

MATRIX

New Multi-Hazard and Multi-Risk Assessment Methods for Europe



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Risk governance and the communication process from science to policy:
Evaluating perceptions of stakeholders from practice in multi-hazard and
multi-risk decision support models

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Abstract

As populations increase, especially in urban areas, the number of people affected by natural hazards is growing, as many regions of the world subject to multiple hazards. Although the volume of geophysical, sociological and economic knowledge is expanding, so are the losses from natural catastrophes. The slow transfer of appropriate knowledge from theory to practice may be due to the difficulties inherent in the communication process from science to policy-making, including perceptions by stakeholders from disaster mitigation practice regarding the usability of any developed tools. As scientific evidence shows, decision-makers are faced with the challenge of not only mitigating against single hazards and risks, but also multiple risks, which must include the consideration of their interrelations. As the multi-hazard and risk concept is a relatively young area of natural risk governance, there are only a few multi-risk models and the experience of practitioners as to how to use these models is limited. To our knowledge, scientific literature on stakeholders' perceptions of multi-risk models is lacking. In this document, we identify the perceptions of two decision-making tools, which involve multi-hazard and multi-risk. The first one is a generic, multi-risk framework based on the sequential Monte Carlo method to allow for a straightforward and flexible implementation of hazard interactions which may occur in a complex system. The second is a decision-making tool that integrates directly input from stakeholders by attributing weights to different components and constructing risk ratings. Based on the feedback from stakeholders, we found that interest in multi-risk assessment is high, but that its application remains hampered by the complexity of the processes involved.

The work presented in this document is based on the manuscript,

“Multi-hazard and multi-risk decision support tools as a part of participatory risk governance: feedback from civil protection stakeholders”

by Nadejda Komendantova, Roger Mrzyglocki, Arnaud Mignan, Bijan Khazai, Friedemann Wenzel, Anthony Patt, Kevin Fleming,

which has been recently accepted for publication in the *International Journal of Disaster Risk Reduction*.

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1 Introduction

Historical records show that economic losses from disasters have increased steadily from € 150 billion (value inflation adjusted for the year 1999) in the period 1950-1959 to about € 375 billion in the decade 1990-1999 (Munich RE, 2000). Non-economic losses, such as human lives, are much more difficult to define and they are not included in the majority of databases, but there is ample evidence in the literature that the number of people who are directly or indirectly affected in terms of daily life disruptions, losses of livelihood and deepening of poverty continues to increase (Arnald et al., 2006; Daniell et al., 2011; Hoyois and Guha-Sapir, 2003; World Bank, 2010). Many regions of the world are not simply subject to single types of hazards, but may be impacted upon by multiple hazards, which yields higher direct losses, such as damage to infrastructure, as well as higher indirect losses, such as business interruptions.

Existing risk assessment methods integrate large volumes of data and sophisticated analysis, as well as different approaches for risk quantification. However, the key question is why, if our scientific knowledge on multi-risk is increasing, are losses from natural disasters continuing to grow? (White et al., 2001). One reason might be the increasing value of assets exposed to hazards. However, there may be other reasons, and an understanding of these will play a key role in the reduction of losses in the future. As Kappes et al. (2011) state in their work, to be able to understand this question, we need to examine also the frameworks employed in the field of risk management, as well as the interactions between science and practice in terms of knowledge transfer and the applicability of results. The successful implementation of disaster risk reduction options and strategies demands not only comprehensive risk assessment schemes, but also an appropriate mechanism to communicate and transfer knowledge on risk and its underlying drivers to the various stakeholders involved in the decision-making process.

Multi-risk assessment tools have the potential to support decision-makers and provide them with information on mitigation measures. These tools influence the perceptions of stakeholders in terms of the probabilities of hazards and their impacts. But this is a double-sided communication process, as the feedback from stakeholders influences the usability of the tools and the implementation of recommendations provided by the geosciences, sociology and economics. That is why the feedback and perceptions of the usability of these models from the side of stakeholders are extremely important for the process of communication from science to policy and vice versa. So far, however, the literature on the topic of how stakeholders perceive the usability of multi-risk models is very limited.

The major aim of our research was to identify the perceptions of stakeholders to the value of two complementary decision-making tools:

- (1) A generic probabilistic framework that implements hazard correlations in a comprehensive manner (Mignan, 2013), and
- (2) An evaluation methodology based on the concept of the risk matrix to incorporate expert knowledge through stakeholder interactions into multi-hazard scenario

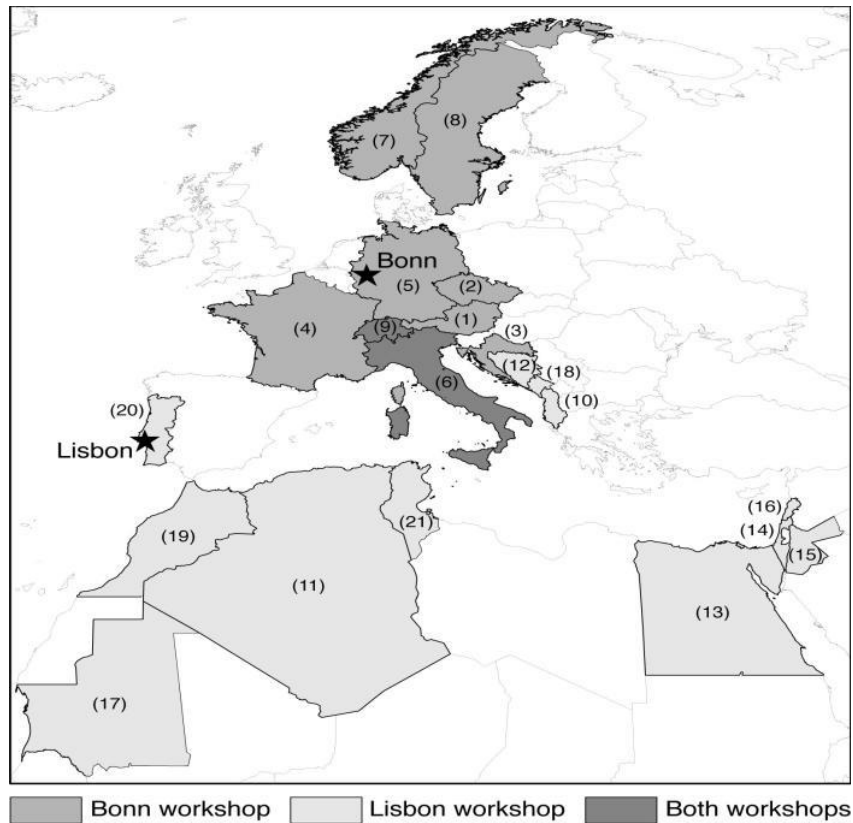
development developed by B. Khazai at the Karlsruhe Institute of Technology and described in this deliverable.

This work is a first approach to collect the perceptions of stakeholders from civil protection authorities on the decision-making tools being developed within the context of the MATRIX project. The research within this work encompasses three overarching questions:

1. How do stakeholders perceive multi-hazard and multi-risk situations and what are their requirements for multi-risk assessment tools?
2. How do stakeholders perceive the decision-making process for the mitigation of multi-risk and their perceptions on the usability of decision-making tools?
3. Is there a difference in the resulting perceptions between stakeholders (based on practice) and academia (based on more theoretical considerations)?

We collected perceptions from stakeholders within framework of two workshops (figure 1). The first was held in Bonn, Germany, on the 6th and 7th of July 2012, under the auspices of the MATRIX project, while the second took place on the 17th to 19th of October 2012 in Lisbon, Portugal, sponsored by the Italian Civil Protection (“Multi-hazard risk assessment in urban environment”, 12th PPRD South “prevention and preparedness” workshop for staff-level officials). The workshop in Bonn was the main source of data on stakeholder’s perceptions while the one in Lisbon provided us with a secondary source of data dealing with perceptions of the tools developed after feedback from stakeholders in Bonn.

The selection of stakeholders for our study forms a representative sample, given the fact that over 50% of all national platforms in Europe were involved into our research. The stakeholders, except for Austria, represented the National Platforms. Someone might argue that the number of stakeholders involved is too small for a large-scale survey. However, here we would like to point to the fact that our aim was not to conduct a large-scale survey, but to reach targeted groups of stakeholders, such as civil protection platforms and the UN-ISDR. As we did not apply methodologies appropriate for large-scale surveys, but instead used specialized targeted questionnaires as well as collect feedback during workshops, we regard our sample of stakeholders as being representative, as it covers most of the European countries.



- | Bonn Workshop | | Lisbon Workshop | |
|----------------------|---|------------------------|---|
| (1) | Austria - Federal Ministry of Agriculture, Forestry, Environment and Water Management | (10) | Italy - Civil Protection Department |
| (2) | Czech Republic - National Committee for Natural Disaster Reduction | (11) | Switzerland - United Nations Office for Disaster Risk Reduction |
| (3) | Croatia - National Protection and Rescue Directorate | (12) | Albania - Civil Emergencies |
| (4) | France - Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer | (13) | Algeria - General Directorate of Civil Protection |
| (5) | Germany - Federal Office of Civil Protection and Disaster Assistance | (14) | Bosnia and Herzegovina - Ministry of Security |
| (6) | Italy - Civil Protection Department | (15) | Egypt - General Administration of Civil Protection |
| (7) | Norway - Directorate for Civil Protection and Emergency Planning | (16) | Israel - Ministry of Home Front Defence |
| (8) | Sweden - Center for Climate and Safety | (17) | Jordan - Rescue and Support Directorate |
| (9) | Switzerland - United Nations International Strategy for Disaster Reduction | (18) | Lebanon - Civil Defence |
| | | (19) | Mauritania - Mayor |
| | | (20) | Montenegro - Department for Civil Protection |
| | | (21) | Morocco - General Directorate of Civil Protection |
| | | (22) | Portugal - National Authority for Civil Protection |
| | | (23) | Tunisia - Civil Protection |

Figure 1: The countries that participated in the workshops held in Bonn and Lisbon, as well as in the questionnaire prior to the Bonn workshop and the survey after it.

2 Background

2.1 Definitions of multi-risk assessment

Risk assessment includes hazard assessment, followed by estimations of the vulnerability and values of the elements at risk (or exposure), all leading to the computation of risk as a function of hazard, vulnerability and exposure (Varnes, 1984). The term “natural hazard” refers to the “natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage” (UNISDR, 2009). Risk is defined as “expected losses of lives, persons injured, property damages and economic activities disrupted due to a particular hazard for a given area and reference period” (WMO, 1999). Another definition of risk is “the combination of the probability of an event and its negative consequences” (UNISDR, 2009). In any case, a definition of risk must also include the interaction of hazards and the vulnerability of the affected area, especially the built environment. Definitions developed by the European Commission extend the previous definitions by incorporating the terms “exposure” and “vulnerability” (COM, 2010a). This foresees that an event of the same magnitude can have a different impact, dependent upon the vulnerability and exposure of a given population and the associated elements, thus also involving the need to take into consideration preparedness and preventive measures. The definition of risk is also closely connected with the definition of uncertainty, as the term “probability” itself implies uncertainties. Risk can also be understood as “the effects of uncertainty on objectives” which appear as a “combination of the consequences of an event and the associated likelihood of occurrence” (ISO Guide 73:2009). It is therefore important to understand such uncertainties when it comes to the development of decision-making models and tools for the purposes of civil protection.

The purpose of multi-risk assessment is therefore to establish a ranking of different types of risk, taking into account possible conjoint and cascade effects. Multi-risk assessment is a relatively new field, until now developed only partially by experts with different backgrounds such as engineering, statistics or various fields of geosciences. Currently, there is no clear definition of “multi-risk”, neither in science, nor in practice (COM, 2010a; Kappes et al., 2012). The only definition that exists concerns the requirements for multi-risk, which needs to consider multiple hazards and multiple vulnerabilities (Carpignano et al.; Di Mauro et al., 2006; Marzocchi et al., 2012; Selva, 2013).

There are essentially two ways to approach multi-risk. The first considers the different types of hazards and vulnerabilities of a region and combines the results of various single risk layers into a multi-risk concept (Grünthal et al., 2006). This approach provides an overview of multiple risks, but neglects the interactions between the hazards and vulnerability. The second one considers the risk arising from multiple hazardous sources and multiple vulnerable elements coinciding in time and space (Di Mauro et al., 2006). In these cases, we speak here about conjoint and cascading events. Conjoint events are when a series of parallel adverse events are generated by different sources, for example a windstorm occurring at the same time as an earthquake (Di Mauro et al., 2006). Cascading events on

the other hand are when an initial event (located inside or outside an area) triggers a subsequent event or series of events, for example an earthquake that then triggers landslides or tsunamis (Marzocchi et al., 2012).

The first approach considers more than one type of hazard, but it ignores the spatial and temporal relationships between the hazards and other elements of the risk chain. For example, in the Cities Project in Australia (Granger, 1999), a number of urban and regional areas were assessed for a wide range of geohazards, however, the various interactions that may arise between them were not part of this program. Similarly, in the German Research Network Natural Disasters Project, the city of Cologne was assessed for earthquakes, windstorms and river floods separately, and while losses in terms of monetary values arising from each hazard were plotted together against the probability of occurrence to allow a comparison, the possible interactions between them and the effect this has on the final risk were not considered, nor were the associated uncertainties (Grünthal et al., 2006). Again, neither of these studies considered the possibility of one hazard type triggering another, nor the consequences of events occurring simultaneously, or nearly-simultaneously, and how this affects an area's vulnerability. Hence, by not considering such interactions, which may lead to increased losses, such frameworks potentially grossly underestimate the final risk. Moreover, most of these studies employ the term "multi-risk" to describe what should really be referred to as "multiple single risk", which adds to the confusion.

By contrast, the second type explicitly considers spatial and temporal interactions between different hazards and their subsequent risk. An example is the EC FP6 NaRaS project for the Casalnuovo municipality in the province of Naples in Italy. This municipality is located just 13 km away from the crater of the Mount Vesuvius volcano and is exposed to several kinds of hazards, such as the Vesuvius volcano itself, active faults in the Apennine chain (the tectonic source area of the damaging 1930 and 1980 Irpinia earthquakes), as well as the presence of industrial landfills. A study supported by the local government, who was interested in the identification of the most dangerous hazards and the most effective way of financing risk mitigation measures, found that volcanic risks significantly overwhelm all others, but also that the risks associated with volcanic processes and the effects these have on industry may be underestimated if the interactions between them is not considered (Marzocchi et al., 2012).

2.2 Experience of civil protection authorities with multi-risk assessment

The reduction of risks cannot be only based on scientific knowledge about natural hazards, since risks also have social and psychological dimensions which are in turn shaped by political and cultural values (Assmuth et al., 2010). Therefore, for the successful implementation of risk mitigation measures, it is necessary to identify these different factors. The newly appearing concept of *risk governance* takes into account these ingredients and emphasizes the role of participation and communication. It is also crucial to incorporate the "insider" knowledge of stakeholders into multi-risk assessment models, and their underlying parameters and outputs, such as the consequences in case of failure. Risk governance is concerned with how information is collected, perceived and communicated and follows how management decisions are taken (IRGC, 2005). Within the context of risk governance, risk

communication not only transfers information on risk or risk management decisions, but it also includes a two-way process for communicating stakeholder perceptions in shaping the outcomes of risk assessments.

Civil protection authorities have started only recently to apply multi-risk assessments for natural and technological disasters. In 2009, the European Commission issued a communication document with a set of measures to be included in the strategy of the European Commission for the mitigation of natural and man-made disasters (COM, 2009). Amongst other elements, the communication document outlines the need for multi-risk assessment. The development of multi-risk assessment methods, however, is not an easy task, given the diversity of methodological approaches in mapping risks among Member States. As an answer to this challenge, the European Commission also highlights the need for common guidelines, which will enhance the comparability of risks across Member States and will lead to a common European picture of risk.

The European Union Internal Security Strategy is another milestone towards the development of multi-risk assessment. The strategy foresees the establishment of a coherent risk management policy, which will link threats and risk assessment into decision-making (COM, 2010b). The major aim is to increase the resilience of EU member countries to crises and disasters. Among other risk mitigation measures, the strategy foresees an “all hazards approach to threat and risk assessment”.

The Risk Assessment and Mapping Guidelines for Disaster Management, published in 2011, is the third milestone (COM; 2010a). The guidelines are based on the existing national risk assessment methodologies and take into account existing EU legislation, such as the European Flood Directive. The guidelines focus on the processes and methods of national risk assessments, as well as on the mapping of risk assessment into the prevention, preparedness and planning stages. Even though it provides guidance for such steps as risk identification, risk analysis and risk evaluation, it does not deal with capacity analyses, capability planning, monitoring and review, nor with the consultation and communication of findings and results of risks assessments with stakeholders. Instead, it focuses on risk assessment not only in terms of methodologies, but also with respect to the harmonization of previous and current initiatives on risk assessment and procedures for risk assessment at the national and the European levels. However, it does not evaluate the pattern of decision-making and barriers for the implementation of risk assessments.

2.3 Existing decision-making models for multi-risk assessment

Currently, various decision models for multi-hazard and multi-risk assessment are being developed, but to be useful in disaster management, these models must respond to the requirements and expectations of the civil protection community. The principle aim of such models should be to provide stakeholders with a set of scenarios or alternatives to help them make or select the most appropriate decision or action. In risk assessment, decision models display different risks with respect to their probability and frequency, as well as to their possible outcomes. Even though the majority of decision models were developed to assess

single types of risks and hazards, some models are available for multi-risk mapping of natural hazards and their impact assessment. These are the decision-making model developed within frameworks of the FP6 project ARMONIA¹ (T6, 2007) and the scenario-based approach for risk assessment used by the German Federal Office of Civil Protection and Disaster Assistance.

A decision-making model “Multi-Risk Land Use Management Support System” was developed through the ARMONIA project. The objectives of the decision-making model are to provide a basis for planning activities in areas that are prone to multiple natural hazards. The model provides assessments of both the exposure and vulnerability of a region. As a decision-support tool, it is intended to support planners with their decisions regarding land-use issues and the location of strategic facilities. Another objective of the tool is to develop a structure which will help ensure that planning decisions are made while being fully informed about multiple risks and the respective vulnerability of different population structures and land-use types in order to provide options for mitigating risks. The model provides different options for the mitigation of risks and the reduction of vulnerabilities through a system of Multiple Criteria Evaluations. Also, it provides a knowledge base on different approaches, which can be taken to mitigate risks through land-use management decisions.

The German Federal Office of Civil Protection and Disaster Assistance (BBK) use a scenario-based approach for risk assessment (BBK, 2010). If understood as a combination of hazardous events, multi-risk can be integrated into the concept of visualizing risks by using a risk matrix, which combines likelihood and impact. The development of such risk matrices was proposed by the risk assessment and mapping guidelines for disaster management developed by the European Commission in 2010 and is current practice in several European countries. Within the risk matrix, multi-risk events could be represented as additional scenarios (figure 2) and thus integrate this information into the knowledge base for decision-making processes.

To date and to the best of our knowledge, three principal software tools have been developed to provide multi-hazard risk assessments of a given territory. These are HAZUS² for the USA, RiskScape for New Zealand (Schmidt et al., 2011) and CAPRA³ in Central America. HAZUS provides estimates of potential losses from hurricanes, earthquakes and floods, considering the physical, economic and social impacts of disasters and graphically illustrates the extent of identified high risk locations due to the three above-mentioned hazards. HAZUS is largely used by stakeholders, mainly government planners and emergency managers, to determine losses and the most beneficial approaches for their mitigation. However, it is also used by communities for the evaluation of economic loss scenarios with respect to certain hazards and to increase public awareness (FEMA, 2013). RiskScape facilitates estimations of volcanic ash falls, floods, tsunamis, landslides, storms and earthquakes. It is intended to be an “easy to use multi-hazard impact and risk assessment tool”. Its aim is to inform decision making, including land-use planning,

¹ Applied Multi Risk Mapping of Natural Hazards for Impact Assessment

² <http://www.fema.gov/hazus>

³ <http://www.ecapra.org>

emergency management, assets management and insurance. This tool foresees interactive cooperation with users, and has put in place a development blog on-line where users can exchange their experience with the software and suggest improvements (Reese et al., 2007). CAPRA provides analysis for hurricanes, heavy rainfall, landslides, floods, earthquakes, tsunamis and volcanic hazards. It combines hazard information with exposure and physical vulnerability data and allows users to determine conjoint and cascade risk on an inter-related multi-hazard basis (CAPRA Probabilistic Risk Assessment Initiative, 2011).

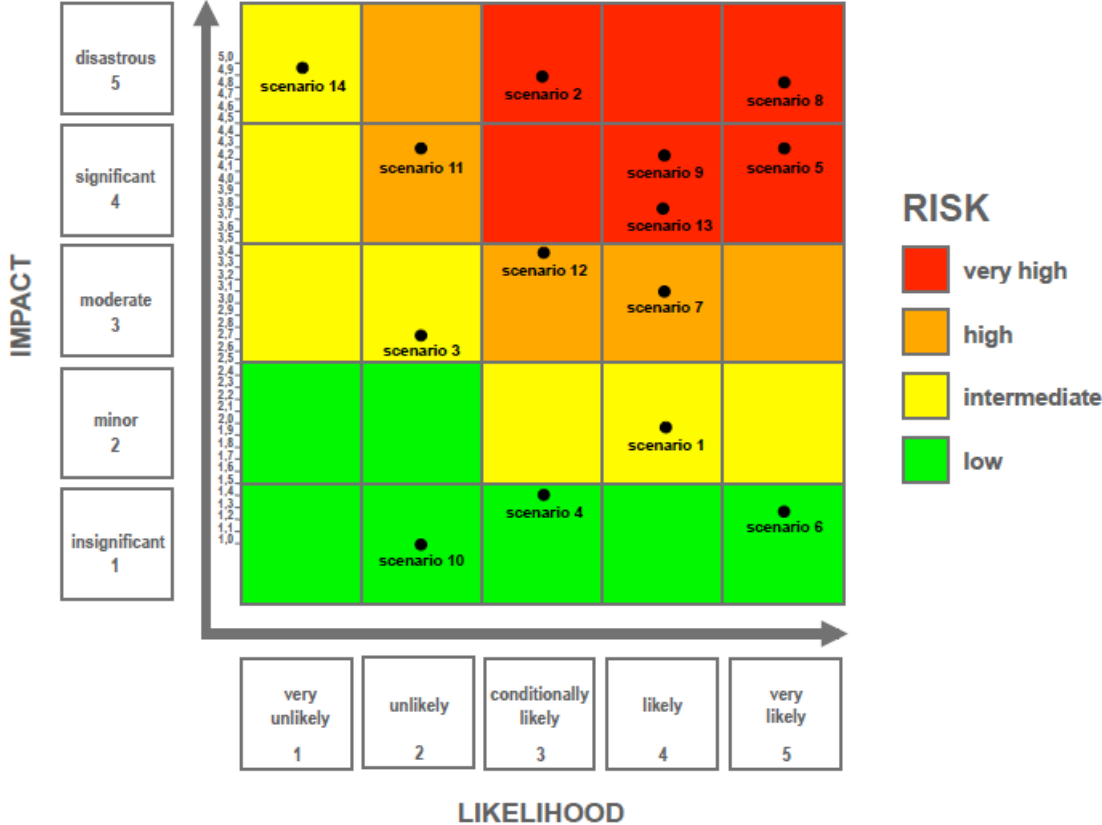


Figure 2: Example of how different scenarios fit within a risk matrix (BBK 2010).

These models focus on different geographical regions, such as the United States of America in the case of HAZUS, New Zealand for RiskScape, and Latin America and some Asian countries with CAPRA. HAZUS has been further developed as HAZTURK and HAZTAIWAN with customized functionality for Turkey and Taiwan, respectively. CAPRA is applied outside of Central America in countries such as India, Bangladesh and Nepal. RiskScape has also recently been applied in South East Asia. Even though the developers of these tools propose an interactive process with stakeholders, currently a scientific review or evaluation of the results from the use of these software and feedback from stakeholders is not available.

To our knowledge, even though some of these models have been tested by operational and practicing stakeholders, there is no evidence of stakeholder feedback. For example, the decision-making model developed by ARMONIA defines weights based on the judgments from stakeholders on different vulnerabilities within the area of their interest. Thus, it produces the risk factors for each hazard, as the risk factor is given as the vulnerability weight. Although risk factors cannot be compared across hazards, they can be compared

across different scenarios. Once risk factors are included in one scenario, the stakeholder can run another scenario. By the end, the stakeholder is able to see a set of risk futures created by changes in the environment. However, there is no scientific work which analyses the perceptions of experts from civil protection in terms of usability and applicability. This deficiency is therefore one of the motivations for our research, where we have collected the perceptions of stakeholders through the methodology of stakeholders' interactions via such means as questionnaires, decision-making experiments and workshops.

2.4 Multi-risk decision-support methods

Social science scholars argue that because production of scientific tools is a social process, it is essential to involve relevant stakeholders who will be using the tools into the process through collection and integration of their feedback (Tesh, 1990). We collected feedback from stakeholders regarding two decision support models. Both models were developed in frames of the MATRIX project. The first model "Generic multi-risk framework" was developed by the Swiss Federal Institute of Technology in Zurich (ETH Zurich). It quantifies multi-risk in a controlled environment to show the benefits of such an approach for decision-making (Mignan, 2013; Mignan et al., submitted). The second model was developed by B. Khazai at the Karlsruhe Institute of Technology (KIT). It communicates multi-hazard and multi-risk results to stakeholders, by using concepts of risk ranking and the risk matrix metric (Wenzel, 2012). While these methods were treated independently during interactions with stakeholders, we will show in our results and discussion sections that method (1) should be combined with method (2) to facilitate the communication of multi-risk assessment, as was discussed at the stakeholders' workshop in Bonn. During the workshop in Lisbon, Method (1) was combined with the visual tool developed within the framework of Method (2).

Method (1): Generic multi-risk framework

The development of a comprehensive multi-risk framework is limited by three main requirements, namely the large amount of input data required, cross-disciplinary expertise and innovative risk assessment methods. The first two points are generally solved in dedicated multi-risk projects at the national, international or private sector levels (see the previous description of the tools HAZUS, RiskScape and CAPRA). The third point remains to be solved. As indicated by Kappes et al. (2012), "despite growing awareness of relations between hazards, still neither a uniform conceptual approach nor a generally used terminology is applied".

Mignan (submitted) proposed a novel, generic, multi-risk framework based on the sequential Monte Carlo method to allow for a straightforward and flexible implementation of hazard interactions, which may occur in a complex system. Considered hazard interactions are analogue to the ones observed in recent catastrophes, such as the 2005 hurricane Katrina or the 2011 Tohoku earthquake. Validation of the framework of Mignan, which should be considered as a proof of concept, was made on a synthetic data set, based on the concept of a virtual city within a virtual hazardous region where generic data are defined heuristically (Mignan et al., submitted).

In an early version presented at the two workshops (figure 3), the role of intra-hazard earthquake interactions and of inter-hazard hurricane/storm surge interaction was presented. In the latest version of this work, additional interactions have been considered, such as an explosion at an oil refinery due to a natural event or to a cascade of natural events (figure 4). Other events considered in the latest version include asteroid impacts (AI) and technological accidents (TK).

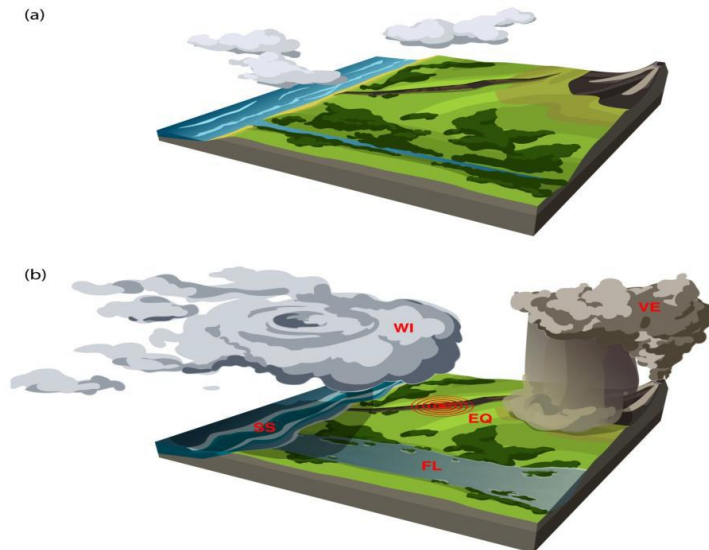


Figure 3: Artistic representation of an early version of the proposed virtual hazardous region. Top: Morphology of the 100 by 100 km region. Bottom: hazards considered are earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI) and sea submersions (SS). See also MATRIX deliverable D7.2. (Mignan, 2013).

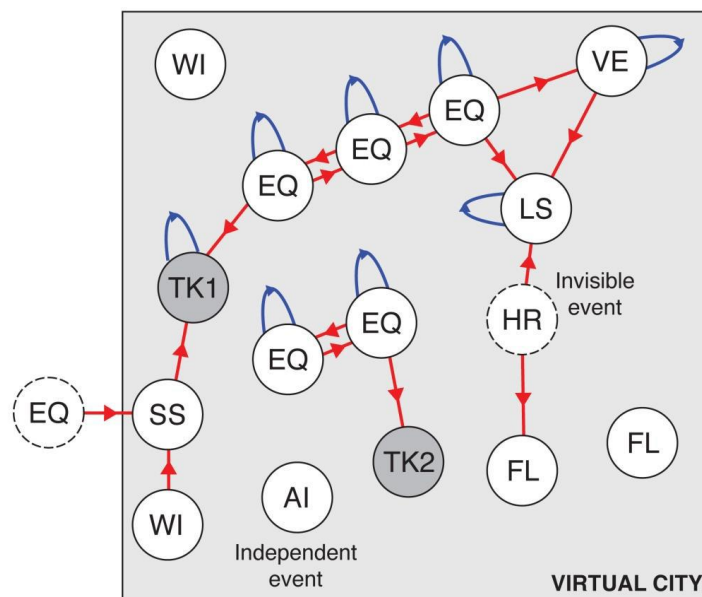


Figure 4: Network representation of the hazard interactions defined by Mignan et al. (submitted) within the concept of a virtual city within a virtual region. Hazards are: earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI), sea submersions (SS), landslides (LS), asteroid impacts (AI), heavy rains (HR) and technological accidents (TK).

In the figure 4, positive and negative effects are represented by red and blue arrows, respectively. The spatial distribution of the different hazards roughly follows the virtual region's constraints, as defined in figure 3. The hazards considered are earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI), sea submersions (SS), landslides (LS), asteroid impacts (AI) and technological accidents (TK). Some events, referred to as independent events, are not influenced by the occurrence of other events (e.g., AI) but may occur simultaneously. Mignan et al. (submitted) also introduced the concept of invisible events (e.g., heavy rains, HR; offshore earthquakes), which do not yield any direct damage, but interact with other damaging events. Some interactions have analogues to recent catastrophes. For example, EQ → SS (tsunami) → TK is reminiscent of the Tohoku earthquake / Fukushima nuclear disaster of 2011, Japan. Here TK also refers to a NaTech (Natural - Technological) event, since it (TK) is triggered by a natural hazard (SS). A negative effect represents the case when the occurrence of a second event becomes less likely or even impossible. For example, if a landslide occurs, a stable slope may be created, which hampers the occurrence of a new landslide at the same location. Again, if a technological accident occurs and the critical infrastructure is not repaired, the repeat of the same technological accident may be impossible.

The heuristic strategy, that is the use of intuitive judgment and simple rules, allows for the solving of problems that are otherwise too difficult to consider. As explained later in the results section, this approach is a very effective way to communicate the role of multi-hazard to stakeholders, regardless of their level of familiarity with the concepts of correlated chains of events and their impact on risk.

Method (2): Decision-support tool

The methodology of the decision-support tool follows the agreed definition on risk as a combination of the consequences of an event or hazard and the associated likelihood of its occurrence. Adapting the BBK (2010) framework, consequences are expressed in terms of impacts in the following categories: people (expected casualties, homeless, affected persons), economy (expected financial losses, capital stock, business disruptions), environment (threat to ecosystem, groundwater, agricultural areas stability and sustainability), infrastructure (Interruption in fresh water, gas, energy, telecommunications, transportation systems) and intangibles (public security, political consequences, psychological implications and loss to cultural values). In this way, a risk matrix relating the two dimensions of likelihood (in terms of probabilities of occurrence) and impact (in terms of an ordinal category of loss which can be expressed as “catastrophic”, “large”, “moderate”, “small” and “irrelevant”) is a graphical representation of different risks in a comparative way, and can be used as a simple approach for setting priorities. Accordingly, the risk matrix presents a visual two-dimensional display of the “ranking” of risk scenarios in terms of a frequency and impact scale that is relevant to the region of interest, and will help in interpreting historical experience and translating expert opinion in a consistent manner.

The risk matrix methodology was implemented into decision-support software based on the principles of Multi-Criteria Decision Analysis (MCDA), and tested with a group of stakeholders to communicate and transfer the information contained for the different risk scenarios in the risk matrix to the various stakeholders involved. We describe our methods of interactions with stakeholders in the methodology section. The decision-support tool allows the stakeholders to display the total risk index ranking of different risk scenarios (e.g., an extremely rare offshore earthquake which can trigger a tsunami, or a release of toxic material with severe impacts on the local environment, etc.) affecting a region in terms of expected losses that are quantitatively derived in different sectors (human, environment, economy, infrastructure, intangibles) for each scenario (figure 5).

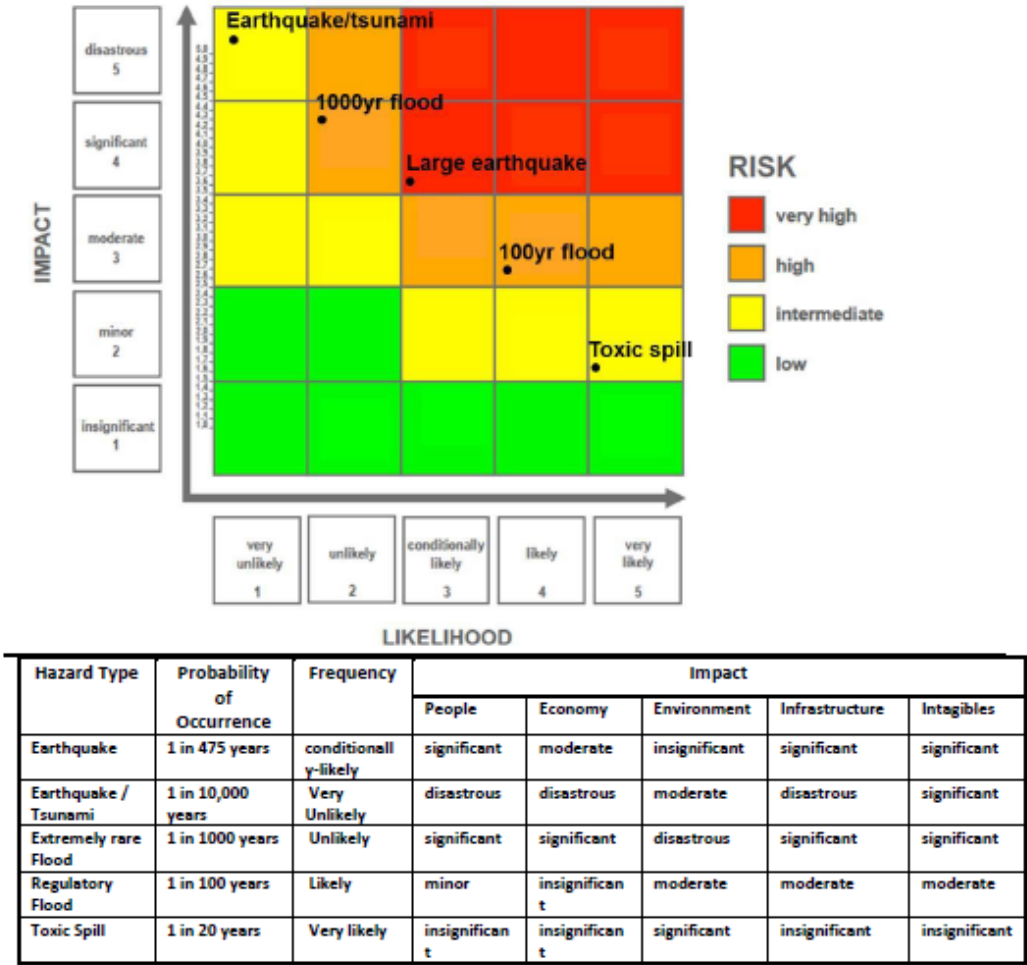


Figure 5: Methodology of the decision-support tool, where scenarios are ranked in the risk matrix (top).

According to this approach, the sectoral losses are combined together as a weighted sum into one single aggregated *loss score* for each scenario (figure 6). Together, these two steps (i.e., severity and loss scores) are combined to produce a *total risk index* for each scenario.

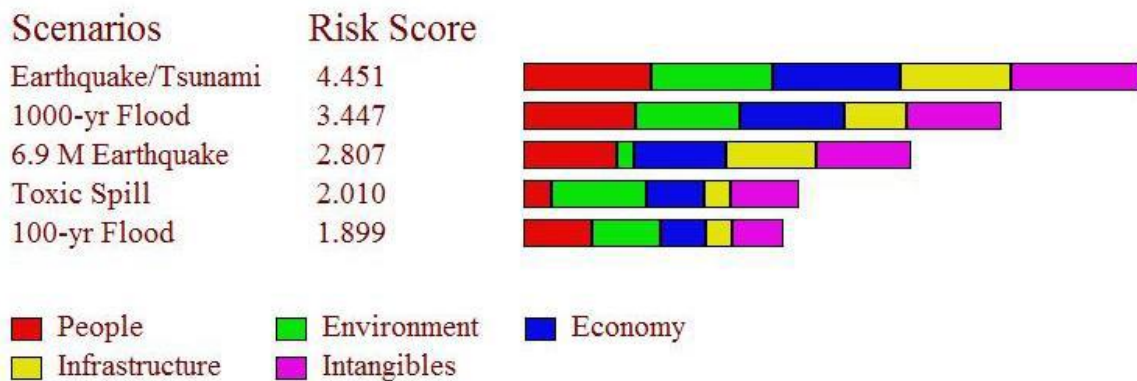


Figure 6a: Total risk score and ranking shown for each of the scenarios.

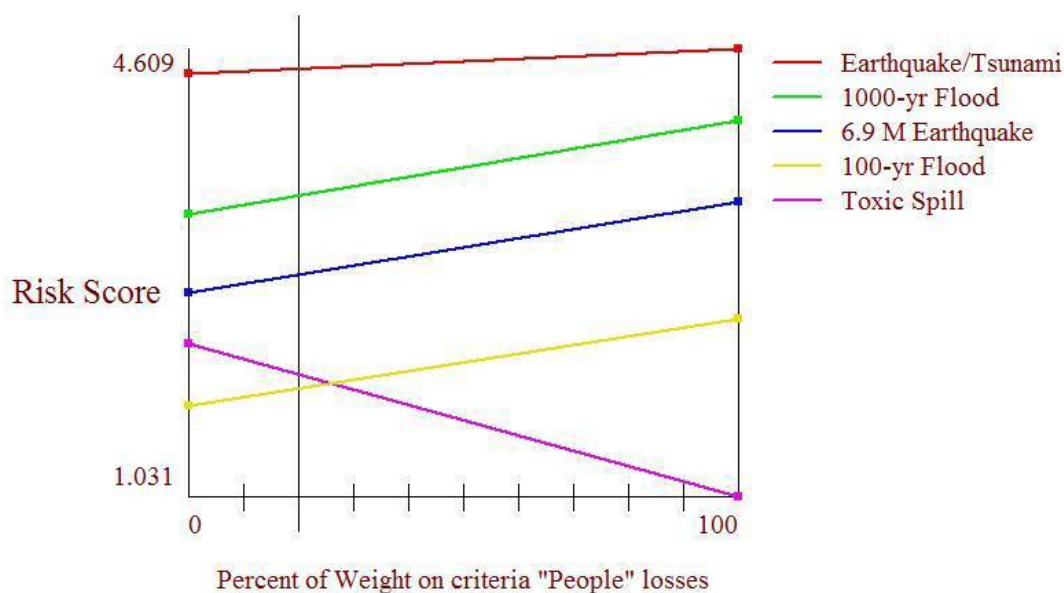


Figure 6b: Graph showing sensitivity of the total risk score to changes in the weights applied to the "People" losses criteria.

For example, in figure 6a, it can be seen that the offshore earthquake triggering a tsunami is deemed to have a much greater risk score than the toxic spill. As the total risk index for each scenario is determined as the aggregate weighted sum of each of the loss measures in each of the different sectors, the risk index ranking will also depend, of course, on the weights given to each sector. Through a participatory approach, the stakeholders assign the relative importance (weights) to the losses for the different sectors for each of the scenarios likely to occur in the region. Next, the decision support software is used in a group setting to discuss the weighting outcomes and interactively examine the variability of the ranking results. For example, a sensitivity graph can be used to see the effect on the rankings as the weights are changed. In figure 6b it can be seen that as more weight is given to the "People" criteria (i.e., casualties, short- and long-term mass care), the risk score for the toxic spill decreases considerably. This is due to the fact that the toxic spill scenario produces none to very few

fatalities and has an insignificant impact on mass care. As a result, when all the weight is given to only one measure, in this case human losses, the risk score for this scenario is minimal. On the other hand, the risk score of all other scenarios goes up, but importantly the relative rankings between them stays the same. Using various visualization tools in the decision support software, such as sensitivity graphs, stacked bars, scatter plots, and one by one comparison between scenarios, the stakeholders are able to evaluate the total risk from different scenarios by considering many variables at once, which enables them to separate facts from value judgments, and better communicate their choice to others.

3 Methodology

In this document, we follow the MATRIX lead and consider only those hazards that are most likely to affect Europe, in particular earthquakes, landslides, volcanoes, tsunamis, wild fires, storms and fluvial and coastal flooding. However, NaTech disasters, while a critical, were outside the scope of the project and therefore are not addressed in this approach.

As mentioned in the introduction, we worked together with stakeholders from National Platforms for Disaster Risk Reduction, which are most commonly part of national Civil Protection organisations. Furthermore, the United Nations Office for Disaster Risk Reduction (UN-ISDR⁴) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austrian Service for Torrent and Avalanche Control⁵, were involved. National Platforms are governmental organizations, for example, at the level of the Ministry of Interior - Civil Protection Department or are acting as non-governmental organizations like the German Committee for Disaster Reduction (DKKV)⁶. They are multi-stakeholder committees comprising experts and members from different sectors, enabling them to act as centres of expertise in the field of disaster risk reduction (DRR). National Platforms are advocating for DRR at all governmental and social levels and are generally responsible for coordinating DRR activities, which require a coordinated and participatory process. According to the definition from the UN-ISDR, a National Platform for Disaster Risk Reduction “should be the coordination mechanism for mainstreaming DRR into development policies, planning and programs in line with the implementation of the Hyogo Framework for Action (HFA). It should aim to contribute to the establishment and the development of a comprehensive national DRR system, as appropriate for each country”.

The United Nations Office for Disaster Risk Reduction is the secretariat of the UN-ISDR, and is the successor arrangement of the secretariat of the International Decade for Natural Disaster Reduction (IDNDR). It was established in 1999 in order to ensure the implementation of the UN-ISDR and the Hyogo Framework for Action (HFA, 2005), which was adopted during the World Conference on Disaster Reduction in Kobe in 2005. Amongst the different activities the secretariat’s mandate involves, one is to “provide support to countries and HFA focal points in the establishment and development of national platforms for disaster risk reduction and backstop their policy and advocacy activities; develop improved methods for predictive multi-risk assessments, including the economics of disaster risk reduction and socio-economic cost-benefit analysis of risk reduction; and integrate early warning systems into their national disaster risk reduction strategies and plans”.

The research questions considered in this work are focused on stakeholders’ perceptions. This is why we use the methodology of stakeholders’ interactions. Our methodology includes several methods, among them the distribution of questionnaires to collect the perceptions of stakeholders on multi-hazard and multi-risk terminology and their views on existing multi-risk assessment tools, decision-making experiments and workshops. Importantly, we collected

⁴ <http://www.unisdr.org/>

⁵ <http://www.lebensministerium.at/en/fields/forestry/Naturalhazards/Avalanchecontrol.html>

⁶ <http://www.dkkv.org/>

feedback from those stakeholders who participated in the workshops mentioned above and combined this information with that obtained from our surveys.

The Bonn workshop provided the opportunity to present and discuss current hazard and risk mapping concepts and highlight the importance of data and information for hazard and risk assessments. It allowed time for discussions on the added value of risk assessments within the context of disaster risk reduction, and to better understand current national hazard and risk assessment approaches. The part of the workshop dealing with tools for multi-risk scenarios had three aims. First, it was to capture the status of the different approaches and associated problems with regards to multi-risk assessment in Europe. The second aim was to understand the users' requirements with respect to information technology for the generation of scenarios. The third aim was to understand the range of risk components addressed in the current practice, such as losses to people's health and lives, the economy, ecological damage, impacts upon infrastructure and critical infrastructure, and intangible losses. During the workshop, we presented the results from the stakeholder survey and afterwards collected their feedback.

The general aim of this workshop was to improve the knowledge of the research community about the current status, such as availability, methods, and barriers, of hazard, risk and multi-risk assessment among the involved European countries. The focus was to understand the value of multi-hazard and multi-risk approaches and tools in real world conditions. This involved questions such as: What are the added values of hazard and risk assessments and what are their levels of integration into decision-making processes? What are the requirements for multi-risk assessment methods and tools from the perspective of disaster management? The surveys allowed us not only to gain answers to the questions set above, but also to capture the stakeholders' perceptions of the term "multi-risk".

a. Stakeholders interactions on the Method (1)

The generic multi-risk framework and its application in a virtual city were presented by A. Mignan at the workshop in Bonn. Further on, feedback from stakeholders received during the discussion of the framework was integrated and the improved generic multi-risk framework was presented and discussed with stakeholders during the Lisbon workshop. The presentation of the generic multi-risk framework in Lisbon was followed by a half-day exercise co-organized with the PPRD South team and other speakers. The exercise's aim was to provide a better understanding of the role of multi-hazard in overall risk assessment by considering two sites: Lisbon, Portugal and Istanbul, Turkey. The first part of the exercise consisted in investigating the different hazards present in the two cities based on different data, such as hazard maps, provided in the guidelines of the exercise, and to give some score to their severity and frequency, that is within the concept of the risk matrix, as described in Method (2). The second part of the exercise was to discuss potential triggering effects, based on the Virtual City results and experienced catastrophes. Participants then updated their risk matrix based on multi-hazard information and presented their new results. The final objective was to highlight the idea that new risks emerge and some others may shift

to lower-probability/higher-consequence events when multi-hazard is considered in risk management.

b. Stakeholders interactions on the Method (2)

Several scenarios were developed according to this method and presented to stakeholders at the workshop in Bonn to identify the impacts arising from each type of hazard on society on the basis of multiple loss categories, such as population, economy, ecology, infrastructure, and intangible losses. However, as these losses were not exclusively expressible in monetary terms, but rather in descriptive parameters, stakeholder input was needed to identify the weights with which the impact of particular components in the overall picture of impact are specified in a participatory fashion (i.e., what is the relative importance of the different loss parameters in the risk ranking?). Thus, the primary difficulty in gathering stakeholder input involved creating a “value model” that would support stakeholders in assessing problems and expressing their views more explicitly. Using the decision-support tool in the workshop, the stakeholders ranked and compared risk scenarios to each other relative to one (or several) loss criteria by following the five steps below:

1. Identify all the risk scenarios to be ranked.
2. Identify loss parameters to quantify the risk score of each scenario.
3. Quantify the loss score (5 categories, from irrelevant to catastrophic) for each of the loss parameters for each scenario.
4. Quantify preferences (weights) for different loss categories and loss parameters.
5. Rank the scenarios by combining information from steps (4) and (5).

Following the ranking of the scenarios, the stakeholders used the visualization tools of the decision-support software tool to conduct interactive sensitivity analyses to detect the most significant factors in the ranking of scenarios, and identify whether or not a criteria differentiates between two scenarios. Furthermore, stakeholders discussed ways to characterize uncertainties in the loss parameters and set priorities by determining how much greater risk one scenario poses over another.

4 Results

4.1 Perceptions of multi-hazard and multi-risk situations and the requirements of stakeholders in multi-risk assessment tools

To be useful in practice, multi-risk tools and methods need to be in-line with the requirements and expectations of the civil protection community. The results from the round table discussions at the workshops and from the returned questionnaires showed that stakeholders perceive two areas as being most problematic for multi-risk assessment tools. These are (1) the absence of clear definitions and (2) what is the added value of multi-risk assessment.

First, there is still no common understanding, nor a smooth transition between the terms “multi-risk” and “multi-hazard”. These facts indicate that a common terminology does not exist and disaster management terms are used differently among different European countries. It showed the need to develop a glossary with definitions and terms relevant to multi-risk and multi-hazard, going beyond already existing basic definitions developed, for example, by the UN-ISDR. However, during the workshop discussions and as indicated in the questionnaires, almost all stakeholders agreed with the proposed definition of multi-risk, given as:

“Multi-risk represents a comprehensive risk defined from interactions between all possible hazards and vulnerabilities.”

Second, the added value of multi-risk assessment in comparison to the single risk assessment and hazard assessment was not completely clear. There are also fears that multi-risk assessment will lead to more complicated and time demanding risk assessment procedures in comparison to single risk assessment. Several stakeholders spoke up that it is not possible to identify which assessment is more important, single risk or multi-risk, and spoke for the necessary combination of both of them. However, in the implementation of risk mitigation policies, stakeholders identified several advantages of the multi-risk approach relative to single risk approaches. The major advantage is in the intensified cooperation between stakeholders who are involved in the assessment and mitigation of different kinds of natural hazards, resulting in better planning and cost efficiency during the decision-making processes.

A common opinion was that the results of risk assessment are generally less needed than reliable hazard assessment products, such as hazard maps. The hazard assessment is also more frequently applied, most often for floods and landslides (figure 7).

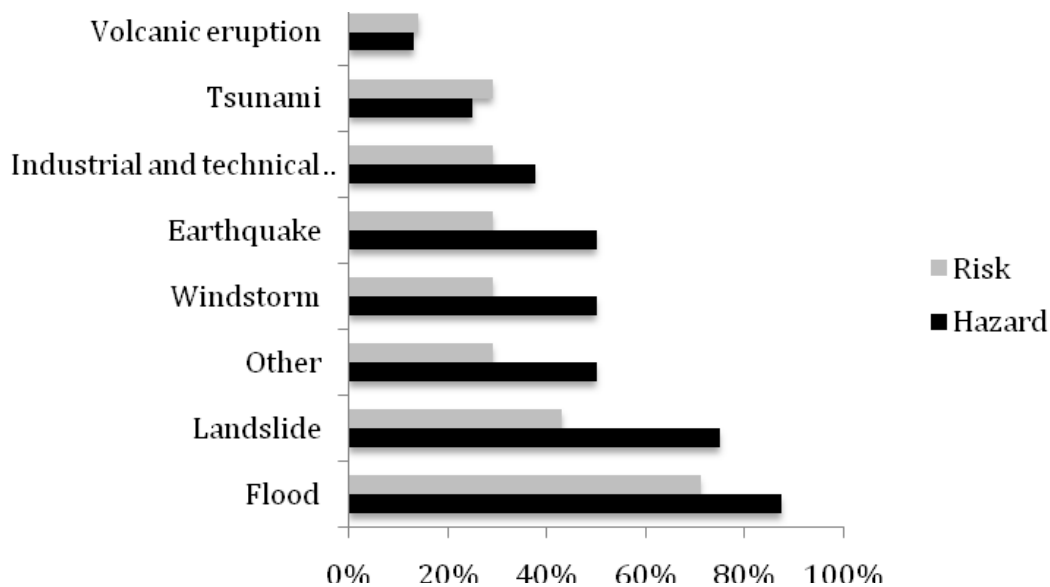


Figure 7: Distribution of the application of different types of hazard and risk assessment in the eight European countries represented in the questionnaire distributed prior to the Bonn MATRIX workshop.

Hazard maps can be used for planning and prevention, whereas risk maps are valuable for awareness raising. The stakeholders indicated five areas where hazard assessments can be used to support decision-making. These are (1) the planning of regional and local protection measures, including land-use planning, urban planning, infrastructure programs and contingency planning, (2) the prioritization and evaluation of protection measures, (3) the safety of critical infrastructure, (4) seismic zoning and building code enforcement, and (5) prevention efforts based on risk prevention plans, public awareness and information. The estimations from stakeholders of the value of hazard assessments for decision-making purposes varied between medium and high. During the workshop, stakeholders identified the advantages of the multi-hazard approach, for example, in the developed synergies in the handling of complex risks, including domino effects, as well as the potential for the instigation of complementary and systematic approaches. Furthermore, the stakeholders furthermore identified five areas for the application of risk assessments for decision-making purposes. These are (1) the formulation of national building codes, (2) scenarios and emergency planning and response, (3) the allocation of funds for risk mitigation, (4) urban management and (5) prevention efforts.

There are different ways of including risk in the mapping process, such as the French approach of overlaying exposure and hazard, or the Norwegian process of defining potential risk maps. Crossing hazard maps and asset maps is the common method used in France within the context of Risk Prevention Plans for defining land-planning zones with specific prevention requirements at the municipal level⁷. Probabilistic and scenario analyses are widespread among the European countries. In particular, scenario analysis seems to be the

⁷ <http://www.risquesmajeurs.fr/les-plans-de-prevention-des-risques-naturels-ppr>

state-of-the-art. However, uncertainties are difficult to address because adequate methodologies and reliable data are not available.

Stakeholders identified three types of problems connected with multi-risk and multi-hazard assessments:

1. The general standards for multi-risk assessment are still missing. The need for harmonization of multi-risk assessments across Europe was already identified five years before (T6, 2007). This includes the harmonization of methodologies for hazard and risk assessment for different types of potentially disastrous events and the different processes of risk mapping, including standardization of data collection, analysis, monitoring, output and terminology. The harmonization (again) of terms and methodologies is essential for stakeholders to understand relationships between risks.
2. Even though cascading phenomena are of great interest, it is still easier to address them with scenarios than by probabilistic methods.
3. Uncertainties, particularly in scenarios, are not addressed in a systematic manner.

In the next step, the stakeholders identified the following requirements for multi-hazard and multi-risk assessments:

1. The availability of basic information as well as qualitative and quantitative data to conduct multi-hazard or multi-risk assessments, including the comparability of hazards.
2. A clear understanding of the spatial and temporal probabilities of multiple risks, of the vulnerabilities of regions to multiple risks, and of the reliability and transparency of the cascading and conjoint probabilities calculations.
3. A combination of consequence analysis, which considers the vulnerability of people, property, infrastructure and goods, and risk calculation, which includes the consideration of the risk to both tangible and intangible assets.

4.2 Perceptions by stakeholders of the decision-making process on the mitigation of multi-risk and on the usability of decision-making tools

The analysis of answers to our questionnaire showed that scenario analysis is the most commonly used tool for scientific assessments, followed by probabilistic analysis, the estimation of uncertainties and socio-economic and engineering models (figure 8).

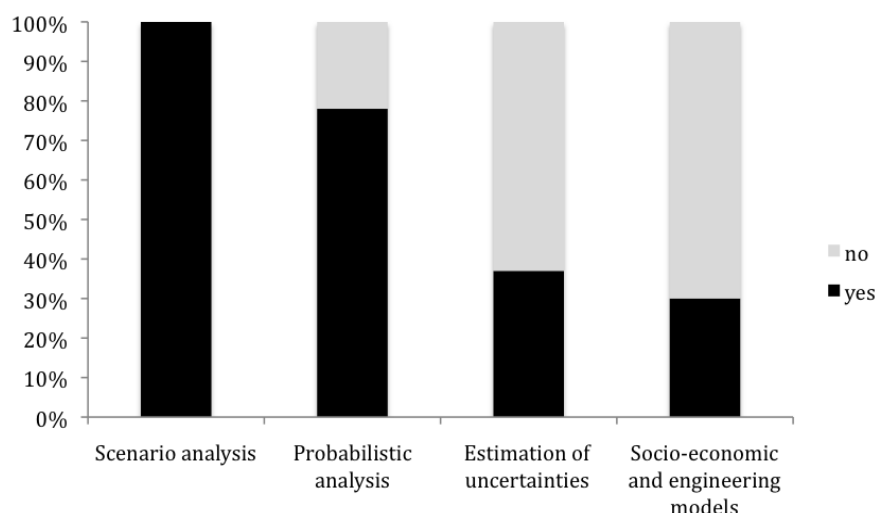


Figure 8: Application of scientific assessment tools for decision-making processes in the eight European countries that responded to the questionnaires.

The stakeholders perceive that probabilistic and scenario analysis has become widespread and has become some kind of state-of-the-art. In addition, the estimation of uncertainties is lacking, believed due to drawbacks in adequate methodologies and reliable data. However, socio-economic and engineering models are at a promising development level, although again these are dependent upon the availability of data.

Stakeholders also expressed their interest in probabilistic information, like joint probabilities for conjoint and cascading events. It was stated that for planning purposes, probabilities of adverse events are of importance. Such information is used in the field of spatial planning and disaster prevention. In Norway, for instance, probabilities of occurrence are used within risk maps to restrict different developments of certain risk-prone areas. Similarly, the Flood Directive 2007/60/EG foresees the development of hazard and risk maps for areas with significant risk of flood and the development of Flood Risk Management plans in order to avoid, protect from, and prevent floods.

Multi-risk is not systematically addressed among the EU countries for all hazards, and is only singularly integrated into risk assessment approaches. Some examples include the superposition of existing single-hazard risk prevention plans for all hazards, for example, combining flood and landslide hazards and flood risks with wind effects, the application of which is in the context for risk assessment of critical infrastructure, in particular the combination of meteorological and technological risks.

The results of the analysis of perceptions from questionnaires showed that generally, multi-risk analysis is barely or not at all integrated into decision-making processes, and only 50% of the responders were aware of methodologies and tools available to assess multi-risk. Nonetheless, all stakeholders are convinced of the usefulness of complex multi-risk scenarios and the majority of them would consider the application of them within their disaster management strategies.

Stakeholders identified several barriers to the implementation of multi-risk and multi-hazard approaches, such as financial, political, conceptual, methodological and operational. In particular, they perceive three barriers as being most problematic.

1. The absence of common methodologies and data for different types of hazards and risks is perceived to be the most problematic barrier. Also, the level of data availability for different types of hazards and risks is very different. The data on costs estimations are also not fully comprehensive. Currently, in the majority of countries, cost assessments come only from insurance companies. Stakeholders perceive this situation as being problematic because insurance companies might be biased and therefore their assessments are not fully comprehensive or independent, as well as there being issues of the transparency of these assessments.
2. Another barrier is that multi-risk assessment often does not match political priorities and public perceptions, and it is not always easy to communicate to the broader public what a multi-risk assessment really is.
3. A significant barrier involves the lack of cooperation between involved institutions, organizations and departments, leading to information about risk and hazard assessments not flowing freely between the different decision-making levels (this issue was of particular concern to Croatia). This is also explained by the fact that the results of assessments are not always available to other stakeholders outside the institution which was responsible for the assessment.

Nonetheless, the reaction of stakeholders to the multi-risk assessment and decision-making tools presented at the Bonn workshop was optimistic. Several stakeholders invited the developers of these tools to give presentations and to conduct training on the tools at their home institutions. The majority of stakeholders would consider the use of the generic multi-risk framework (method 1) and the decision-making tool (method 2) after their testing phase.

They also understood the high potential of the Virtual City concept for educational purposes (figures 3 and 4). However, stakeholders also identified two areas, which they perceived as hindering for the moment the implementation of multi-risk assessment tools like the Virtual City. These involve the input parameters and its possible application.

However, stakeholders also identified two areas of difficulty at this time for the implementation of multi-risk assessment tools like method (1). These are (i) cumbersome data gathering to consider multiple hazards and risks in a given region and (ii) the high-level of expertise required to assess the dynamic multi-hazard and multi-risk processes. The data requirements (stochastic event set, individual hazard footprints, correlation matrix that provides event conditional probabilities of occurrence, etc.) raise questions as to how user-friendly the model is, as the user (for now) needs to be an expert him or herself to be able to apply the model and to provide the necessary input parameters. Taking into account the complexity of the model and the required parameters, stakeholders believe that it is

questionable that the model was applicable in practice for the land-use planning. Another question was if the model could be used to give priority to different kinds of hazards at the European level. It was finally remarked that the application of the multi-risk framework (method 1) might be very useful at a later stage when databases with the required input parameters are developed by national and international stakeholders. This shows that multi-risk assessment cannot be resolved rapidly, but will require a long-term commitment from risk modellers as well as officials, and a “brick-by-brick” approach is necessary to progressively add together all of the complexities of the risk process.

Based on the feedback from the Bonn workshop, A. Mignan improved the communication interface of his multi-risk approach and tested it successfully at the Lisbon workshop. The main criticism, being linked to the complexity of the modelling, has been partly resolved by the use of the risk matrix (see method 2, as well as Cox, 1998; Kraussmann et al., 2012) instead of the loss curve (e.g., Grossi et al., 2005) to show how risk migrates when hazard interactions are included (Fig. 9). General guidelines on how to quantify hazard interactions were also developed, based on an extensive literature search (Mignan et al., submitted). These guidelines should help risk modellers to include, again in a brick-by-brick approach, hazard interactions in their risk management schemes.

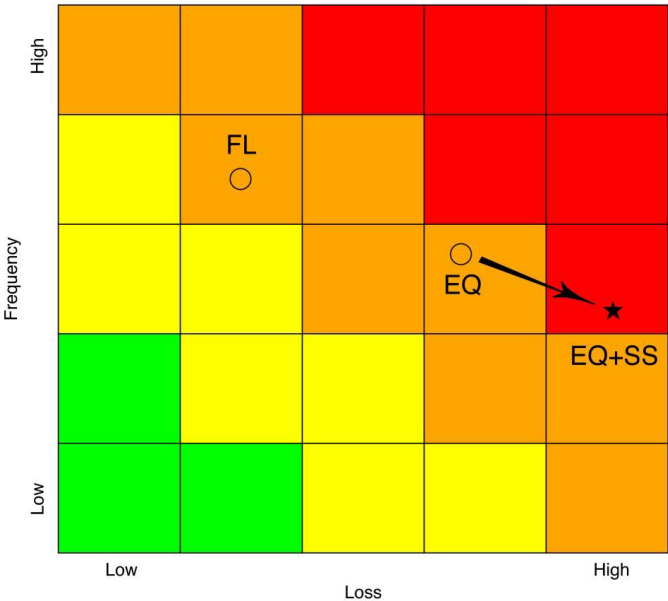


Figure 9: Example of a risk matrix determined during the multi-risk exercise organized during the October 2012 Lisbon PPRD South workshop. The level of risk increases from green, to yellow, to orange and finally to red.

Figure 9 highlights the idea that new risks emerge and some others shift to lower-probability/higher-consequence events when multi-hazard is considered in risk management. The circles represent independent events, while the star represents an event resulting from the interactions of others. In this case, floods (FL) remain independent. While not all earthquakes (EQ) will trigger a sea submersion (SS, here tsunami), the combination of both yields higher losses. The arrow represents the migration of the risk arising from an

earthquake alone to lower-probability but higher-consequences when interactions are considered. While this result may appear obvious when considering this simple example, "surprise" chains of events may emerge from method (1) when numerous event and interactions are included in the system (figure 3).

Interactions with stakeholders with regards to Method 2 allowed us to identify differences in the perceptions between stakeholders from science and practitioners. From among the 14 stakeholders that responded, 6 represented the practice community, such as civil protection, emergency management, and policy making, and 8 represented various academic organizations. In the workshop the stakeholders were asked to rank the usefulness of the decision tool in terms of four categories (highly useful, moderately useful, slightly useful and not useful) for the following three areas.

- 1) Understanding the distribution of losses for different sectors and comparing risk scenarios with each other (figure 10).
- 2) Preparing and planning for a multi-type risk disaster in a region, and optimizing the allocation of resources (figure 11).
- 3) Communicating multi-type risk parameters to different stakeholders and for developing strategies for risk management (figure 12).

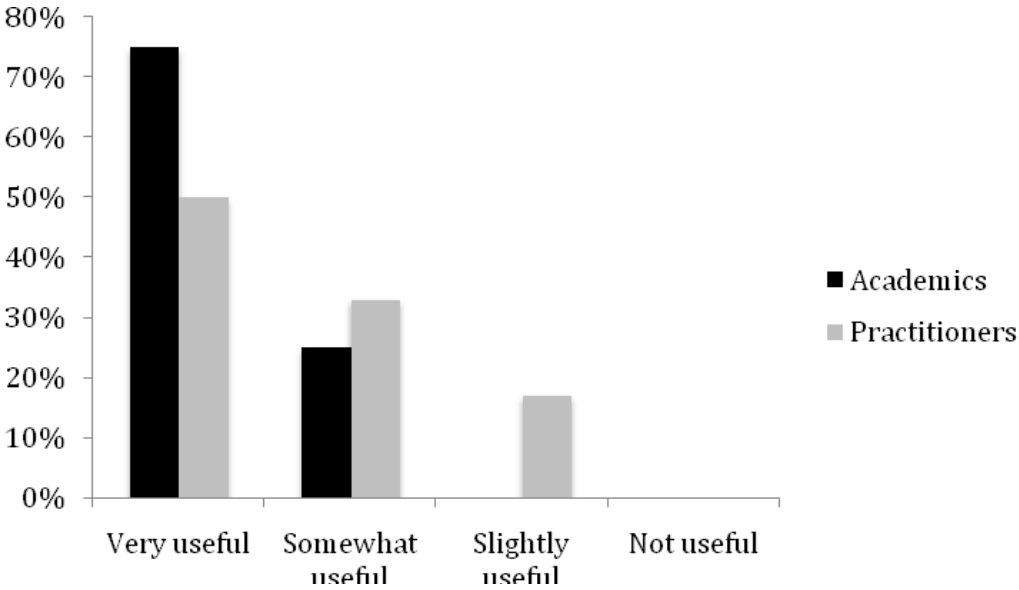


Figure 10: The results of the survey in how the Method 2 tool helps with the understanding of losses and their contribution in a risk scenario (14 answers).

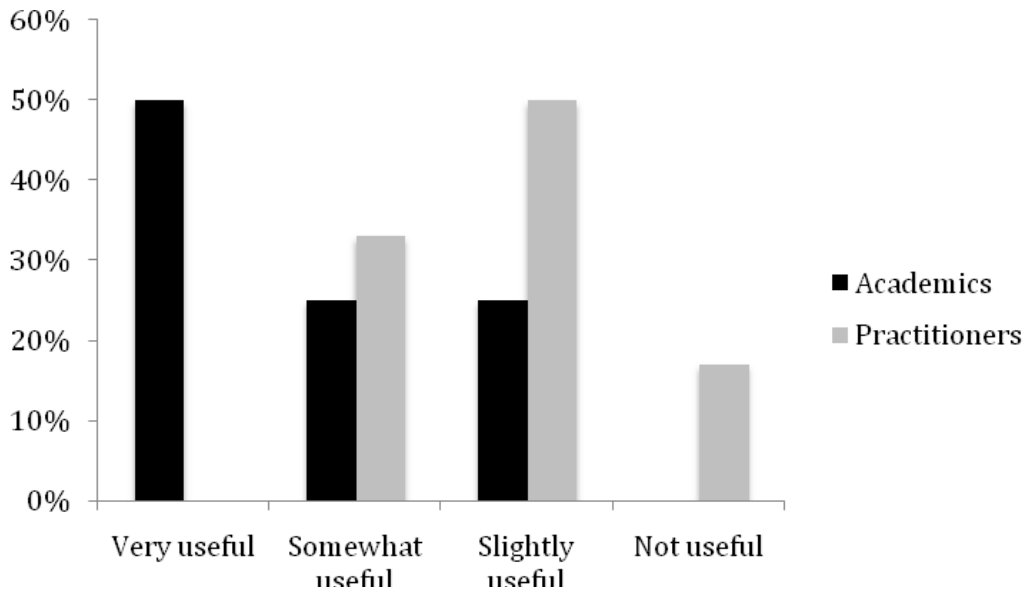


Figure 11: Same as for figure 10, but for how the Method 2 tool helps with preparing for multi-risk disasters and optimizing allocation of resources (14 answers).

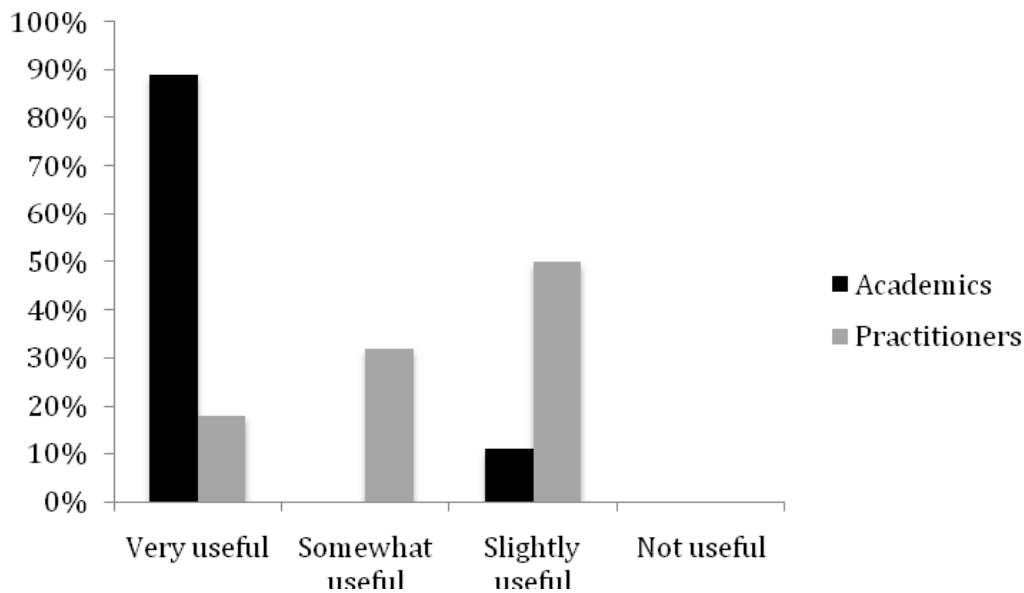


Figure 12: Same for figure 10, but for how the Method 2 tool helps with communicating multi-type risk parameters to different stakeholders for developing risk management strategies (14 answers).

It is interesting to note the variation in the perceptions between stakeholders in academia and those in the practice community in terms of the tool's usefulness. While both academicians and practitioners agreed that the tool is useful for understanding losses and their contributions in a risk scenario (figure 10), there is a difference between how practitioners viewed the usefulness of the tool when it comes to prioritizing risk and developing risk management strategies (figure 12). In the case of the latter, most practitioners viewed the tools as being only slightly to somewhat useful, while academics believed it to be very useful for this purpose. Similarly, practitioners found the tool not to only

slightly useful when it came to preparing for disasters and allocating resources as opposed to most academics, who thought it would be somewhat to very useful (figure 11). In the discussion that followed with the stakeholders, it arose that a precondition for the useful application of the tool is expert knowledge, and thus the tool is ideally to be used by risk analysis experts. In this way, the tool brings added value by providing transparency and a rational breakdown of risk against a competing set of criteria. Furthermore, the stakeholders commented that the usefulness of the tool could only be gauged following an in-depth exercise with stakeholders for a region where the expertise and context (i.e., a case study with specific problem) is available.

5 Discussion

The results from the discussions with and the undertaking of surveys by stakeholders on the usability and user-friendliness of decision-making models showed that stakeholders still have questions about the availability of data for input parameters, but that they did not question the usefulness of the results.

For example, the decision-making model developed by the ARMONIA project was tested in only two case studies and not by a number of stakeholders from different countries. Nevertheless, it was found that, firstly, doubts in the methodology arose, as there was the tendency to exaggerate one hazard over other ones. Second, there were concerns about methodology's output, such as the risk factor, which could be used only by decision-makers who are familiar with this method. The recommendations were to develop alternative multiple-risk mapping methods, which were not as data specific as the methods developed by the ARMONIA project. The recommendations also highlight strongly the need to appreciate participative governance and the need to conduct further research into what the end users of such risk maps actually require.

With the existing decision-making model and generic multi-risk tool, we still could not address the first recommendation. The feedback from stakeholders showed us that there is a need for a significant simplification in terms of the required input data. However, we addressed the second recommendation by collecting and addressing perceptions of stakeholders from several European countries in terms of the usability and the areas of application of the multi-risk assessment tools.

During several rounds of stakeholders' interactions, we received the following recommendations. First, as already mentioned, there is an urgent need for more clarity with regards to the terms and definitions connected with multi-risk and multi-hazard. This will require the terminology currently being employed, for example within the MATRIX project, to be disseminated and agreed upon with all relevant stakeholders (note one of the MATRIX deliverables, D3.2 "Dictionary of terminology" is publically available via the MATRIX website⁸). Second, for input parameters, there is a need to harmonize existing methodologies on data collection and databases across the European countries. In this case, there are already on-going initiatives dealing with this, such as the INSPIRE⁹ initiative of the European Union. Third, we received several recommendations regarding the area of application for multi-risk assessment tools such as the decision-making model and the generic multi-risk framework. This includes the application of the multi-risk approach to enable the comparability of risks. This recommendation was included in the ongoing development of the generic multi-risk framework by comparing various risks with the use of risk as a common metric. This could be a complementary approach to single-risk assessments, where the single and multi-risk approaches relate to two different risk systems.

⁸ <http://matrix.gpi.kit.edu/index.php>

⁹ <http://inspire.jrc.ec.europa.eu/>

Our interviews with stakeholders showed that, first, the risk systems need to be defined, and only afterwards could the risk analysis and assessment be used. There are expectations on the multi-risk systems to be able to address dependencies between hazards. For politicians and decision-makers, it would be interesting to compare two sets of scenarios, one with the interdependencies between different kinds of hazards included, and the other without considering such interdependencies. This is an advantage of the generic multi-risk framework (Method 1) as it is able to provide such comparisons by including or excluding interdependencies between different risks. The developed models could also be used as a test to compare these results with previous results and data developed by insurance companies. Although insurance companies might be interested in such applications, their results would probably remain confidential. Also, the developed models could be used in training purposes in two possible ways. The first would be in a more narrow sense to convince stakeholders in the decision-making process about the usefulness of the multi-hazard approach. The second one could be with the broader view of presenting these results to the general public, hence dealing with public acceptance issues. Some stakeholders expressed the opinion that politicians should be obliged to use this model in their training regimes to see what the consequences of a multi-hazard situation could be. The general recommendation was that the model (including the concept of the Virtual City) could be used for educational purposes.

In conclusion, while the stakeholders involved in this study saw the value of the multi-risk approach, a great deal of work is required by researchers in terms of the methodological development, and in shaping these methods to meet the needs of end-users. From the other side, further efforts are required to actually understand what is required by end-users, while continuing to further disseminate the message of the value multi-hazard and risk approaches.

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