pennsylvania.

[11] Marsh (2018). Retrieved from https://www.marsh.com/de/de/home.html

[12] Moteff, D. (2012). *Critical Infrastructure Resilience: The Evolution of Policy and Programs and Issues for Congress*. CRS Report for Congress.

[13] Munich Re (2018). Epidemic Risk Insurance – Saving lives, protecting economies. Retrieved from https://www.munichre.com/topics-online/en/business-risks/epidemic-risk-insurance-saves-lifes.html

[14] National Academy of Sciences (2012). *Disaster Resilience – A National Imperative.* The National Academies Press, Washington D.C.

[15] Øien K., Jovanović A., Grøtan T. O., Choudhary A., Øren A., Tetlak K., Bodsberg L., Jelic M. (2017a). *SmartResilience D3.2: Assessing Resilience of SCIs based on Indicators,* EU project SmartResilience, Project No. 700621 (2016–2019). EU-VRi, Stuttgart. Retrieved from http://www.smartresilience.eu-vri.eu/sites/default/files/publications/SmartResD3.2.pdf

[16] Øien, K., Bodsberg, L., Hoem, Å., Øren, A., Grøtan, T. O., Jovanović, A., ... Tuurna, S. (2017b), *SmartResilience D4.1: Supervised RIs: Defining resilience indicators based on risk assessment frameworks,* EU project SmartResilience, Project No. 700621 (2016–2019). EU-VRi, Stuttgart. Retrieved from http://smartresilience.eu-vri.eu/sites/default/files/publications/SmartResD4.1.pdf

[17] Øien, K., Bodsberg, L., & Jovanovic, A. (2018a). Resilience assessment of smart critical infrastructures based on indicators. *In* Haugen et al. (Eds), *Safety and Reliability – Safe Societies in a Changing World.* Taylor & Francis Group, London.

[18] Øien, K., Jovanović, A., Bodsberg, L., Øren, A., Choudhary, A., Sanne, J., Bergfors, L., Molarius, L., Vollmer, M., Walther, G., Szekely, Z., Auerkari, P., Klimek, P., Bezrukov, D. (2018b). *SmartResilience D3.6: Guideline for assessing, predicting and monitoring resilience of Smart Critical Infrastructures (SCIs)*, EU project SmartResilience, Project No. 700621 (2016–2019). EU-VRi, Stuttgart. Retrieved from http://smartresilience.eu-vri.eu/sites/default/files/publications/SmartResD3.6.pdf

[19] RE.bound (2018). *A guide for public-sector resilience response sponsorship. Available on* www.refocuspartners.com/rebound

[20] World Bank (2017). *Resilient Infrastructure Public-Private Partnerships: Contracts and Procurement – The Case of Japan.* Retrieved from http://documents.worldbank.org/curated/en/479931516124878843/Resilient-infrastructure-public-private-partnerships-PPPs-contracts-and-procurement-the-case-of-Japan

ANNEXES

Annex 1 Workshop agenda

Monday 18 February 2019

16:30 – 17:00 Registration

17:00 – 19:00 Session 1: The role of insurance for strengthening resilience

This session will set the scene for the workshop by discussing how insurance can enhance resilience and how the insurance industry should engage in resilience assessment and management. There are challenges for insurance to address a changing risk landscape with conventional risk-based tools. Insurance can also help make long-term investment in CI, which are otherwise hard to make because cost-effectiveness is difficult to work out in the short term. However, challenges to measure and quantify resilience must be overcome.

Briefing document:

- "The importance of insurance for stronger resilience in an interconnected risk landscape"

Brief presentations:

- Marie-Valentine Florin, IRGC @EPFL: introduction
- Rainer Sachs: challenges and opportunities, needs and questions
- Remo Steinmetz, Swiss Re: perspective from (re-)insurance

Questions to guide the discussion:

- *How are resilience-based and risk-based approaches differentiated in the insurance industry?*
- *Which practical approaches and definitions for resilience are already used, or would be required in the industry?*
- *How is resilience assessed, measured and quantified?*
  Which aspects are important for practical applications?
  What methodology is used, or needed?
- *How are interdependencies and systemic risks assessed/quantified? What methodologies are used or needed?*
- *Do we need to differentiate between climate resilience and resilience to technical failures, when both involve disruption to critical services such as those provided by energy grids, water supply, transportation networks, financial systems or health care?*

19:00 Dinner

Tuesday 19 February

09:00 – 12:30 Session 2: Assessing the resilience of a critical infrastructure (CI) using the SmartResilience indicators and methodology

Presentation of resilience indicators and other tools developed by the SmartResilience project, including for assessing interconnectedness between critical infrastructure (CI). Discussion with insurance representatives.

Briefing documents:

- http://www.smartresilience.eu-vri.eu/Results
- http://www.resiliencetool.eu-vri.eu/
- "SmartResilience: a discussion of project outcomes from an insurance perspective"

Presentations by partners in the SmartResilience project:

- Aleksandar Jovanovic, EU-VRI: Different views on resilience in SmartResilience: First responders, CI owners, regulators and insurance
- Knut Øien, SINTEF: Indicators of resilience and methods of resilience assessment
- Peter Klimek, University of Vienna: Data-driven resilience assessment approaches for interdependences of CI
- Question of clarification

10:15 – 10:45 Coffee break

10:45 – 11:45 **Breakout groups**

- Group 1: *Indicators of resilience and methods of resilience assessment*. Focus on:
  - types of indicators relevant to insurance
  - how to determine and use specific indicators
- Group 2: *Data-driven resilience assessment approaches for interdependences of critical infrastructures*. Focus on:
  - types of modelling techniques relevant to insurance needs
  - accumulation risk

Each group will discuss the following questions:

- *How can outcomes from the SmartResilience project (i.e., resilience assessment through indicators and functionality level modelling) be of help for current insurance activities and potential innovations in insurance?*
- *What levels of transparency and standardisation are needed in the choice of indicators and modelling techniques?*
- *Which stakeholders should have access to the resilience assessment?*
- *How should insurers be involved in the assessment process?*
- *How can resilience indicators be commercialised?*
- *Measurement of risks in long-term infrastructure projects*

11:45 -12:30	Reporting and discussion in plenary
12:30 -13:30	Lunch

13:30 – 15:30 Session 3: Insuring critical infrastructure resilience

In a changing risk and insurance landscape, the need for resilience can be an opportunity for the insurance industry to develop and offer new products and services for CI. This session will discuss:

- The need for reliable measures of resilience, to allow for conclusions on individual risks and insurance premiums, including the need for independent and objective measurement of resilience
- Various types of insurance products ("resilience-related solutions") that can be developed, for incentivising investment in a CI's ability to absorb or withstand damage or disruptions, or providing ex-ante disaster financing
- Legal and liability considerations as main drivers for insuring CI resilience

Brief presentations about insurance needs and solutions

- Otto Kocsis, Zurich Insurance: Consideration of business resilience in insurance - today & tomorrow
- Stefan Thumm, Allianz Consulting: comments from liability, engineering and property business lines
- A resilience assessment and rating agency
- Other perspectives

Briefing document:

- "ERRA- the European Risk and Resilience Assessment and Rating Agency "

14:15 – 14:30	Coffee break
14:30 – 15:30	Discussion

Questions to guide the discussion:

- *What does insurance need to know in order to cover damage or loss due to lack of CI resilience (disruption of critical services caused by systemic risk events and cascading failures between systems)? How to adapt methods used to quantify risk to the specific purpose of resilience management?*
- *Do we need standardisation methods that can be applied by an independent and trusted agency, to provide independent measurement and rating of a CI resilience?*
- *Which CIs mostly need or demand resilience solutions that require insurance? In each case, who bears the risks and would buy risk/resilience solutions?*
- *How to convince decision-makers in CIs?*
- *What resilience-related solutions does the insurance industry currently work on? What are the biggest obstacles to their implementation?*

15:30 – 16:00 Conclusion

The concluding session will summarise:

- *What are the most promising solutions (in terms of resilience assessment tools and insurance products) to trigger the positive feedback mechanism where higher resilience can improve insurability*

and additional insurance can strengthen resilience?

- *What are the key recommendations for the SmartResilience project's outcome going forward?*

Annex 2 feedback questionnaire

Workshop participants were requested to send feedback using the questionnaire below. Feedback received was used to prepare this version of the workshop report.

ORGANIZATION NAME:

Website(s)		
Description		
Contact(s)		

Partner Organization Interests in SmartResilience

Threats

❑ Terrorist Attack	❑ Social Unrest	❑ Other:
❑ Cyber Attack	❑ New Technological Accident	
❑ Natural Threats	❑ Cascading Effects	

Infrastructures

❑ Financial Systems	❑ Industrial Production Systems
❑ Energy Supply Systems	❑ Water Supply Systems
❑ Health Care Systems	❑ ICT Systems
❑ Transportation Systems	❑ Other:

Partner Priority 1	
Partner Priority 2	
Partner Priority 3	

Feedback

1. General impression of the project results

Comments

2. General impression of the SmartResilience tool

Comments

3. Possibilities to use the SmartResilience methodology and/or tool

Comments

4. Interest in becoming a member of ERRA	
Comments	

5. Please briefly list your three main recommendations for Smart Resilience.

Recommendation 1	
Recommendation 2	
Recommendation 3	

6. General Comments	

Testimonial

Testimonial for the Smart Resilience 'Welcome' web page

Contact Name	
Contact Title	
Testimonial Quote (one or two sentences!)	
Insert Picture Here	

Annex 3 Review process

The Content of this Annex has been submitted as part of the periodic review report to the PO/EU/ Reviewers.