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

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Abstract

The number of people affected by natural hazards is growing, as many regions of the world become subject to multiple hazards. Although volume of geophysical, sociological and economic knowledge is increasing, so are the losses from natural catastrophes. The slow transfer from theory to practice might lay in the difficulties of the communication process from science to policy-making, including perceptions by stakeholders from disaster mitigation practice regarding the usability of 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 article we identify 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 straight forward and flexible implementation of hazard interactions, which may occur in a complex system. The second is a decision-making tool that integrates direct input from stakeholders by attributing weights to different components and constructing risks 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 processes involved.

Keywords: Multi-hazard, Multi-risk, Risk governance

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 assess and they are not included in the majority of databases. Nonetheless there is ample evidence in the literature that the number of people who are directly or indirectly affected by disasters will continue to increase (Arnold et al., 2006; Bilham, 2009; Daniell et al., 2011; Hoyois and Guha-Sapir, 2003; World Bank 2010). Many regions of the world are not simply subject to single hazards, but may be impacted upon by multiple hazards, which may also be correlated. Conjoint disasters and other cascading effects yield higher direct losses, such as damage to infrastructure, as well as higher indirect losses, such as business interruption.

Existing risk assessment methods integrate large volumes of data and sophisticated analyses, as well as different approaches to risk quantification. However, the key question is why do losses from natural disasters continue to grow if our scientific knowledge on multi-risk increases? (White et al., 2001). One reason is 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. (2012) stated in their review on multi-hazard risk, 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 demand 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 to provide them with information on mitigation measures. These tools can 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 feedback and perceptions of the usability of these models from the side of stakeholders are extremely important to the process of communication from science to policy and vise versa. So far, however, the literature on the topic of how stakeholders perceive the usability of multi-risk models is very limited.

The aim of this paper is to identify the perceptions of stakeholders to the value of two complementary decision-making tools developed within the context of the EU FP7 project New Multi-Hazard and Multi-Risk Assessment Methods for Europe (MATRIX):

- (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 paper.

This work is a first attempt to collect and to integrate feedback of stakeholders from civil protection authorities into decision-making tools, which include aspects of multi-hazard and multi-risk. The feedback was gained during two workshops, in Bonn (July 2012) and in Lisbon (October 2012), and from a questionnaire distributed prior to the first workshop. The research within this work encompasses three overarching questions:

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

2. Background

This section aims at providing basic terms in multi-risk assessment and examples of past experiences in multi-risk. This short review especially highlights the fact that decision-making under multi-risk is a nascent field. Feedback from stakeholders on newly developed multi-risk tools in participatory process is greatly needed to avoid a dichotomy between science and practical applications.

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" already itself implies aleatory 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). Distinction between conjoint and cascading events must be made here. 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 triggers a subsequent event or series of events, for example an earthquake that triggers a landslide or a tsunami (e.g., 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 geo-hazards, however, the various interactions that may arise between hazards 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 NaRaS EU 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, active faults in the Apennine chain (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 cultural and political 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 experience of stakeholders into multi-risk assessment models. Risk governance is concerned with how information is collected, perceived and communicated and follows how management decisions are taken (IRGC, 2005). In 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 into the strategy of the European Community for the mitigation of natural and man-made disasters (COM, 2009). Amongst other elements, the communication document outlines the need for multi-risk assessment and the need for common guidelines, which will enhance the comparability of risks across Member States and will lead to a common European picture of multi-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 focuses 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 (COM, 2010a). 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, with the consultation and communication of findings and results of risks assessments with stakeholders.

2.3. Participatory modeling and presentation of information under uncertainty

Participatory modeling is an important part of the risk governance and is the process which allows to take into consideration not only facts but also values by asking questions and collecting feedback from stakeholders (Forester, 1999). Therefore, it requires active participation of stakeholders and two-way communication, when feedback is collected and implemented into risk assessment and decision-support tools. This process is especially useful when facts are uncertain, values are in dispute, stakes are high and decisions are urgent (Funtowicz and Ravetz, 1994). The process of interactions with stakeholders leads to an enhanced understanding about points of view, criteria, preferences and trade-offs in decision-making (Antunes et al., 2006).

The participatory modeling is also used to build consensus among the group of stakeholders on controversial issues, such as for example attribution of weights to different loss parameters under multi-risk scenarios. First, such models integrating stakeholders perceptions were developed for business management applications (Senge and Sterman, 1994). Recent trends also foresee application of the decision-support models as a problem structuring method and to facilitate group decision support (Phillips, 1990). Thus, decision-support models become a part of executive debate and dialogue to help avoid judgment biases and systematic errors in decision-making (Morecroft, 1994) and to help in complex decision-making process grounded on human rationality, which can create persistent judgment biases and errors (Kahnemann and Tversky, 1874). The issue of what input science should provide to policy-making through developed models was discussed already widely in literature (Jasanoff, 1990). However, it is also known that the process of development of models involves many assumptions and judgments (Korfmacher, 1998).

The models, such as STELLA or the Coastal Ecological Landscape Spatial Simulation (CELSS), which integrate the knowledge of stakeholders in consultation process such as interviews, workshops and focus groups, were developed to support decisions on environmental investments and problems (Constanza and Ruth, 1998). The decision-makers had chance to apply these models in practice and to choose different parameters according to their understanding of the problem (Weston and Ruth, 1997). As the participants were providing feedback during all stages of model development, the models results were much easier to communicate and implement. Also participants had a much more sophisticated understanding of underlying assumptions, uncertainties and strength of the model and could use it effectively as a management tool (Costanza and Greer, 1995).

Currently, some decision models for multi-hazard and multi-risk assessment are being developed with the aim to provide stakeholders with a set of scenarios or alternatives. These models display different risks with respect to their probability and frequency, as well as to their possible outcomes. The decision-making models, such as a Multi-Risk Land Use Management Support System developed in frames of the ARMONIA project (T6, 2007) and the scenario-based approach for risk assessment used by the German Federal Office of Civil Protection and Disaster Assistance (BBK, 2010) integrate multi-risk concept by visualizing risks and using the 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 1) and thus integrate this information into the knowledge base for decision making processes. The objectives of these tools are to provide assessment of exposure and vulnerability, to support regarding land-use issues and location of strategic facilities, to provide options for mitigating risks through a system of Multiple Criteria Evaluations.

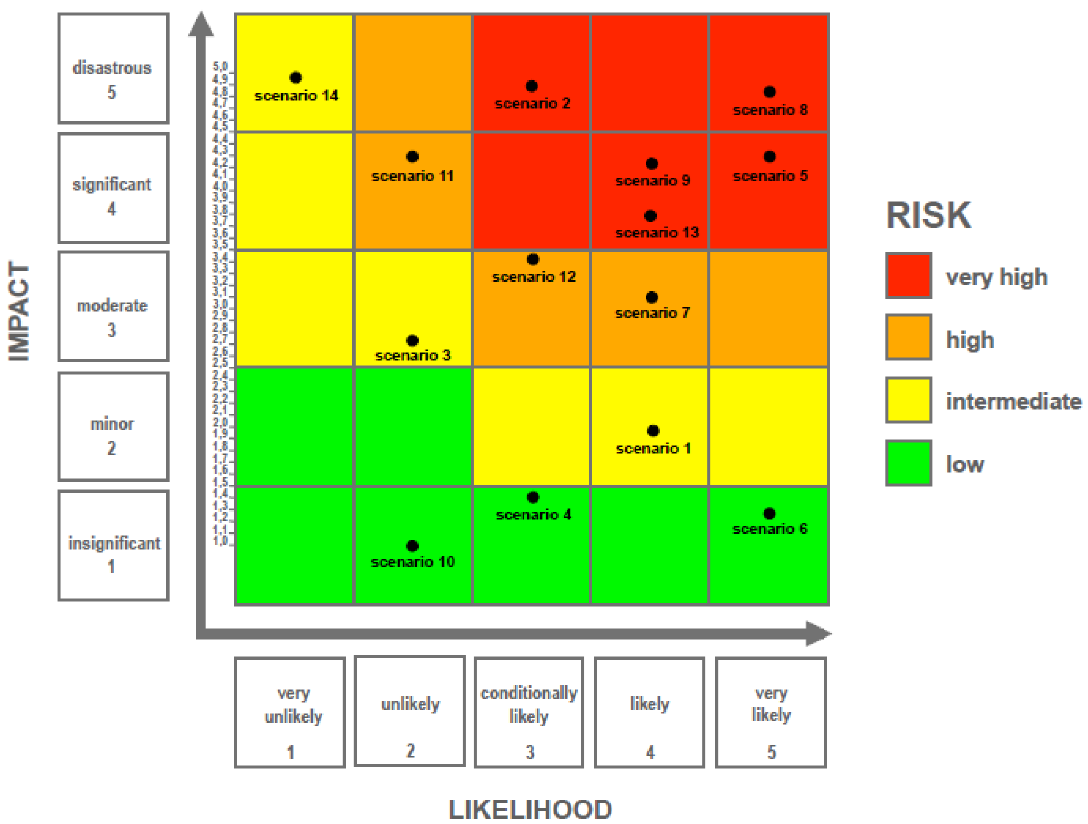


Figure 1: Example of how different scenarios fit within a risk matrix (BBK, 2010).

In addition, three principal software tools have been developed to date to provide multiple single risk assessments of a given territory. These are HAZUS[1] for the USA (hurricanes, earthquakes and floods), RiskScape for New Zealand (volcanic ash falls, floods, tsunamis, landslides, storms and earthquakes; Schmidt et al., 2011) and CAPRA[2] in Central America (hurricanes, heavy rainfall, landslides, floods, earthquakes, tsunamis and volcanic hazards; CAPRA Probabilistic Risk Assessment Initiative, 2011). Variants of these softwares have been used in other parts of the world (e.g., HAZTURK and HAZTAIWAN, CAPRA in Asia, RiskScape 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 softwares and feedback from stakeholders is not available. More importantly, these softwares do not include conjoint or cascading disasters, which is the strict definition of multi-risk.

To our knowledge, even though some of these models have been tested by operational and practicing stakeholders, there is limited evidence of stakeholder feedback. HAZUS is largely used by stakeholders, mainly government planners and emergency managers, to determine losses and the most beneficial approaches for their mitigation. 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). The aim of RiskScape is to be an "easy to use multi-hazard impact and risk assessment tool" and to inform decision-making, including land-use planning, 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).

The evidence of participation of stakeholders in the tool development and integration of their feedback is almost absent. One decision-making model developed by ARMONIA defines weights based on the judgments from stakeholders on different vulnerabilities within the area of their interest. However, there is no scientific analysis of feedback from 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 feedback of stakeholders through the methodology of stakeholders´ consultation via such means as questionnaires, decision-making experiments and workshops.

3. Methodology

3.1. Decision support tools, which were applied to collect feedback from stakeholders

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

[1] http://www.fema.gov/hazus
[2] http://www.ecapra.org

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). We describe briefly these models below (see also Appendix).

3.1.1. Tool #1: Generic multi-risk framework

Mignan et al. (submitted) proposed a generic multi-risk framework based on the sequential Monte Carlo method to allow for a straightforward and flexible implementation of conjoint and cascading events. The model considers hazard interactions, which are analogue to the ones observed in recent catastrophes, such as the 2005 hurricane Katrina or the 2011 Tohoku earthquake. It also includes time-dependent exposure and time-dependent vulnerability, although these aspects were not discussed with stakeholders. Validation of the framework was based on the testing of generic data and interaction processes (see Appendix A1 for the detail of the method). For a presentation of the multi-risk framework to stakeholders, another set of data and interaction processes was used, based on the concept of virtual city, which is illustrated in figure 2. This concept was also developed within the scope of the MATRIX project (Mignan, 2013) but has yet to be fully described (Mignan et al, in preparation). A virtual city located in a virtual hazardous region gives the baseline for the investigation of hazard interactions in a controlled - yet realistic - environment. Perils and interaction processes are defined heuristically (e.g., earthquakes from simple ground motion prediction equations, floods from water height in a V-basin, storm surge height as a function of wind speed based on the Saffir-Simpson scale, etc.). Risk is also computed from simple considerations (e.g., lognormal distribution as a proxy to various vulnerability curves). By construction, epistemic uncertainties are high but could be reduced when switching from a virtual scenario to a real one.

Several examples of multi-risk scenarios based on the generic multi-risk framework and on the virtual city concept were presented at both workshops. At the second workshop, we conducted the decision-making experiment to test the tool again, which was improved after the first workshop according to feedback from stakeholders.

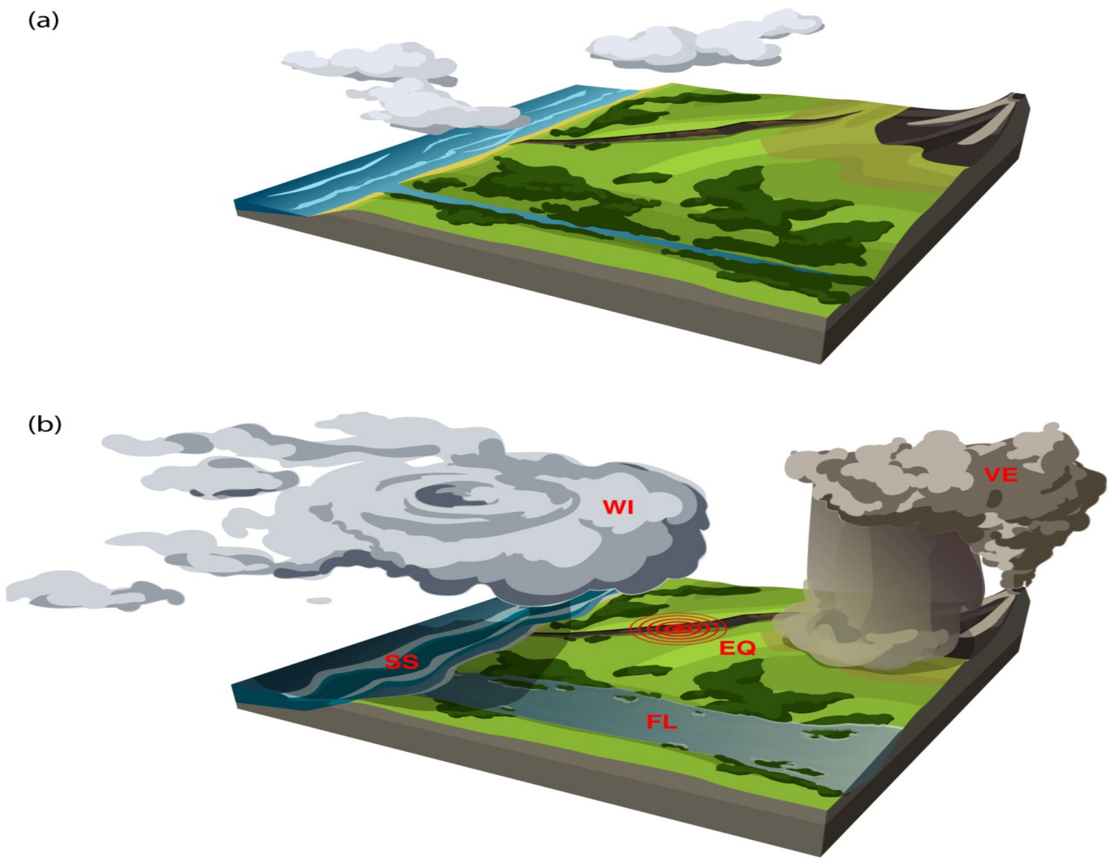


Figure 2: Concept of virtual city: Artistic representation of a virtual hazardous region. Top: Morphology of the 100 by 100 km region. Bottom: perils considered in this version are earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI) and sea submersions (SS). The virtual city can be located anywhere in that region. Source: Mignan (2013).

3.1.2. Tool #2: Risk matrix decision-support tool

The BBK (2010) risk matrix framework was implemented into decision-support software by B. Khazai at the Karlsruhe Institute of Technology based on the principles of Multi-Criteria Decision Analysis (MCDA) (see Appendix A2 for the detail of the method). The tool was tested with a group of stakeholders for the prioritization of risk scenarios in a delineated region based on user input. The goal was to test the different interactive features and visualization formats in the tool for communicating and transferring the information contained for the different risk scenarios in the risk matrix to the various stakeholders involved. The risk matrix relates the two dimensions of likelihood (in terms of probabilities of occurrence) and impact (in terms of severity of impact) in a graphical representation of different risks (along multiple impact dimensions) in a comparative way and can used as a simple approach for setting priorities (figure 3).

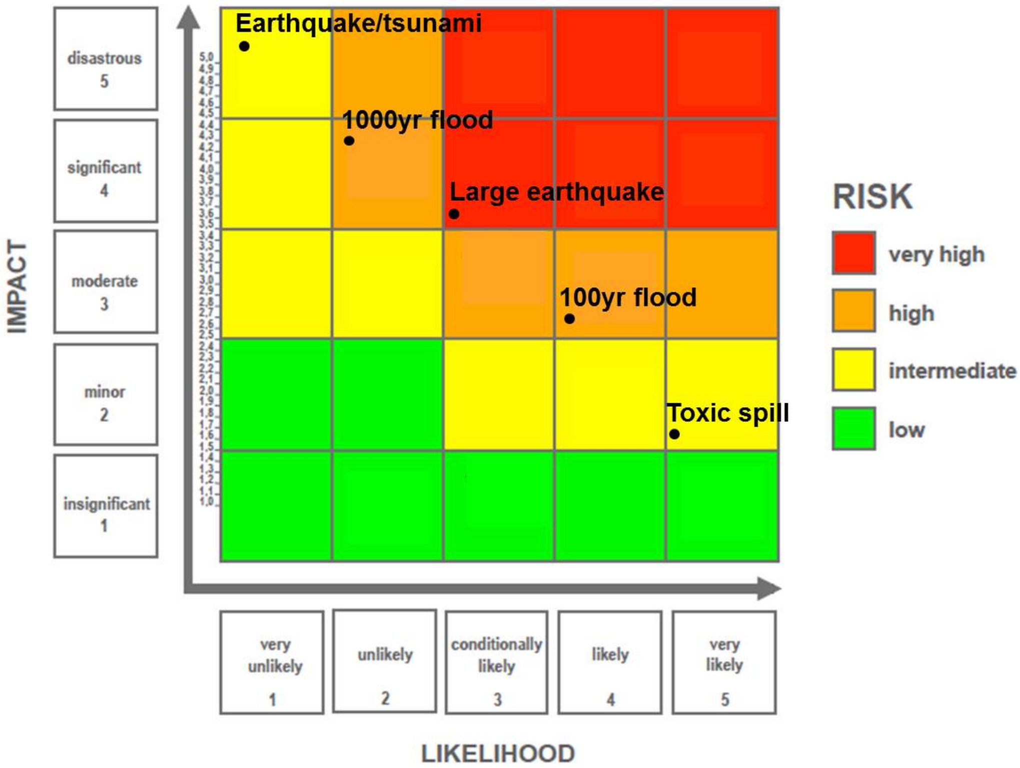


Figure 3: Risk matrix. Source: BBK, 2010

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. In this way, 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.

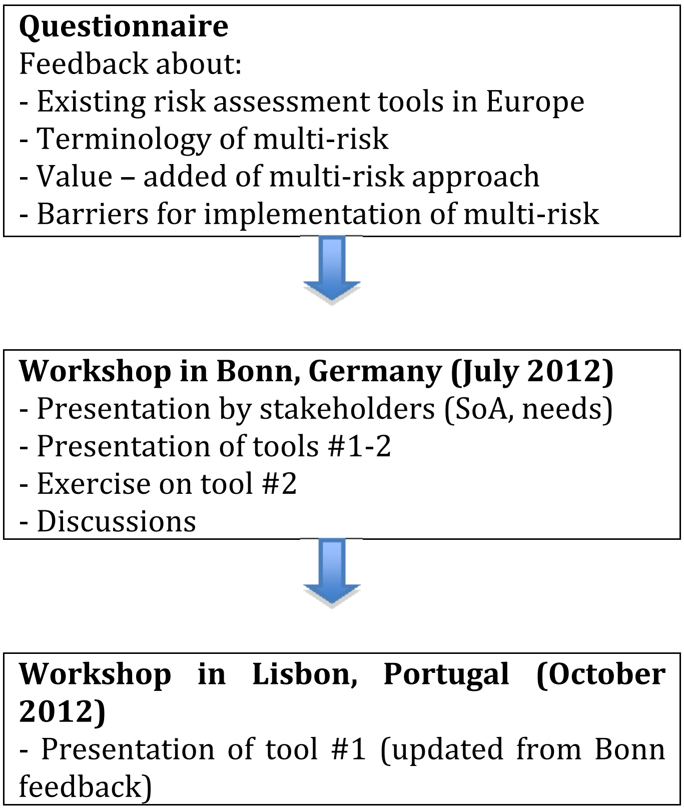
The decision support tool allows users to construct a composite impact score for each hazard scenario, by the mathematical aggregation of a set of individual impact indicators that measure multi-dimensional concepts but usually do not have common units of measurement (Nardo et al. 2005). In this way the tool allows the user to input impact from different hazard scenarios in terms of the following dimensions and respective indicators: 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 implications, psychological implications and loss to cultural values).

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. While this approach may invite stakeholders to draw simplistic conclusions, it can provide a big picture by accounting for different dimensions of impact, including dimensions that are difficult to measure and are often ignored. In this way the tool is able to summarize a complex multi-dimensional view of scenarios and allows a more rounded assessment of impacts. Furthermore, not all the impact measures and dimensions are of equal importance, and the decision support tool allows the users to dynamically change the weights assigned to each indicator based on its perceived importance and immediately observe changes in the composite impact score of the different risk scenarios.

Using the interactive features and various visualization tools in the decision support software, such as sensitivity graphs, stacked bars, scatter plots, and pair-wise comparisons between scenarios, the aim is to facilitate communication among the stakeholders to determine which of the multiple risk scenarios should be prioritized by considering many variables at once and better communicate their choice to others.

3.2. Methods of stakeholders interactions

Our approach to collect feedback from stakeholders includes several methods, among them the distribution of questionnaires and the organization of workshops with presentation of tools, exercises and discussions (figure 4). Importantly, we collected feedback from those stakeholders who participated at the workshops mentioned above and combined this information with that obtained from questionnaire distributed prior to the workshops.



- Exercise on tool #1
- Discussions

Figure 4: Consultation process with stakeholders

Two workshop were organized, the first one was held in Bonn, Germany, on the 6th and 7th of July 2012, under the auspices of the MATRIX project. The second workshop 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 list of stakeholders present during the two workshops is given in Table 1 and Figure 6. Additionally, other stakeholders answered to a questionnaire sent before the Bonn meeting but without participating to the workshop.

During our stakeholder consultations, we worked together with representatives from National Platforms for Disaster Risk Reduction, which are most commonly parts of the national Civil Protection. Furthermore, the United Nations Office for Disaster Risk Reduction (UN-ISDR) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austrian Service for Torrent and Avalanche Control, have been involved. The stakeholders agreed to cooperate and to provide their feedback on tools after an official request from GFZ (the MATRIX project coordinator) and the German Committee for Disaster Risk Reduction (DKKV).

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). They are multi-stakeholder committees comprising experts and members from different sectors, enabling them to act as centers 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 Disater Risk Reduction (DRR) "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 DRR and backstop their policy and advocacy activities; develop improved methods for predictive multi-risk assessments, including on the economics of DRR and socio-economic cost-benefit analysis of risk reduction; and integrate early warning systems into their national DRR strategies and plans".

The selection of stakeholders 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 might be 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 UN-ISDR. As we do not apply methodology of large-scale survey but use specialized targeted questionnaire as well as collect feedback during workshops, we regard our sample of stakeholders as representative as it covers most of the European countries (figure 5).

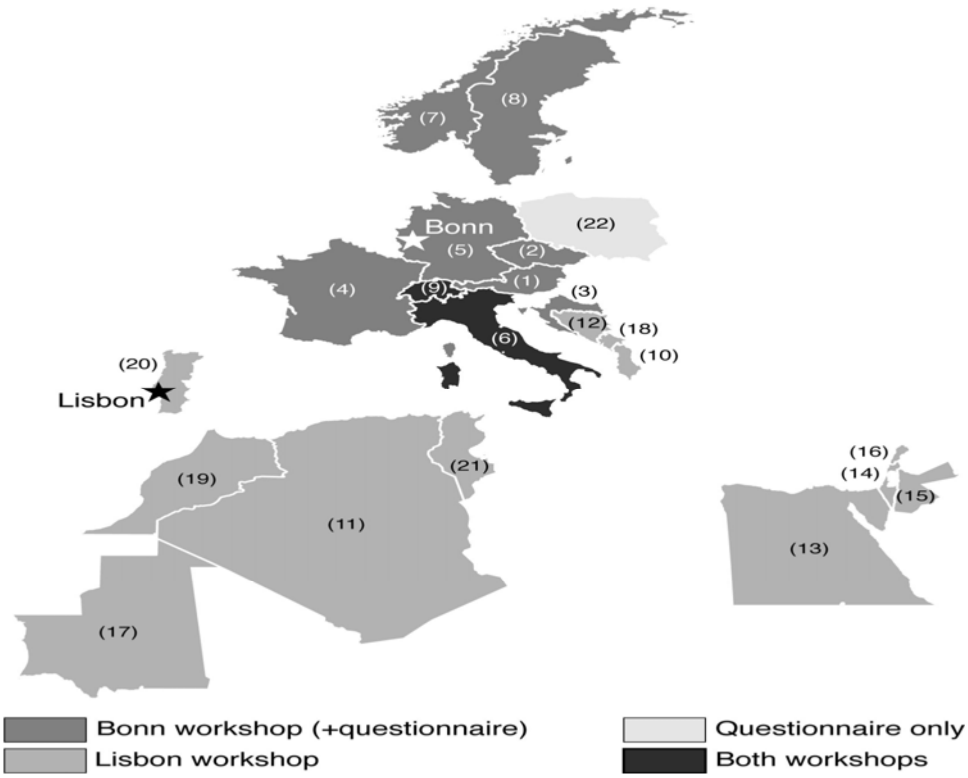


Figure 5: Countries that participated in the workshops held in Bonn and Lisbon as well as in the questionnaire prior to the Bonn workshop and the survey after it. See also table 1.

Table 1: List of participating institutions

Bonn Workshop	Lisbon workshop
1. Austria, Federal Ministry of Agriculture, Forestry, Environment and Water Management 2. Czech Republic, National Committee for	10. Albania, Civil Emergencies 11. Algeria, General Directorate of Civil Protection

Natural Disaster Reduction 3. Croatia, National Protection and Rescue Directorate 4. France, Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer 5. Germany, Federal Office of Civil Protection and Disaster Assistance 6. Italy, Civil Protection Department 7. Norway, Directorate for Civil Protection and Emergency Planning 8. Sweden, Center for Climate and Safety 9. Switzerland, United Nations International Strategy for Disaster Reduction	12. Bosnia and Herzegovina, Ministry of Security 13. Egypt, General Administration of Civil Protection 14. Israel, Ministry of Home Front Defence 6. Italy, Civil Protection Department 15. Jordan, Rescue and Support Directorate 16. Lebanon, Civil Defence 17. Mauritania, Mayor 18. Montenegro, Department for Civil Protection 19. Morocco, General Directorate of Civil Protection 20. Portugal, National Authority for Civil Protection 9. Switzerland, United Nations Office for Disaster Risk Reduction 21. Tunisia, Civil Protection
Questionnaire only	
22. Poland, Institute of Meteorology and Water Management, National Research Institute (IMGW)	

With regards to the Bonn workshop and the questionnaire, considering that there are about 15 national platforms in Europe, 8 participated in the workshop, as well as UNISDR, and 8 responded to a questionnaire (Austria, Czech Republic, France, Germany, Italy, Norway, Poland and Sweden), which was distributed before the workshop. At the Lisbon workshop, stakeholders from Southern Europe, the Balkans, Middle Eastern and North African countries participated.

3.2.1. Questionnaire

A first questionnaire was developed and distributed to stakeholders before the Bonn workshop to elicit baseline perception of the group of civil protection officers in order to compare with perceptions afterwards. It also served as a way to elicit problems perceived by stakeholders in order to discuss them during the first workshop. The general aim of the questionnaire was to collect feedback from the civil protection community about the current status of multi-risk approaches, such as availability, methods, and barriers, of hazard, risk and multi-risk assessments 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 to also capture the stakeholders' perceptions of the term multi-risk. We summarized the results of the questionnaire, presented them and discussed outputs with the stakeholders during the workshop in Bonn.

The aim of the developed questions was to capture their understanding of the term "multi-risk", to obtain an overview of the state-of the art of hazard, risk and multi-risk assessment, to receive feedback on the level of integration of hazard and risk assessments into decision making processes, to assess the usefulness of multi-risk scenarios for disaster management strategies, to receive feedback on requirements for multi-risk methods and tools, to receive feedback on the potential of integrating the multi-risk methodology developed by MATRIX in the domain of the National Platform.

Questions were related to: the availability of comprehensive hazard, risk and multi-risk assessments, description of applied hazard and risk assessment methodologies, use and usefulness of hazard, risk and multi-risk assessments in decision making processes, use of probabilistic and scenario analysis, estimations of uncertainties and socio-economic and engineering models in hazard and risk assessment, requirements for multi-hazard and multi-risk assessment methods and tools, parameters require to be considered, communication of multi-risk to decision making processes, advantages of multi-risk in comparison to single risk assessment, potential of integrating the multi-risk methodology developed by MATRIX in the domain of the National Platform and barriers in implementing multi-risk methods.

3.2.2. Bonn workshop

The following activities were performed during the Bonn workshop: presentation and discussion of the results of the questionnaire, which was submitted to the stakeholder before the workshop, presentations from stakeholders and discussion on hazard and risk assessment approaches in Europe, presentation and discussion of the generic multi-risk framework and the decision support tool. These activities contributed to a better understanding of the current approaches and to the further development of the tools.

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 multi-hazard and multi-risk assessments as well as the added value of the multi-risk approach. It also provided an opportunity to discuss multi-risk decision support tools in three aspects; first, to capture the status of different approaches and open problems with regards to multi-risk assessment in Europe, second, to understand the users' requirements with regards to information technology for the generation of scenarios, third, to understand the range of risk components addressed in the current practice, such as losses to people's health and lives, economy, ecological damage, impacts upon infrastructure and critical infrastructure, and intangible losses. Additional interactions on tool #2 allowed us to identify differences in the perceptions between stakeholders from science and practitioners.

The generic multi-risk framework (tool #1) and its application in a virtual city were presented by A. Mignan and the risk matrix decision-support tool (tool #2) was presented by B. Khazai. No exercise involving tool #1 was proposed in the Bonn workshop. An exercise of tool #2 followed in which 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. Noteworthy, to save on time, only B. Khazai was directly interfacing with the tool, taking into account recommendations from the stakeholders and showing the outcomes on a large screen (i.e., interactive tutorial).

3.2.3. Lisbon workshop

A presentation of the generic multi-risk framework (tool #1) 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 participants were divided in several groups of about 5 persons with discussions promoted within and between groups (figure 6). The first part of the exercise consisted in investigating the different hazards present in the two cities based on various 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 - hence here combining the tool #1 core modeling concept with a visualization and ranking of multi-risk similar to tool #2. This upgrade of tool #1 was based on feedback obtained during the Bonn workshop (see section 4). The second part of the exercise was to discuss potential triggering effects, based on the virtual city results and past catastrophes known of the participants. 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-consequences events when multi-hazard is considered in risk management. While the participants did not use the generic multi-risk framework per se, they could perceive its basic concept via the exercise.

4. Results

The following results were derived from the questionnaire and from further feedback obtained from stakeholders during the two following workshops. This feedback relates to multi-risk and multi-hazard, in general, and their added value compared to single risk.

4.1. Multi-hazard and multi-risk approach, terminology and added-value

This section does not contain specific feedback on the tools, which is discussed in section 4.2. The general results show that for usage of multi-risk decision-support tools, two areas are most problematic. These are (1) the absence of clear definitions and (2) the lack of information on the added value of multi-risk assessment.

First, there is still no common understanding what does the term "multi-risk" means. The common terminology on multi-risk does not exist and disaster management terms are used differently among different European countries. It shows the need to develop a glossary with definitions and terms relevant to multi-hazard and multi-risk, 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 claimed 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, involved into assessment and mitigation of different kinds of natural hazards, better planning and cost efficiency during the decision-making process.

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 6). It remains unclear why hazard was favored against risk. We may suggest that hazard provides first-level information, simplifying interpretations. The participating stakeholders may also unconsciously consider risk, as they know where infrastructures and populations are located on the hazard maps, meaning that risk is in fact implicitly favored against hazard. Finally this result may simply indicate that there is still much work to be done at the hazard level, before any detailed risk analysis.

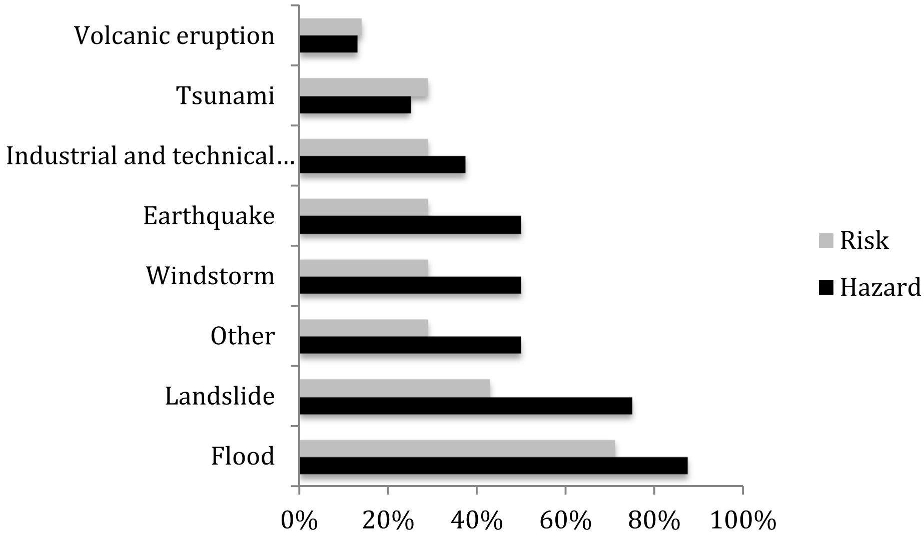


Figure 6: Distribution of the application of different types of hazard and risk assessment in the eight European countries represented in the questionnaire distributed prior to the Bonn MATRIX workshop.

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.

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. During the workshop, stakeholders identified the advantages of the multi-hazard approach, for example synergies in the handling of complex risks, including domino effects, as well as the potential for the instigation of complementary and systematic approaches.

There are different ways of including risk in the mapping process, such as the French approach of overlaying exposure and hazard, or the Norwegian approach 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 level[3]. Probabilistic analysis and scenario analysis are widespread among the European countries. In particular, scenario analysis seems to be state-

[3] http://www.risquesmajeurs.fr/les-plans-de-prevention-des-risques-naturels-ppr

of-the-art. Uncertainties are difficult to address because adequate methodologies and reliable data are not available.

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 7).

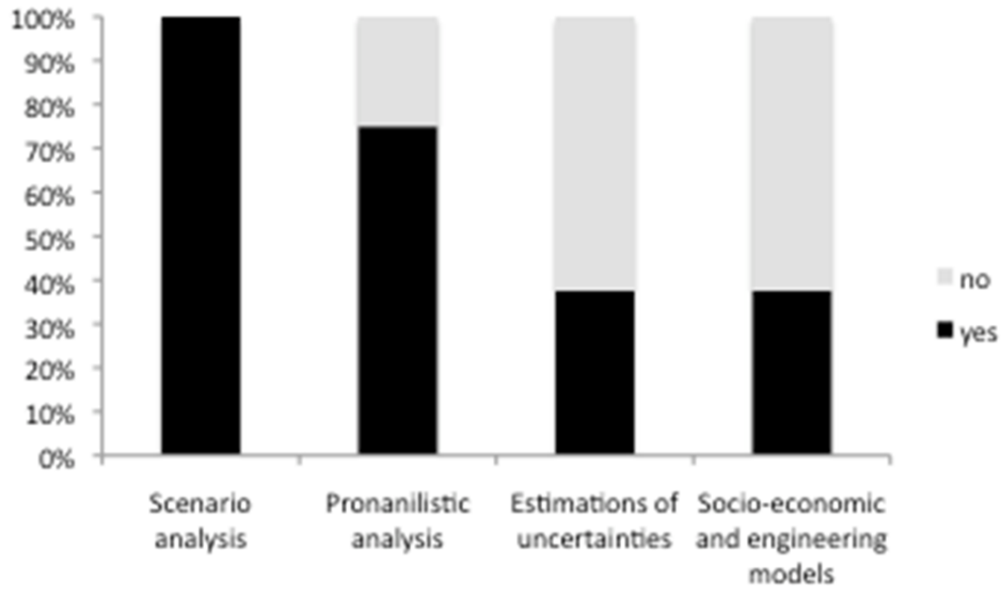


Figure 7: Application of scientific assessment tools for decision-making processes in the eight European countries that responded to the questionaires.

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 European Flood Directive 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, 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.

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 include 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 way.

Stakeholders identified several barriers to the implementation of multi-risk and multi-hazard approaches, such as financial, political, conceptual, methodological and operational aspects. In particular, they perceive three barriers as 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 diverse. The data on cost 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 the insurance companies might be biased and therefore their assessments are not fully comprehensive or independent. There are as well issues of 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 that lack of cooperation between involved institutions, organizations and departments, because information about risk and hazard assessments does not flow 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.

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 spatial and temporal probabilities of multiple risks as well as vulnerabilities of regions to multiple risks; additionally the reliability and transparency of the calculation of cascading and conjoint probabilities.

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. Usability of MATRIX decision-support tools

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

The reaction of stakeholders to the multi-risk assessment and decision-making tools presented at the 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 (tool #1) and the decision-making tool (tool #2) after their testing phase.

4.2.1. Generic multi-risk framework (tool #1)

The stakeholders see the usability of the generic multi-risk framework combined to the use of the virtual city concept primarily for educational purposes. Currently two areas are most problematic for implementation of tool #1. First, this is the required volume of input parameters, which involves cumbersome data gathering to consider multiple hazards and risks in a given region. The data requirements (stochastic event set, individual hazard footprints, correlation matrix that provides event conditional probabilities of occurrence, etc. - see details of the method in Appendix A1) raise questions as to how user-friendly the model is, as the user (for now) needs to be an expert himself to be able to apply the model and to provide the necessary input parameters. Second is that possible application is limited only to a narrow number of experts as high-level expertise is required to assess the dynamic multi-hazard and multi-risk processes. Taking into account the complexity of the model and the required parameters, stakeholders believe that it is questionable that the model is at the present time applicable in practice for the land-use planning. It was finally remarked that the application of the multi-risk framework 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 modelers as well as officials, and a “brick-by-brick” approach is necessary to progressively add together all of the complexities of the risk process.

Importantly, the feedback from stakeholders during the Bonn workshop helped to improve the communication interface of the multi-risk framework. The updated framework was then tested successfully during an exercise at the Lisbon workshop. The main criticism observed during the Bonn workshop, being linked to the complexity of the modeling, has been partly resolved by the use of the risk matrix (Cox, 1998; Kraussmann et al., 2012; Tool #2) instead of the loss curve (e.g., Grossi et al., 2005) to show how risk migrates when hazard interactions are included (figure 8). General guidelines on how to quantify hazard interactions were also developed, based on an extensive literature review (Mignan et al., in preparation). These guidelines should help risk modelers to include, again in a brick-by-brick approach, hazard interactions into their risk management schemes.

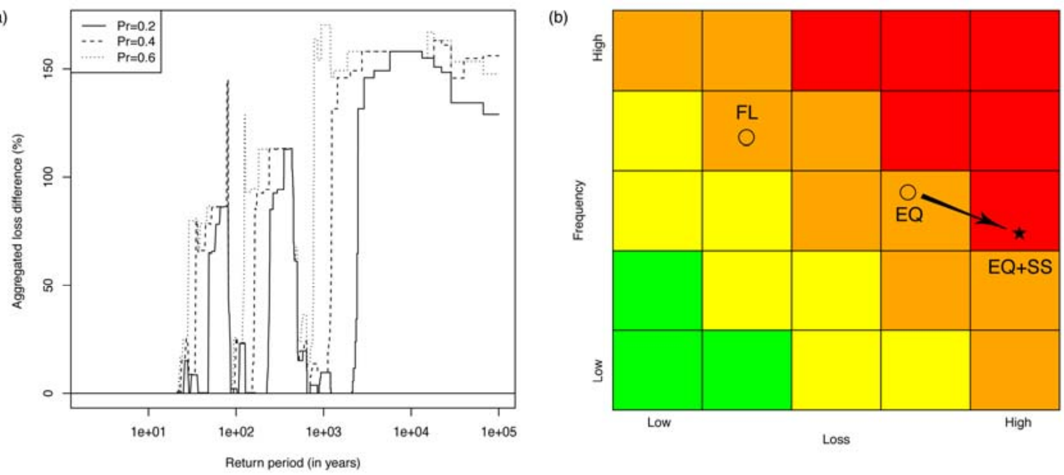


Figure 8: Including stakeholder feedback in tool #1. (a) Original metric proposed to identify the impact of multi-risk versus multiple single-risk. The curve, which represents the difference between two loss curves, was not well received by the stakeholders in general. The jumps represent the increased risk when including storm surge compared to storm alone. Source: Mignan (2013); (b) Example of a risk matrix determined "by hand" during the Lisbon multi-risk exercise. This metric is simpler than the differential loss curve originally proposed since the different risk scenarios (circles and stars) and the migration of risk (arrow) are here explicit (FL: flood, EQ: earthquake, EQ+SS: interaction earthquake → sea submersion, i.e. tsunami). An example generated from tool #1 including numerous multi-risk scenarios from Mignan et al. (submitted) is given in Appendix A1.

Figure 8 highlights the idea that new risks emerge and some others shift to lower-probability high-consequences events when multi-hazard is considered in risk management. This had not been fully understood during both Bonn and Lisbon workshops when using differential loss curves (Fig. Xa). Using the concept of risk matrix helped improving the comprehension of the results obtained by the generic multi-risk framework (Fig. Xb). The circles represent independent events, while the star represents an event emerging from interaction processes. 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 here represents the migration of the risk arising from an earthquake alone to lower-probability but higher-consequences when interactions are considered (which is similar to the jumps observed at longer return periods in Figure Xa). While this result may appear obvious when considering this simple example, "surprise" chains of events may emerge when numerous events and interactions are included in the system (see Appendix A1). This idea was well grasped during the exercise organized during the Lisbon workshop.

4.2.2. Decision support model (tool #2)

In the workshop the stakeholders were asked to rank the usefulness of the decision-support tool in terms of four categories (highly useful, moderately useful, slightly useful and not useful) for the following three areas. The feedback was collected with the help of a questionnaire.

a) Understanding the distribution of losses for different sectors and comparing risk scenarios with each other (figure 9).
b) Preparing and planning for a multi-type risk disaster in a region, and optimizing the allocation of resources (figure 10).
c) Communicating multi-type risk parameters to different stakeholders and for developing strategies for risk management (figure 11).

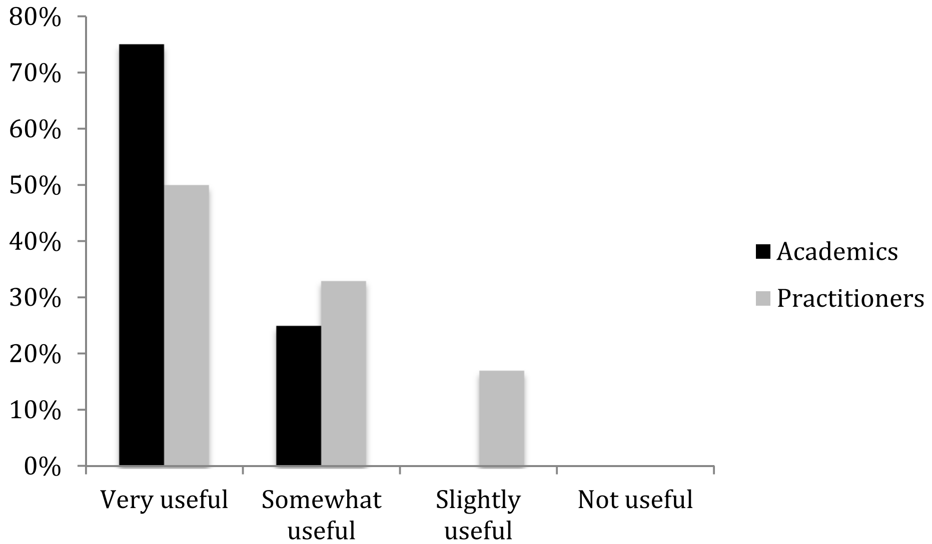


Figure 9: The results of the survey in how tool #2 helps with the understanding of losses and their contribution in a risk scenario (14 answers).

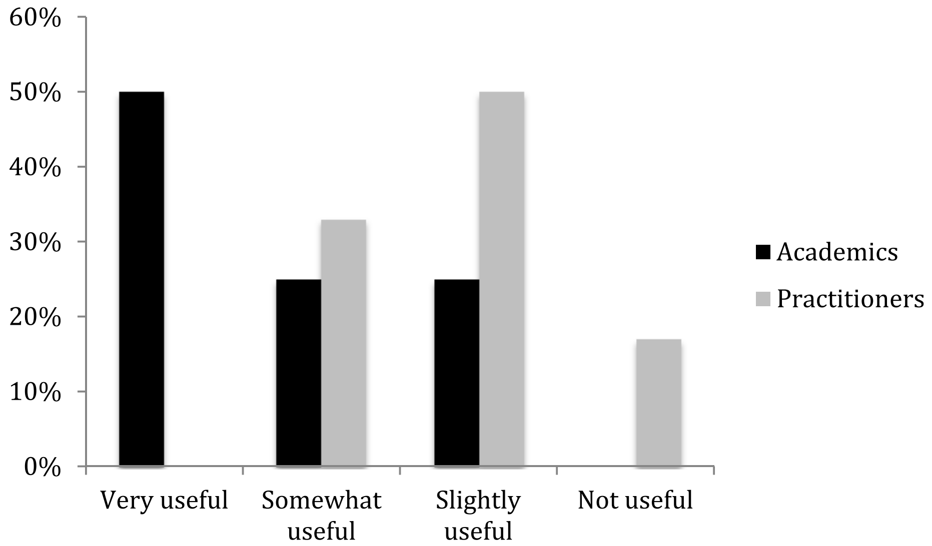


Figure 10: As for Figure 10, but for how tool #2 helps with preparing for multi-risk disasters and optimizing allocation of resources (14 answers).

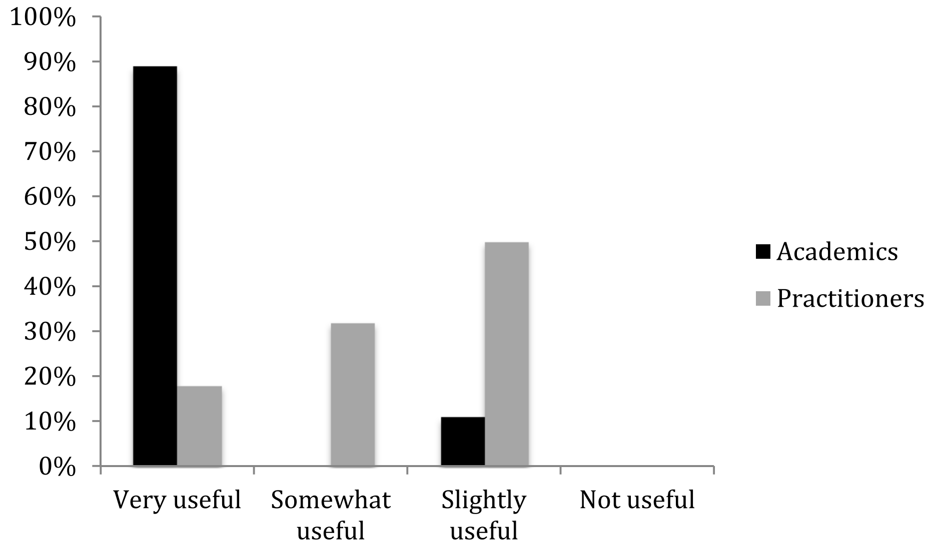


Figure 11: As for Figure 10, but for how tool #2 tool helps with communicating multi-type risk parameters to different stakeholders for developing risk management strategies (14 answers).

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 9), 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 11). 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 comes to preparing for disasters and allocating resources as opposed to most academics, who thought it would be somewhat to very useful (figure 10). 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 adding 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. Noteworthy, academics seem more optimistic to an innovative tool than stakeholders possibly because academics may push for innovation while stakeholders may prefer well-established methods.

5. Discussion

The results from of 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. It showed, firstly, that 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 recently proposed MATRIX 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 website[4]). 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

[4] http://matrix.gpi.kit.edu/index.php

already on-going initiatives dealing with this, such as the INSPIRE[5] 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.

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 as it is able to provide such comparisons by including or excluding interdependencies between different risks (e.g., figure 2). 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 could 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 disseminating these results to the general public, hence dealing with public acceptance issues. Some stakeholders expressed the opinion that politicians shall be motivated to use this model in their training purposes to see what the consequences of a multi-hazard situation could be. The general recommendation was that the model (including the concept of 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 of multi-hazard and risk approaches.

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[5] http://inspire.jrc.ec.europa.eu/

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Appendix

A1. Generic multi-hazard and multi-risk framework

The multi-risk framework proposed by Mignan et al. (submitted) is formed of a core simulation algorithm based on the Monte Carlo method (MCM). The MCM was adopted for its flexibility when dealing with complex systems. It generates N_{sim} time series, sampling from the Poisson distribution (homogeneous or non-homogeneous process). Each time series represents one risk scenario and the analysis of N scenarios allows for the probabilistic assessment of losses and for the recognition of more or less probable risk paths. These risk paths emerge naturally from the system implemented in the MCM.

Hazard interactions represent a non-stationary process, which requires a sequential processing strategy. The proposed sequential MCM is defined as follows:

- <u>Multi-hazard assessment</u>: define the simulation set with simulation identifier, event identifier and event occurrence time t.
    1. Generate N_{sim} random time series: Sample N_{sim} sets of events over the time interval Δt = [t_0; t_{max}] drawn from the Poisson distribution with each stochastic event i characterized by the long-term rate parameters λ_i. Affix an occurrence time t to each event following the random uniform distribution. Record the time series in the simulation set S_0, which

represents the null hypothesis H_0 of having no interaction in the system. Fix j =1.

2. For each of the N_{sim} simulations, record the characteristics of the jth event, which occurs at t_j, in simulation set S_1. Resample events k occurring in the interval $(t_j; t_{max}]$ if the conditional probability $\Pr(k \mid j)$ exists (concept of hazard correlation matrix). Affix $t_k = t_j + \varepsilon$ with $\varepsilon \ll \Delta t$. Fix $j = j+1$.
3. Repeat step 2 while $t_j \leq t_{max}$.
4. Fix j =1.

- Multi-risk assessment: update the simulation sets S_0 and S_1 with event loss Λ.

5. For each of the N_{sim} simulations, calculate the mean damage ratio δ_j due to the jth event, which is conditional on the occurrence of previous events.
6. For each of the N_{sim} simulations, calculate the loss Λ_j due to the jth event, which is conditional on the occurrence of previous events. Record Λ_j.
7. Repeat steps 5 and 6 while $t_j \leq t_{max}$.

Mignan et al. (submitted) used $N_{sim} = 10^5$, $\Delta t = [t_0 = 0; t_{max} = 1]$ and $\varepsilon = 0.01$. They defined a hazard correlation matrix, considering possible interactions between ad-hoc perils A, B, C, D and E. Noteworthy, these ad-hoc perils and associated interactions are more abstract than the concept of virtual city. They are also more difficult to comprehend but provide an elegant mathematical framework. Figure A1 shows an example of risk migration matrix generated by the MCM. In the present case, occurrence of peril A leads to the occurrence of peril C with a probability Pr(C|A). C can then trigger D and D can then trigger E. A and C may represent earthquake/tsunami interactions for instance while D and E may represent domino effects in critical infrastructures (i.e. NaTech events). Figure A1 shows that the risk migrates to low probability-high consequences events when interactions are considered (i.e., moving from yellow to orange/red). More details can be found in Mignan et al. (submitted).

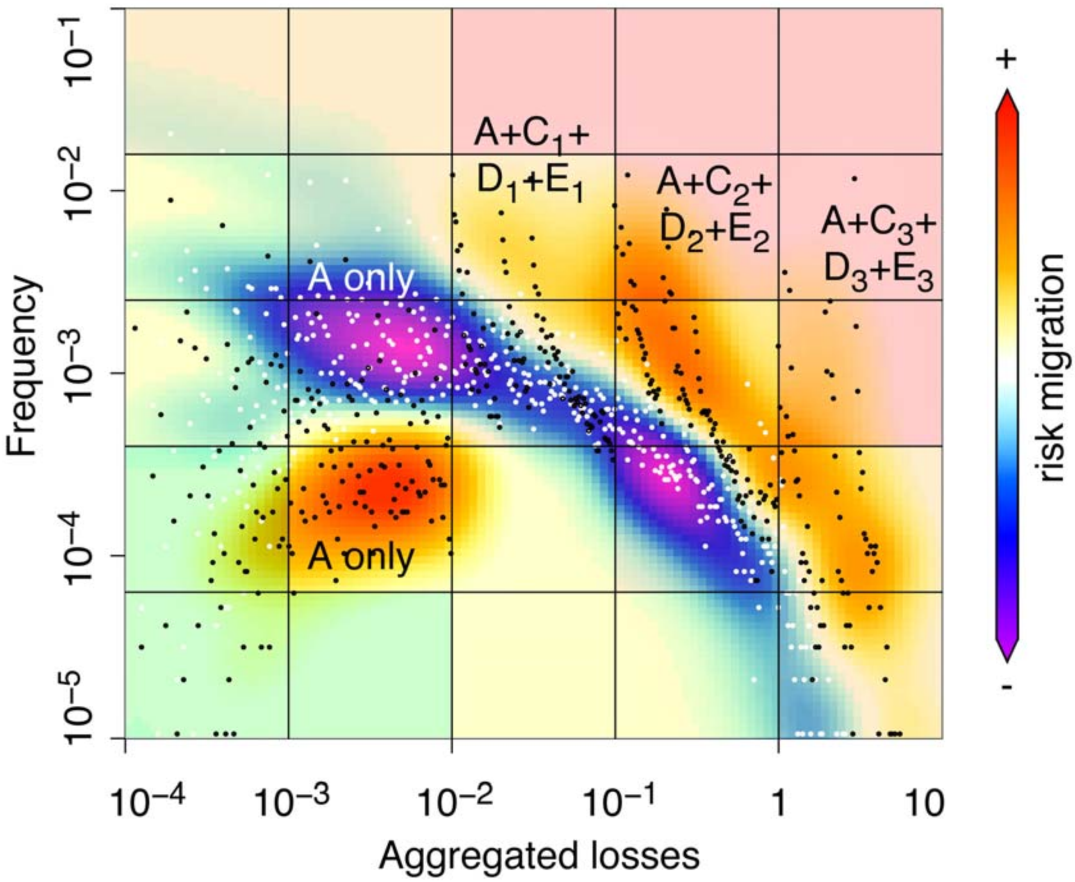
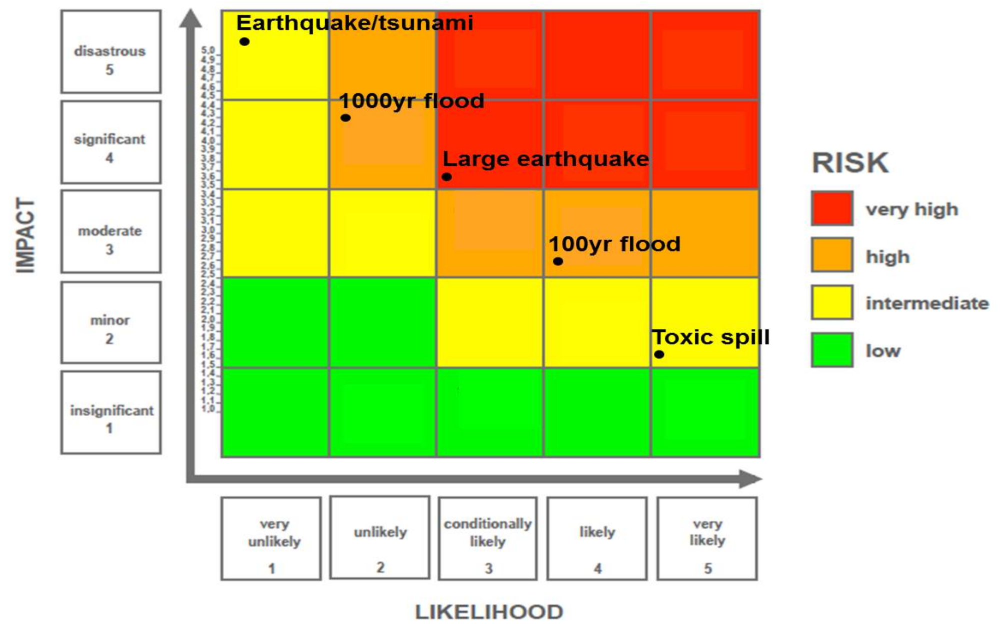


Figure A1: Example of risk migration matrix generated by the generic multi-risk framework. Black and white dots represent risk scenarios where hazard interactions are or are not included, respectively. Risk increase is represented in red and risk decrease in blue. Source: Mignan et al. (submitted).

A2. Decision Support Tool

Impact values for each hazard scenario can be inputted into the decision support tool as both numerical values (either single value or probabilistic distribution) or nominal categories where the numbers are simply labels that can be expressed in categories such as: "catastrophic", "large", "moderate", "small" and "irrelevant". For impacts such as casualties and capital stock losses, where the required vulnerability functions are typically available, impacts are computed using loss estimation models (e.g. CAPRA, HAZUS, etc.).

In other cases, for example intangible impacts such as political implications, where impacts cannot be computed in a numeric form, an expert-driven participatory modeling approach is used to assign nominal rankings for these types of impacts along each of the considered hazard scenarios. The spatial extent and temporal dimensions (i.e. immediate vs. short, mid- and long-term) of impact have to be clearly defined in the expert solicitation process. As the participatory modeling process is likely to produce a spread in the results, the decision-support tool provides the ability to assign a probability distribution around the impact classification (for example loss in an intangible category such as "political implications" may be judged by experts to be 0.25 catastrophic, 0.50 large, 0.20 moderate, 0.05 small and 0 irrelevant) (figure A2).



Hazard Type	Probability of Occurrence	Frequency	Impact				
			People	Economy	Environment	Infrastructure	Intagibles
Earthquake	1 in 475 years	conditionally-likely	significant	moderate	insignificant	significant	significant
Earthquake / Tsunami	1 in 10,000 years	Very Unlikely	disastrous	disastrous	moderate	disastrous	significant
Extremely rare Flood	1 in 1000 years	Unlikely	significant	significant	disastrous	significant	significant
Regulatory Flood	1 in 100 years	Likely	minor	Insignificant	moderate	moderate	moderate
Toxic Spill	1 in 20 years	Very likely	insignificant	Insignificant	significant	insignificant	insignificant

Figure A2: Methodology of the decision-support tool, where scenarios are ranked in the risk matrix (right). Source: BBK, 2010

According to this approach, the sectoral losses are combined together as a weighted sum into one single aggregated *loss score* for each scenario (figure A3). Together, these two steps (i.e., severity and loss scores) are combined to produce a *composite impact score* or each scenario.

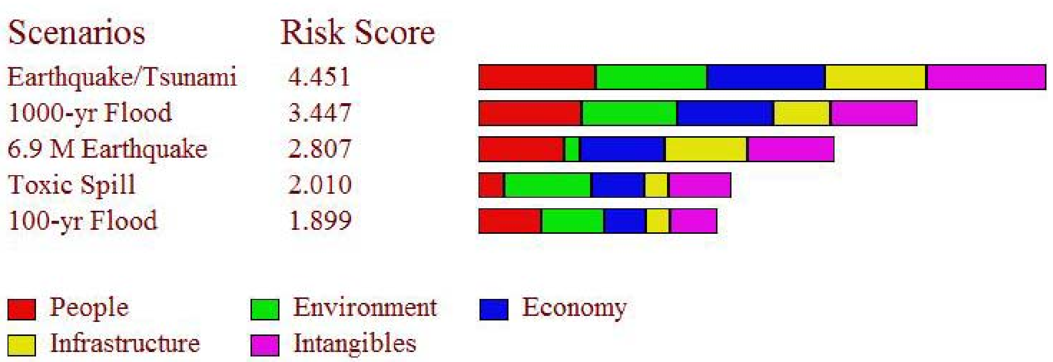


Figure A3a: Total risk/impact score and ranking shown for each of the scenarios

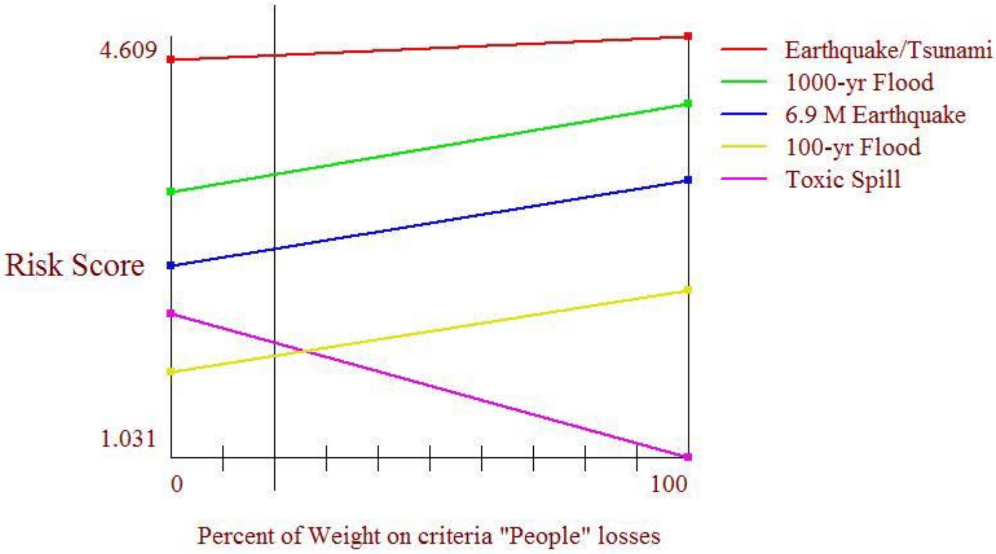


Figure A3b: Graph showing sensitivity of the total risk score to changes in weights of the "People" losses criteria

For example, in figure 4a, 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.

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 4b it can be seen that as more weight is given to the casualties, short- and long-term mass care represented by the “People” criteria, 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.