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Leading partner:

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AMRA (Analisi e Monitoraggio del Rischio Ambientale - Scarl)

KIT (Karlsruhe Institute of Technology)

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Authors: Anna Scolobig, Nadejda Komendantova, Paolo Gasparini, Angela Di Ruocco, Alexander Garcia-Aristizabal, Charlotte Vinchon, Mendy Bengoubou-Valerius, Daniel Monfort-Climent, Friedmann Wenzel, Anthony Patt

Reviewers: Gordon Woo (Aspinall Consulting Ltd), Roger Mrzyglocki (German Committee for Disaster Reduction), Kevin Fleming (Helmholtz-Zentrum Potsdam Deutsches GeoForschungs Zentrum)

Authorised:

Kevin Fleming (GFZ) 01.2014

Signature Date

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Summary

This final deliverable of the **MATRIX** Workpackage 6 “Decision support for mitigation and adaptation in a multi-hazard environment” is based upon conceptual and empirical work of four research institutes from Austria (International Institute for Applied Systems Analysis), Italy (Analisi e Monitoraggio del Rischio Ambientale – Scarl), France (Bureau de Recherches Geologiques et Minieres) and Germany (Karlsruhe Institut für Technologie) between 2010 and 2013. During this time, our interdisciplinary team investigated the benefits and barriers to the implementation of multi-hazard/risk assessment into current risk governance systems with the aim of providing recommendations for decision support.

By taking into account several historical case studies of multi-hazard disasters (e.g., the Messina earthquake of 1908; the Tohoku earthquake, tsunami and nuclear accident in 2011) and real test sites in Italy (Naples) and the French West Indies (Guadeloupe), we examined the process through which practitioners and policy makers can take advantage of new knowledge about multi-hazard and multi-risk and effectively implement this knowledge into existing institutional and governance structures. The following hazards are considered within the test sites: earthquakes, volcanic eruptions, landslides, floods, tsunamis, fires, cyclones and marine inundations.

The research design included documentary analysis and extensive empirical work involving policy makers, private sector actors and practitioners in risk and emergency management. This work was informed by 36 semi-structured interviews, three workshops with over seventy participants from eleven different countries, feedback with questionnaires and focus group discussions.

Out results reveal that in the present single-risk centred governance systems (which evolved in parallel with the single-risk centred risk assessment systems), practitioners rarely have the opportunity to discuss multi-risk issues, including triggered events, cascade effects and rapid increase of vulnerability during successive hazards. Therefore, a first step to bridge the gap between research and practice would be to create these fora for discussion at the local level, including researchers, practitioners and local advisors. These “local multi-risk commissions" can have several tasks, such as to provide suggestions for the integration of multi-risk assessment in land use planning, to identify priorities for future research and for the development of local capacities, to discuss what kind of new partnerships can be built between the public and private sector, etc. Among the other catalysts for an effective implementation of multi-risk assessment, there is the development of multi-risk platforms for data and knowledge exchange between researchers and practitioners and the engagement in a permanent dialogue between different risk communities (both in research and practice, with a focus on the divide between geological and meteorological hazards).

Risk and emergency managers clearly observe the benefits of integrating a multi-risk approach into their everyday activities, especially in the urban planning sector, but also into emergency management and risk mitigation. Decisions on building constraints for urban planning have to take into account the results of multi-risk assessment. Also, new options for protection - e.g., insurance schemes, new forms of public-private responsibility sharing - have to be suitable for households exposed to multi-risks.

Finally, since we worked in close cooperation with practitioners from different authorities, we could also compare their views. The lessons learnt through these interactions led us to address our recommendations not only to policy makers and practitioners, but also to researchers. Efforts on both sides are needed in order to overcome the barriers to a successful implementation of multi-risk assessment.

Acknowledgments

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CONTENTS

1. Introduction

In risk assessment research and policy, there is currently much debate on multi-type hazard and risk assessment and scenarios (e.g., UNISDR 2005, 2013; SEC (2010) 1626 Final; COM (2010) 673 Final; Council of European Union 2009). This debate has been evoked, not least, by several disasters in recent years, resulting in a number of fatalities and considerable property damage. An example is the Tohoku earthquake, tsunami and nuclear accident, which happened in Japan in 2011. An earthquake caused a tsunami, leading to both a shutdown of the plant (from the earthquake) and devastating flooding. Some other historical cases can be mentioned, such as the Messina earthquake and tsunami of 1908, the Kobe earthquake and cyclone of 1995, the Haiti earthquake and tropical cyclone of 2010, etc. (Komendantova et al., 2013). These historical cases clearly show how disasters caused by natural hazards can trigger a chain of multiple natural and man-made hazards events at different spatial and temporal scales, which are often poorly observed and reported.

Multi-hazard and multi-risk approaches allow for consideration of interactions between different risks, by using harmonized procedures based on common metrics. Classes of interactions include triggered events, cascade effects and rapid increase of vulnerability during successive hazards (MATRIX Description of the Work, 2009). As a result, multi-risk assessment may establish a hierarchy of risks, with the help of quantifying and comparing different types of hazardous related events. It can also identify areas where efforts to mitigate against one hazard may come into conflict or create synergies with the planned adaptation and mitigation activities for a second type and suggests how the severity of hazards, and the resources required for their mitigation, may be higher than anticipated (Marzocchi et al., 2009; Marzocchi et al., 2012).

Finding better ways to assess and respond to these “multi-risk/worst case scenarios” is a concern, if not a priority, for both scientists and policy makers. This is already reflected in a number of documents at international and national levels. For example, the Hyogo Framework for Action on disaster risk reduction (UNISDR, 2005) states that research methods and tools for multi-risk assessments should be developed and strengthened (priority 3, indicator 3.3). Several European communications, guidelines and the results of research projects (e.g., Armonia; Na.R.As; Enhance) emphasise the importance of covering all natural and man-made disasters and their interdependencies by developing these methodologies. The recently adopted Commission Communication on the Internal Security strategy (e.g., SEC (2010) 1626 Final) advocates an “all-hazard approach to threat and risk assessment” and states that the Commission will develop EU risk assessment and mapping guidelines for disaster management based on a multi-hazard and risk approach. Similar statements can be found in the Community framework on disaster prevention within the EU (point 22: “The Council of EU underlines the usefulness of a multi-hazard approach to a Community disaster prevention framework”) and in the European disaster risk reduction strategy (COM(2008)130) that acknowledges the need of a comprehensive approach to disaster management. Moreover, a new coherent risk management policy is expected to be established at the European level by 2014 (COM (2010) 673 Final), linking risk and multi-risk assessment to decision making.

At present, this still seems to be a weak link. As the results of our research reveal, multi-risk assessments and scenarios are rarely performed by practitioners at the national or local levels. In the current single-risk centred governance systems, practitioners rarely have the opportunity to discuss multi-risk scenarios. Especially in the hazard-risk assessment sector, there are very few institutionally established arenas where professionals working in different natural hazards sectors can meet and discuss how to reduce the risk derived from the interactions among hazards. As a consequence, these interactions are not considered in many relevant decision-making processes surrounding, for example, building constraints in risky areas, urban planning, risk mitigation measures, etc..

The research results presented in this deliverable are derived from interviews, focus groups and workshops involving policy makers, private sector actors and researchers. The research focused on the links between the new methods for multi-hazard and risk assessment developed in other Workpackages of the MATRIX project and existing governance/decision-making structures. The following chapters provide a synthesis of the identified benefits and barriers to multi-hazard mitigation and adaptation, with recommendations for decision-support. The aim was also to provide recommendations on how to facilitate the transfer of knowledge about multi-hazard and risk assessment from scientists to practitioners, in order to provide better decision making outcomes.

2. Background

In the period between 2010 and 2013, the authors of this deliverable investigated how to effectively implement multi-risk assessment in existing governance systems. The research was performed for the EC-funded MATRIX project[1], workpackage WP 6 “Decision support for mitigation and adaptation in a multi-hazard environment”. The focus of the research was on appropriate decision-analytic methods for mitigation and adaptation to multiple hazards, lessons learnt from historical cases, individual perceptual, cognitive and institutional barriers to effective decision making in the case of multiple hazards, and benefits of multi-risk assessment (especially in comparison with single risk assessment).

The research conducted in WP6 was organised around four main tasks:

1. *Task 6.1 Decision analytic frameworks* provided an overview of decision support systems and models in multi-risk assessment, with a focus on how risk assessment is planned to be implemented in the European Union. The aim was to identify the needs for decision support models and suggest practical approaches that can be tested in one or several test areas of MATRIX and have potential use (to be explored in MATRIX WP8) for the European risk mapping process (task 6.1. report: Wenzel, 2012).
2. *Task 6.2 Individual perceptual and cognitive barriers* focused on how the presence of behavioural and cognitive biases influences perceptions of probabilities and outcomes of multi-risks and influences choices regarding risk mitigation strategies. The research included case study analysis of five historical multi-hazard events. The theoretical background is grounded in behavioural economics, classical utility theory, environmental psychology, information theory and Bayesian decision theory (task 6.2. report: Komendantova et al. 2012).
3. *Task 6.3 Identification of barriers to effective decision making* provided a description of the institutional, political and legal framework for natural risk governance in two case studies, Naples and Guadeloupe. It also identified the social and institutional barriers to the implementation of a multi-risk approach on the basis of extensive interactions with stakeholders (task 6.3 report: Scolobig et al., 2013).
4. *Task 6.4 (on which this deliverable reports) Synthesis: Benefits and barriers to multi-hazard mitigation and adaptation, with policy recommendations for decision-support.* The main aim was to compare the benefits of operating at a multi-hazard level with the individual, social, and institutional barriers to doing so, by presenting the decision support tools developed in other WP6 tasks and in other WPs of the MATRIX project to practitioners. This comparison and the synthesis of the key results of previous WP6 tasks represent the basis from which we identify recommendations for eventually overcoming these barriers.

[1] The project MATRIX tackled multiple natural hazards and risks in a common theoretical framework. It integrated new methods for multi type assessment, accounting for risk comparability, cascading hazards and time-dependent vulnerability. The project, during its three years length, identified the conditions under which the synoptic view provides significantly different and better results – or potentially worst results – than established methods for single-type hazard and risk analysis.

3. Methodology

The research included a wide array of methods and tools aimed at fostering a continuous dialogue and a two-way interaction between researchers (involved in the MATRIX project) and practitioners/decision makers. Ten researchers with different disciplinary backgrounds (spanning from the social sciences to geology and hydrology) and more than seventy practitioners from eleven different countries (Italy, France, Norway, Germany, Hungary, Bulgaria, Sweden, United Kingdom, Iceland, Croatia and Austria) have been involved in the research process (for a list of the participants, see Scolobig et al., 2013, Mrzyglocki, 2013).
Table 1 summarises the main steps of the research conducted in the four tasks of workpackage 6.

Tab. 1 - WP 6 methodology

	Research phase	**Method**
Task 6.1.	Analysis of decision-analytic frameworks for multi-hazard mitigation and adaptation	Study of the implementation of risk assessment in the European Union in order to identify the needs for decision support models, suggest practical approaches and have potential use (explored in MATRIX WP8) for the European risk mapping process. Aims: - to understand the role of decision support systems and decision models in the European Risk Assessment Process; - to develop a decision support tool that provides loss index indicators that allow for the filling of risk matrices.
Task 6.2	Case study analysis	Desk study of legal, regulatory and policy documents on five historical multi-hazard disasters. Aims: - to identify evidence of behavioural and cognitive biases in decision-making associated with prior historical multi-hazard events; - to identify how the presence of behavioural and cognitive biases influenced multi-hazard risk mitigation strategies; - to provide recommendations on how these biases can be corrected.
	Bayesian statistics and mathematics	Desk study of Bayesian decision making theories and methods, development of inputs to existing theoretical frames. Aims: - to identify decision weights and probabilities in judgements about utility values and possible outcomes of decisions on multi-risk mitigation in terms of monetary gains and losses; - to assign mean and standard deviation values of the utilities probability distributions to act as a numerical handle in estimating probability distributions in the decision-making process; - to assign relevancies to sources of information and then operate on these relevancies by way of the information theoretic product and sum rules; to identify how the likelihood of danger is perceived by stakeholders according to the source of information.

<table>
<tr><td rowspan="3">Task 6.3.</td><td>Documentary analysis</td><td>Desk study of legal, regulatory and policy documents (focus on two test sites: Naples and Guadeloupe).

Aims:
- to provide a description of the institutional and regulatory framework for risk governance in different natural hazard contexts;
- to identify comparable sets of governance characteristics (stakeholders and governance level; decision support tools and mitigation measures; stakeholder cooperation and communication).</td></tr>
<tr><td>Semi-structured and in-depth interviews</td><td>32 stakeholders* (focus on two test sites: Naples and Guadeloupe).

Aims:
- to identify the social and institutional barriers to effective decision-making in the case of multiple hazards;
- to propose initial options for overcoming them.</td></tr>
<tr><td>Focus group</td><td>12 participants (researchers involved in the MATRIX project and experts on natural hazard management).

Aim:
- to provide feedback on previous results.</td></tr>
<tr><td rowspan="2">Task 6.4</td><td>Workshops</td><td>3 workshops.
- 20 participants* (Naples)
- 32 participants* (Guadeloupe)
- 21 participants* (Bonn; organized in cooperation with WP8 of the MATRIX project).

Aims:
- to present the new multi-hazard and risk assessment methods developed in other tasks of the MATRIX project and receive feedback on the developed IT framework (WP 3, 4 and 7);
- to collect feedback on the most frequent cognitive/behavioural biases and how they influence decision-making processes (based on 6.2 results) on multi-risk mitigation strategies;
- to discuss the barriers and benefits to the implementation of multi-risk assessment already identified in task 6.3.</td></tr>
<tr><td>Feedback interviews and questionnaires</td><td>Feedback by in-depth interviews with the participants in the workshops.
Post-workshop questionnaire submitted to the participants of the workshop in Bonn.

Aims:
- collect feedback on the workshop results;
- provide suggestions for the recommendations.</td></tr>
</table>

*includes risk and emergency managers, officers/directors of civil protection and fire brigades corps at different levels (from national to local) and for different risk sectors; officers responsible for hazard/risk assessment, urban planning and emergency management, etc.

Fig. 1 – Task 6.4 workshop in Naples

4. Historical case studies and test sites

As outlined in the methodology, the synthesis of results presented in this document is based on evidence collected not only in different tasks, but also within different multi-risk environments.

For example, in task 6.2, five historical multi-hazard disasters have been considered: the Messina earthquake of 1908, the Kobe earthquake of 1995, the 2004 Sumatra-Andaman earthquake , the 2010 Haiti earthquake, and the Tohoku earthquake of 2011. The research approach of task 6.2 consisted of identifying the relevant heuristics and biases, as proposed by behavioural economics and environmental psychology, and applying them to the analysis of the historical cases of multi-hazard events (mentioned above), based on the review of legal, regulatory and policy documents. This approach was complemented by the Bayesian decision theoretic framework and an extended information theoretic framework, also called inquiry calculus (Erp and Gelder, 2011). As an example, box 1 reports on the major identified cognitive and behavioural biases, which affect decision-making in terms of perceptions of probabilities of multiple risks and making choices for risk mitigation strategies, with a focus on the 2011 Tohoku earthquake, tsunami and nuclear accident.

Box 1- Historical case studies

The historical case studies show evidence of several behavioural and cognitive biases in decision-making by individuals and how these biases resulted in the failure to take into account interactions between different hazards and influenced the decision-making process in terms of the mitigation of multiple risks. These biases are availability heuristics, dread risk, experimental versus statistical evidence, bounded rationality, limited worry and loss aversion. We present here examples of evidence of three biases and their influence on decision-making processes. The availability heuristics was caused in the cases of the 1995 Kobe earthquake and the 2004 Sumatra earthquake by the absence of recent large earthquakes in this region. The limited worry resulted in the orientation of risk mitigation measures towards typhoons as opposed to earthquakes in the case of the Kobe earthquake, in misperceptions of the early warning signals from stations in the Pacific Ocean in the case of the Sumatra earthquake, and in misperceptions of the probability of a nuclear accident and of the potential severity of tsunamis in the case of the Tohoku earthquake. Loss aversion influence the behaviour of inhabitants of the Kobe region with regards to the necessary investment into house refurbishment, perceptions of the necessary additional investment into risk mitigation measures, like Multi-Purpose Cyclone Shelters (as used in India), and the perceptions of the additional investment required for the application of tools designed for estimating the diffusion of radioactive materials (that is, this being seen as a greater loss in the present than a possible gain from the mitigation of these risks in the future).

More precisely, in the 2011 Tohoku earthquake, tsunami and accompanying nuclear accident, the risk analysts failed to adequately take into account the fact that an earthquake could cause a tsunami, leading to both a shutdown of the plant (from the earthquake) and a devastating flood. The problem was the poor estimation of the potential size of an earthquake, and the underestimation of the size of a possible tsunami due to existing oceanographic modelling at the time of the nuclear power plant's construction. Also, the plant designers chose to locate the plant on the coast, rather than inland, in order to be able to build on the more stable bedrock that the coast offered, thus taking precautionary steps for an earthquake, but not towards tsunamis. Another advantage of a coastal site is the partial dispersion of any radioactive aerosol over the ocean. Given the coastal setting, designers did take tsunamis risk into account, but again underestimated the size of a potential event. Hence, the decision to locate the nuclear power plant on the coast was influenced by overconfidence in the degree to which the constructed seawall would cope with tsunami risk (for more information on historical case studies: task 6.2 Report Komendantova et al., 2013).

In task 6.3, the test sites considered in the research activities were Naples, Italy and Guadeloupe, French West Indies (Figure 2). In these two test sites, extensive research on multi-risk assessment has been conducted in other tasks and workpackages of the MATRIX project (Monfort et al., 2013; Desramaut, 2013; Garcia-Aristizabal et al., 2013a,b). The sites are both exposed to multiple hazards, including earthquakes, volcanic eruptions, landslides, floods, tsunamis, fires, cyclones, and marine inundations. Box 2 summarises some relevant information about the test sites (see also Scolobig et al., 2013).

Box 2- Test sites

Naples (population 962,000, ISTAT Census, 2011) is the biggest municipality in southern Italy and the capital of Campania, one of Italy's 20 regions. The city has a widely recognized high volcanic hazard and is also exposed to earthquakes, floods, landslides, and fires. Most of these risks are interconnected. Earthquakes from both the tectonic seismic source (Apennine chain) and volcanic sources (Campi Flegrei and Somma Vesuvio) can be felt in Naples. Flood events are also very frequent because of the Mediterranean climate and the geomorphology of the city, which lies mainly on narrow coastal plains bordered by pyroclastic hills, and whose slopes speed up the flow of sediment-laden waters toward the sea (Alberico et al., 2011). In the last few years, severe forest fires have been reported in the city, mainly during the summer period: for example more than 40 human-made fires affecting the green areas of the city were registered in 2011 (Department of Agricultural, Campania Region, 2012). Forest fires can be caused by another threat to the city: the Somma-Vesuvius and Campi Flegrei volcanic sources. The volcanic risk is high because of the combination of the high population density and the large number of buildings exposed to this explosive and eruptive hazard, which, should pyroclastic clouds occur, would have immense destructive power.

In MATRIX, two scenarios of risk interactions were considered for quantitative analysis in Naples. First, the effect (on seismic hazard and risk) of seismic swarms triggered by volcanic activity has been assessed. Second, the cumulative effect of volcanic ash and seismic loads has been analysed. Both cases (that together can be combined in a single scenario of interactions at the hazard and the vulnerability level) highlighted different aspects of risk amplification detected by the multi-risk analysis (Monfort et al. 2013; Desramaut 2013).

In spite of the geographical distance between our two case studies, the French overseas department of **Guadeloupe** (*Département-Région d'Outre Mer*) is exposed to similar types of hazards, although with different characteristics. In contrast to Naples, it is also prone to tropical cyclones and less exposed to fires since the archipelago has a tropical climate. Guadeloupe is located in the Lesser Antilles and includes five main Islands (Grande-Terre, Basse-Terre, Marie-Galante, la Désirade, and Les Saintes) covering an area of 1628 km^2. The archipelago has 32 municipalities. The major geological risk on Guadeloupe is the active volcano of la Soufrière and seismic activity along the inner Caribbean arc. Tsunamis and landslides can be brought on by those hazards.

The main meteorological hazard to Guadeloupe is the high cyclonic (hurricane) and tropical storm exposure of the archipelago; it can be directly impacted upon by very high winds (up to 200 km/h) and/or rainfall with secondary effects of sea water surges, waves, and marine floods that can erode the coastal zone, and also heavy rainfall that can lead to inland floods and landslides.
In MATRIX, a demonstrator of cascade effects and systemic risk has been conducted. This work has considered, with a deterministic approach, the interaction between earthquake and landslide phenomena and its consequences to road network in Guadeloupe and transport of injured people to

hospitals and clinics (Garcia-Aristizabal et al., 2013a,b,e).

Fig. 2- Maps of the two test sites of Naples and Guadeloupe.

Both Naples and Guadeloupe have embarked upon several short- and long-term plans and projects to make their citizens safer from the multiple risks described above and have consulted local experts in science, engineering and policy making. Besides the historical case studies and the test sites, the research benefited from the testimonies of many other highly capable and dedicated risk professionals and managers in the local public and private sectors, who participated in the workshops, reporting on experience of eleven different countries (see also workpackage 8 of the MATRIX project, Mrzyglocki, 2013).

5. Benefits

In this chapter we present and discuss the benefits of multi-risk assessment, focusing on the ideas, opinions and perspectives of the stakeholders involved in WP6. So far, multi-risk assessment has not been implemented in a systematic way in current risk governance systems. For this reason, the multi-hazard and risk assessments developed in other workpackages of the MATRIX project have been presented and discussed during the workshops and focus groups in the test sites and elsewhere (see chapter 3). The main benefits identified by practitioners[2] were divided into four main categories: i) planning; ii) warning systems; iii) risk mitigation and iv) communication.

5.1 Planning

5.1.1 *Territorial perspective and holistic view*

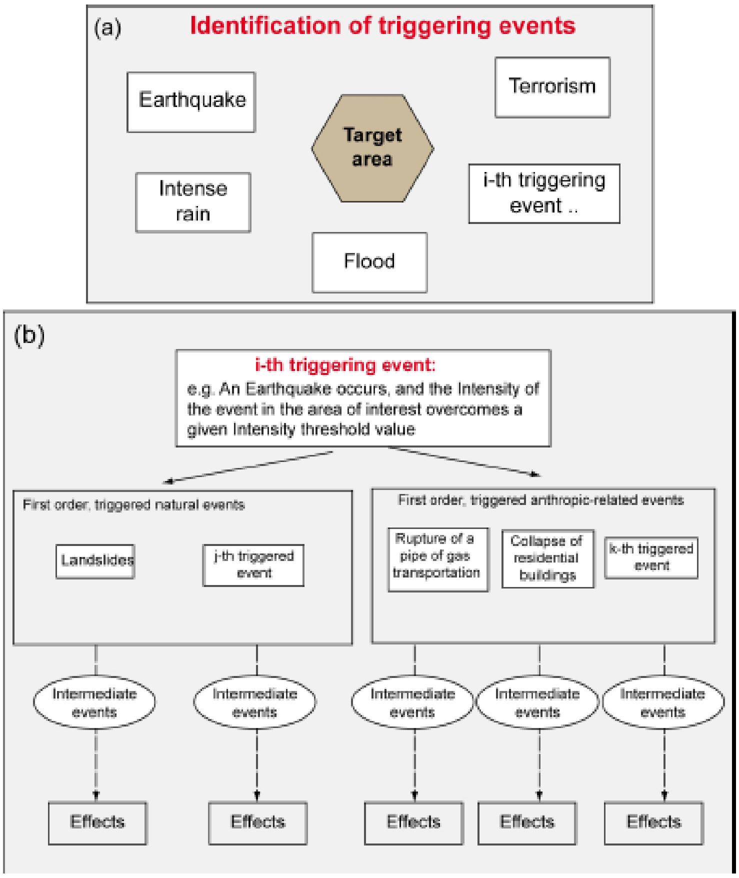
A multi-risk approach is considered to be particularly useful to gain a holistic view of the risks to a territory. This approach should be taken into account in all geographic areas susceptible to several types of hazards. The practitioners working in the municipal technical offices are particularly worried by the fact that focusing solely on the impact of one hazard could result in raising the vulnerability for another hazard.

Figure 3 explains the logic of a multi-risk approach: once the target area has been identified, all possible triggering events can be recognized and, based on a *forward logic*, for each triggering event, the triggered natural and anthropic related events can be defined and their effects can be assessed. This information is crucial for planning at local and regional level.

Many practitioners involved in the research consider the holistic view of the risks on the territory as a key benefit. However, as emerged from the results of the questionnaires, practitioners need clear criteria to decide which scenarios would be the "best candidates" for a multi-risk assessment. For example, a practitioner from Germany reported to be worried about the evaluation of likelihood derived from the combination of two events ("Minimal damage from a flood plus minimal damage from an earthquake will probably not make a building collapse. This can be anyway an interesting scenario for research, but it will be completely irrelevant for civil protection purposes").

[2] To preserve the confidentiality of the information provided by practitioners, we will not report their identity. Interviews and workshop transcript are available. For more information, contact the authors.

Fig. 3 - Logic of a multi-risk approach (Garcia-Aristizabal et al. 2013)



5.1.2 *Comparison and ranking of different risks*

The quantified comparison of risks that would allow a multi-risk approach is definitely a benefit. For example, practitioners from the Naples test site considered it as being particularly useful for the identification of action priorities. Up to now, the decision-makers based their decisions on priorities on the risks that could be most reduced and not necessarily on the highest risks in terms of probability or potential impact, while also taking into consideration cascade and conjoint effects. Some cascade effects are already considered and monitored within a multi-risk approach such as the period after a wild fire being more susceptible to landslides. For example, there is a webcam system in place on the most unstable areas of the Vesuvius slopes. Also in Guadeloupe, some cascade effects such as the side effect of liquefaction, triggered by earthquakes, are taken into account in the microzoning of municipal territories. Moreover, some risks are tightly linked, such as frequent inland inundation and ground movements, and several interviewees think that a common assessment of those risks would improve their management capacity. In general, practitioners lament that cascade and conjoint events need to be taken into account in a more systematic way, in order to benefit from the added value of a multi-risk approach to identify priorities for actions in risk mitigation.

5.1.3 *Urban planning*

Practitioners working in the planning sector are very interested in the implementation of multi-risk assessment. They believe that it is crucial to include the results of such assessments in urban plans.

As a result of the present "single-risk centred" assessment system, building constraints for different natural hazards are defined on the basis of different logics, methodologies, and ultimately different risk levels. For example, in Italy, in the (highest) hydrogeological risk areas (so called risk 4 areas), building private building or productive activities is not permitted, whereas in the highest areas of volcanic risk[3] (red zone) the constraints apply to private buildings, but not to productive activities. As it is well known, building constraints influence urban and economic development, for example, by allowing - or not - the building of new houses and/or economic activities. The adoption of a multi-risk approach can influence the entire decision making process, thus impacting upon delicate public and private economic interests.

Therefore, the implementation of a multi-risk approach will require the identification of the highest (multi-)risk areas, a revision of building constraints based on the results of the multi-risk assessment and an update of urban planning tools.

5.2 Emergency management

Emergency management would highly benefit from the adoption of a multi-hazard/risk approach. Emergency managers are interested in the development of multi-hazard and risk scenarios in order to manage emergency situations in real time (see also Monfort and Lecacheux, 2013). For example, in the Guadeloupe case, evidence suggests that without the consideration of cascade effects (earthquake-landslide interaction) and a systemic approach, risk assessment can be heavily underestimated (by 2-3 times). More precisely, the work undertaken in Guadeloupe considered the interaction between earthquake and landslide phenomena and its consequences for road networks and the transport of injured people to hospitals and clinics. A landslide triggered by an earthquake on the North-West of Basse-Terre can cut one of the main roads of Guadeloupe, the road between the East and the West of the Basse-Terre Island. This road is important for the evacuation of injured people from the most damaged zone to hospitals and clinics all over the archipelago. Damages of some lifelines (water, electricity) were also taken into account. The final result is the calculated time to evacuate injured population, considering or not the damages in the road network and the connectivity to lifelines of the hospitals (Monfort et al. 2013; Desramaut 2013).

Nevertheless practitioners report that there are already some positive experiences of real-time emergency management that take into account interactions among risks. For example, as

[3] The Vesuvius Emergency Plan defines 3 zones that could be prone to different kinds of volcanic hazards: the red zone (prone to pyroclastic flows), the yellow zone (prone to ash-fall), and the blue zone (prone to debris flow). The red zone is not properly defined as the area prone to the highest volcanic risk, but it is undoubtedly the zone where the effects expected by the reference eruption could be the most serious.

reported by an English practitioner, Hazard Manager is a one-stop information source for the emergency response community. It is an interactive web portal using maps, which can be overlaid with weather and incident-related information. It allows users to access their services in one location, using a single username and password. "Events" are posted when there is an active incident, essential for keeping emergency responders up-to-date with the very latest information and developments as they happen.

5.3 Risk mitigation

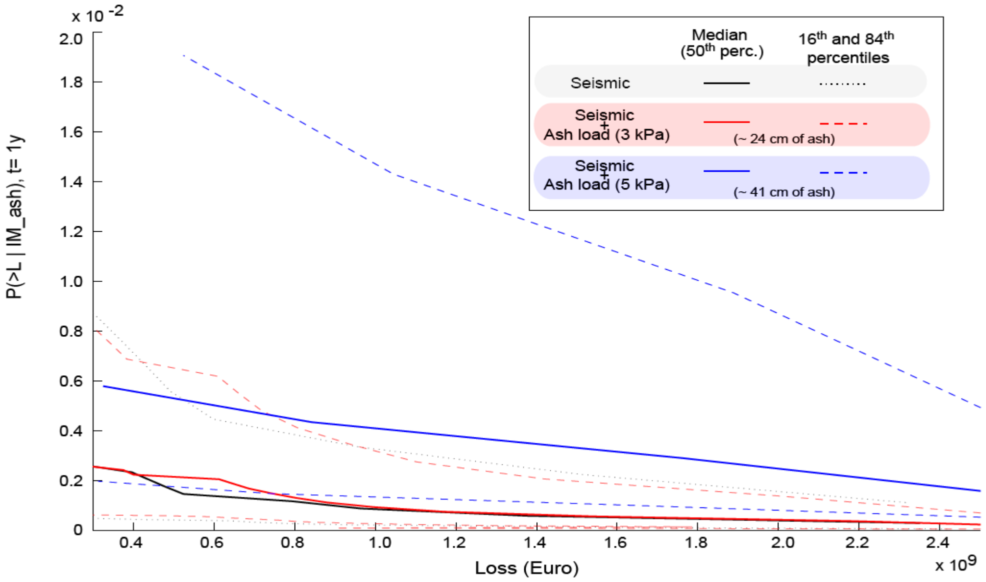
5.3.1 *Evidence on increased expected losses*

Practitioners considered particularly useful the evidence on increased expected losses (of multi vs. single-risk assessment) presented by the MATRIX researchers during the workshops.

For example, in Naples, two scenarios of risk interactions were considered for quantitative analysis within the framework of the MATRIX project (see report of task 3.4. Garcia-Aristizabal et al., 2013). For the first, the effect (on seismic hazard) of seismic swarms triggered by volcanic activity has been assessed, and secondly, the additive effect of volcanic ash and seismic loads has been analysed. In the first case, it has been observed that the seismic hazard can be underestimated in (relatively small) areas close to the epicentral location of the seismic events composing the volcanic seismic swarm; this effect quickly attenuates with distance as the source of the volcanic events is very shallow. Then, from the multi-risk point of view, this interaction scenario may have important consequences (in terms of risk amplifications) in areas immediately located over the volcanic seismic sequence. It is worth noting that considering this interaction scenario can be particularly important for short-term assessments.

On the other hand, the additive effects of volcanic ash (deposited over the roofs of the structures) and seismic loads also show interesting results. It bears a slight increase of the risk in the long term (~3 to 6%), but the differences in the short-term when considering different specific scenarios (e.g., given that a certain thickness of ash has been deposited) produce risk amplifications of higher magnitudes (see e.g., Garcia-Aristizabal and Marzocchi, 2013).
The results are shown in Figure 4, where the resulting risk curves considering different scenarios of ash load (solid lines are the best estimate values and the dashed lines represent the uncertainty range) are presented and compared with the risk curve calculated without the effect of the volcanic ash fall.

Fig. 4 – Evidence on increased expected losses (Garcia-Aristzabal et al., 2013).



5.3.2 *Cost reductions*

Addressing multiple hazards may lead to significant cost reductions and improvements in the efficiency of risk mitigation and management measures compared to cases when hazards are treated separately from each other. The example of Haiti RC roofs made to resist cyclonic winds, which contributed to increase seismic vulnerability of these buildings during the 2010 earthquake, has a strong explanatory power. The claim was that building construction practices made use of heavy roofing material in order to make buildings able to withstand heavy winds, a concern in a city subjected periodically to tropical cyclones. However, the heavy roofs in turn made the buildings more vulnerable to earthquake damage (see also task 6.2 report: Komendantova et al., 2013).

5.4 Communication

5.4.1 *Increased risk awareness*

Multi-risk assessment is a tool that can be used to increase a population's awareness of risks, of multi-risk and cascade effects. For example, in Guadeloupe, practitioners identify different degrees of awareness of the local population, depending on the risks. This can be explained by the intensity and recurrence of events and consequences on human assets. While the culture of primary risks such as cyclonic, earthquake and volcanic is well anchored in Guadeloupe, it is less developed for secondary risks such as tsunamis, landslides, marine and inland floods, and coastal and slope erosion. Practitioners from other countries identify the communication of the results of multi-risk assessment to the general population as one tool (in combination with others) to increase awareness.

5.4.2 *Partnerships*

A multi-risk approach, if implemented effectively, can help to develop partnerships between policy makers, private sector actors and scientists. At present there is a need to develop (new) partnerships between these stakeholders: a key to success is a common understanding of what multi-risk assessment is, what are the preferences and needs of practitioners, and what can be the implications for regulatory instruments (thus including, for example, innovation in urban planning; NRC, 2011; see also chapter 7). Interviewees and workshop participants identified some key sectors where partnerships should be developed in order to maximise the benefits of a multi-risk approach: joint implementation of (non) structural measures such as building codes; the use of improved risk information for the development of risk financing schemes that cover large losses after catastrophic events between insurers and policy makers; and new forms of responsibility sharing between property owners and public actors to develop risk financing schemes.

6. Barriers

In this chapter we present the main barriers to the effective implementation of a multi-risk approach by dividing them into three categories/domains: i) science, ii) practice and iii) interactions between different domains. This division proved particularly useful to synthesise the key messages emerging from the workshops and interviews.

6.1 Science domain

6.1.1 *Different developments in geological vs. meteorological hazards*

Because of different scientific development paths, the process of risk assessment for geological hazards has evolved differently from meteorological hazards. Notwithstanding the step forward represented by multi-risk assessment, comparisons and integration as well as dialogue among researchers (and also among practitioners) belonging to different risk communities remains difficult. The reasons are manifold: different methodologies and levels of uncertainty in hazard/risk assessment, different languages, definitions of concepts, logics and ways of representing risk and hazard etc.

One of the examples often reported by the practitioners concerns monitoring and warning systems. Monitoring, forecasting and hazard/risk assessment for hydro-geological risks is characterized by lower levels of uncertainty in comparison, for example, to earthquakes. Also, inherent to each phenomenon are different temporal/spatial scales, where the methodological approaches for hazard and risk assessment are very different. For example, seismic vulnerability assessment is based on maps and on the physical vulnerability of individual households, while the hydro-geological risk assessment is grounded on the spatialisation of hazard and risk maps (often at a scale of the order of 1:25,000) as well as event modelling and simulations. Some interviewees report on the unsuccessful integration between landslide and flood hazard/risk maps in the existing river basin plans.

The Guadeloupian study underlined a higher level of knowledge and investment in major hazards/risk (earthquakes, volcanism, cyclones) in comparison to secondary hazards such as floods and landslides, due to a culture of focusing on high intensity/low frequency events at the expense of low intensity/high frequency events.

The deep differences in the approaches, tools and methodologies used for single-risk management constitute a barrier to integration also because they resulted in different practices for risk governance (see section 6.2.1).

6.1.2 *Research gaps*

Further research on multi-risk approach is needed and a number of questions still have to be addressed. Researchers working on the technical/scientific aspects mention the following gaps: lack of data, knowledge of the physical processes and models related to the cascade effects; uncertainty assessment; difficulties combining single-risk analyses into integrated multi-risk analyses (available data may refer to different time windows, different typologies of impacts are used etc.); etc. Researchers working on the institutional/social aspects mention the need for increased knowledge about the stakeholders involved in the risk governance; to identify their needs and to identify new forms of partnerships between the public and private sector; extending the multi-risk aspects, which are at present restricted essentially to the assessment process, to the management process, etc.

Practitioners focus on completely different aspects, namely, what kind of research results they would like to consult, to take advantage of and, ultimately, to use in their work. It is important to emphasise that depending also on the stakeholders and practitioners (risk vs. emergency managers; regional officers; insurers; see also Box 3 for a description of the complex network of stakeholders involved in risk governance in the two test sites), needs and expectations vary extensively. For instance, they may be interested in evidence about lives and property saved by using a multi vs. single-risk approach when overviewing multi-risk contexts at the town level. For example, some practitioners working in the town planning units maintain that the more specific and detailed the information is (household level), the more useful it will be. Practitioners working in the emergency management sector maintain the need to develop multi-hazard and risk scenarios in order to manage emergency situations in real time. Moreover, they would like to have more information not only about the most risky areas, but also about the areas where the probability of an event occurrence is higher than the average.

Box 3 –Risk governance: the main stakeholders in Italy and France

In Italy and France, private and public stakeholders from the national to the municipal level interact to guarantee an effective governance system. Several ministries have responsibility for the development of legislation, guidelines, policies, and coordination of other agencies for natural risk management. In Italy, there is a mixed top-down, bottom-up organizational system (OECD, 2009) and the 20 Italian regions also have legislative powers for natural hazard management, as a result of a devolution and decentralization process that started in 1998 (Bassanini Law Decree, 1998; Constitutional Law, 3/2001). In France, risk management has a more centralized/top-down nature with a strong role of the state authorities (either central or local representatives i.e., Prefect and State representation of the ministries for Environment and Equipment). Regions and departments have no regulation competency for risk management.

In Italy, the department of civil protection is a national coordinating body and works together with the competence and functional centres (law decree 3593/2011). These centres are institutions that provide scientific and technical expertise about the nature of hazards and risks, the vulnerability of the population and assets, monitoring and real-time predictions and the development of mitigation measures. Another key actor is the civil protection service (established by law 225/1992, last updated law 100/2012), an umbrella institution that guarantees coordination of the disaster management activities. Its main operational organizations are the fire brigades, army, police forces, forestry service, the national health service, voluntary organizations, etc. Relevant members are also the mayors, the prefects, and the Presidents of the Regional Councils. The guiding principle for emergency management in Italy is subsidiarity. When municipal government capacities are insufficient for managing the scale of an event, they are supported by provinces and regions or the state, depending on the event. When a disaster happens, also municipal and/or provincial, regional and national operations centres (MOCs) are activated. Local emergency units work together to define the intervention strategy (Citta' della Scienza 2008; Regione Campania 2008).

In France, there is a similar emergency organization (law 2004-811 from 13-8-2004). The mayors are the main actors responsible for safety in their respective municipalities. The prefects (State representatives at the department level) are responsible for the local application of policies, they can prescribe implementation plans and are to take over crisis management if a municipality is overwhelmed. Departments and regions can also contribute, mainly by financing equipment or mitigation measures. The risk research and scientific community is made up of several different actors, but they are not organized into networks by law, as is the case of the competence and functional centres in Italy.

Another key difference regards the insurance sector. In Italy, it is not very developed. Indeed, there is no private insurance available for many natural hazards, for example, landslides and floods. For others, like earthquakes and fires, there is only partial coverage. In particular, generally only industrial plants purchase earthquake insurance. This contrasts with the Italian policy of direct intervention by providing post-disaster financial aid and enacting ad hoc laws for recovery.

The French system allows risk transfer to the insurance sector and the state. Compulsory insurance on property and homes includes contributions to a national fund ("fond Barnier", decree 2005-29 from 12-1-2005) which helps indemnify property owners against unexpected and major natural disaster events (CATNAT = *catastrophe naturelle*), and also supports risk research and risk prevention. Figures 5 and 6 summarize the main stakeholders at the different levels in Italy and France.

Fig.5 - Main stakeholders in Italy

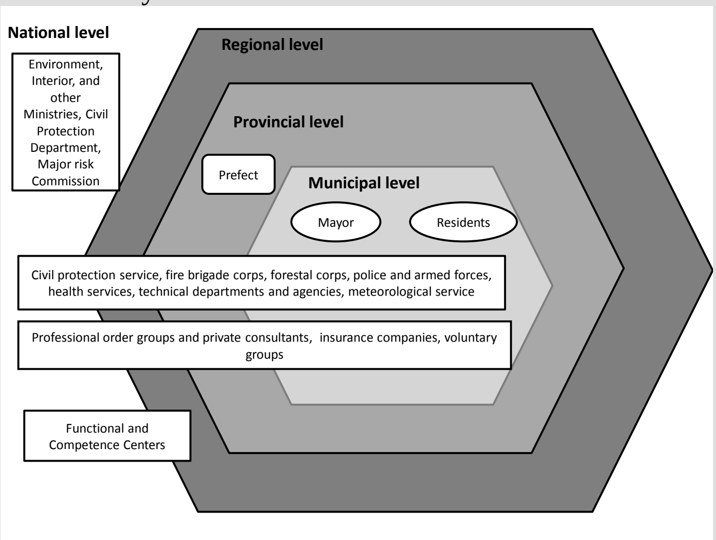
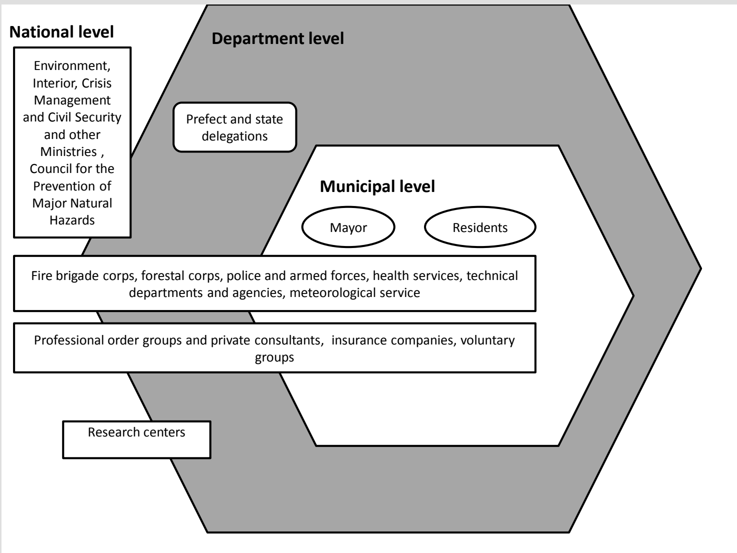


Fig. 6 – The main stakeholders in France



6.1.3 *Lack of open access to databases and research results*

Access to data collected by private consultants or researchers is a problematic issue that goes far beyond the implementation of multi-risk assessment. As reported by one practitioner working for a meteorological service: "the researchers want to keep the data because they want to publish." Another practitioner maintained "Private companies do not make their data available because it is for the benefit of their competitiveness." Publicly (i.e., free) available databases should therefore be established.

At the same time, many research and public institutions are already moving in the direction of increased transparency and providing online access to data (Mrzyglocki, 2013).

In addition to data, new research results are not always available for or consulted by practitioners for a number of reasons, including lack of time and/or of qualified experienced personnel, language issues (research results are often published in English). Moreover, these results do not always reflect the practitioners' needs and expectations.

As in the case of the research gaps, perceptions of researchers and practitioners are different. Scientists maintain that research results are freely available and published online. The same is not true for the databases, but the reason is simple: most of the time, practitioners do not know how to use these databases. The problem is not data availability, but who is going to use and interpret the data and for what purpose. Many practitioners also agree on this point: "the problem is not simply access to data, but how to effectively use them" (urban planner). For the time being, it is suggested that results on multi-risk assessment should be provided by researchers (rather than practitioners). As reported by one practitioner in Naples "it is unrealistic to think that single agencies will be able to provide multi-risk assessment. We rather need to develop stronger partnerships with research institutions working on multi-risk assessment".

In other words, results need to target practitioners (see also chapter 7).

6.2 Practice domain

6.2.1 *Single risk centred governance*

Risk science and governance developed and co-evolved in parallel through time. As such, single-risk cantered assessments implied the adoption of single-risk centred regulation, institutional frameworks, practices and decision-making processes. The deep differences in the approaches, tools and methodologies used for single-risk assessment have resulted in a lack of integrated practices for multi-risk governance. As a consequence, practitioners rarely have the opportunity to meet colleagues working in different risk fields and thus to discuss multi-risk issues (even if there are differences among EU member states).

Box 4 presents some selected results on risk governance in Naples and Guadeloupe that formed the basis for the analysis of institutional barriers to multi-risk governance (see task 6.3 report: Scolobig et al., 2013).

Box 4 - Risk governance in Naples and Guadeloupe

On the basis of the documentary analysis and stakeholders interviews, the research team identified three different sets of characteristics to compare risk governance across natural hazards and countries:

i) stakeholders and governance level: this includes a description of the diverse and interdependent set of stakeholders involved in the natural risk governance system, their roles and responsibilities. These stakeholders typically work at different levels (e.g., national, regional, etc.). This set thus provides information on the institutional architecture;

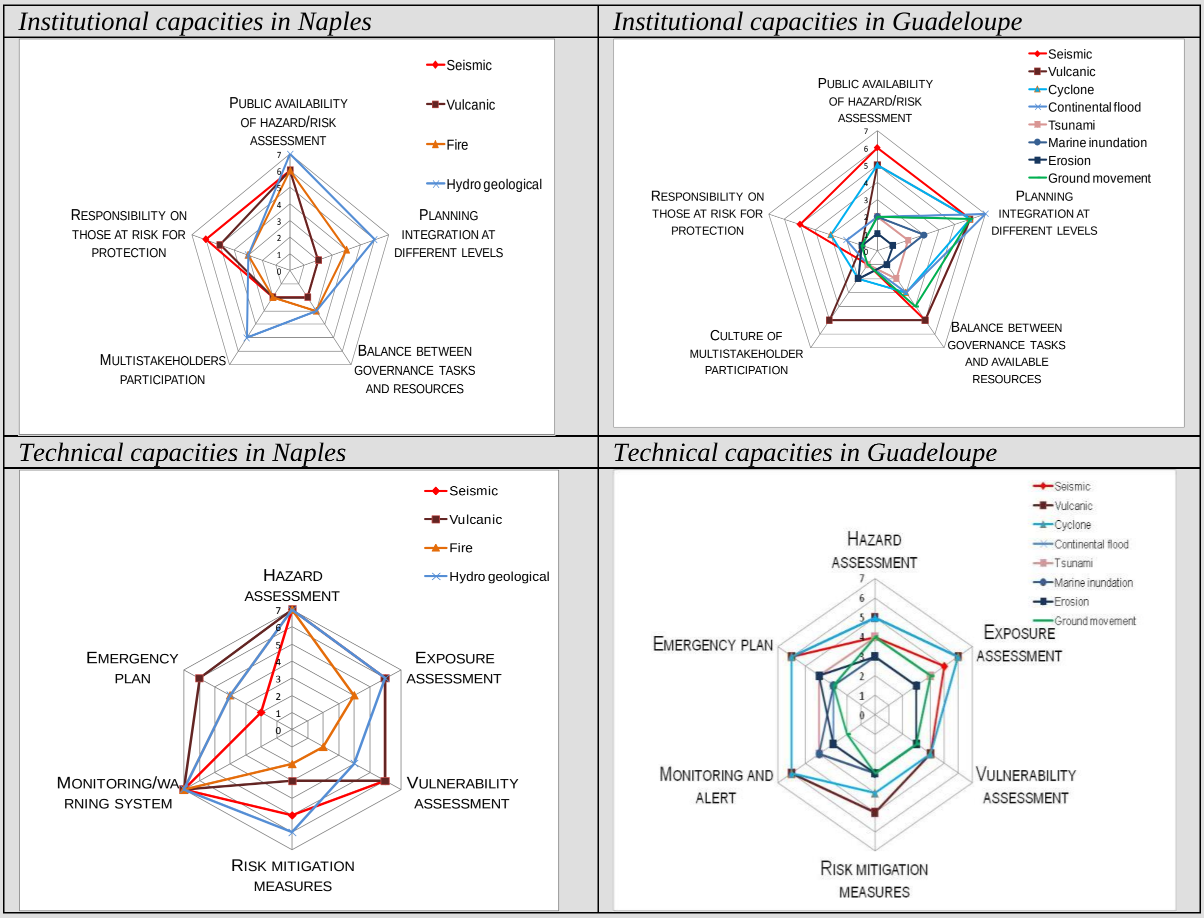
ii) decision support tools and mitigation measures (technical capacities): hazard, exposure and vulnerability maps, monitoring and warning systems, emergency plans, and risk mitigation measures were considered. As a result, this set provides information on the science-based governance tools developed by public agencies or private consultants for public use;

iii) stakeholder cooperation and communication (institutional capacities): this includes information related to the cooperation and exchange of knowledge among actors, as well as their involvement in the risk decision-making processes. It covers a wide range of issues, including public availability of hazard/risk assessment, planning integration at different levels, balance between governance tasks and resources, multi-stakeholder participation, and responsibility to those at risk for protection.

Afterwards, interviewees were asked to provide evaluations for each one on a Likert scale from 1 (min) to 7 (max), with 1 and 7 having different meanings depending on the characteristic being studied[4]. We stopped the round of interviews when the evaluations of the stakeholders converged on the same values. As an example, Fig. 7 reports the evaluation of technical capacities in Guadeloupe and of institutional capacities in Naples (more information can be found in Scolobig et al., 2013).

[4] Likert scales are commonly used in questionnaire surveys and are characterised by two main aspects: unidimensionality and reliability (De Vaus, 2002; Denscombe, 2007). A unidimensional scale is one in which each item measures the same underlying concept (e.g., hazard, exposure and vulnerability assessment as a function of the tools and plans that are available). A reliable scale is one on which individuals obtain much the same scale on two different occasions. To make our scales were unidimesional and reliable, we tested them with interviewees, changed some items, etc. Likert scales with ordinal data, as in our case, normally are five or seven points. We decided to use a seven point scale. The categories are 'in order'. This means that the data in each category can be compared with the data in other categories as being higher or lower. The evaluations were based on the knowledge, judgements and opinions of the practitioners involved in research activities in the MATRIX case studies. We intended to treat these governance profiles as being dynamic rather than static tools that aim to help stakeholders to identify similarities and differences across countries and hazards as well as the institutional barriers to effective decision-making and governance. We stopped the interview round when the new interviewees were in agreement with the evaluations provided by the previous ones.

Fig. 7 – Evaluation of institutional and technical capacities in Naples and Guadeloupe [Evaluation provided on a 1-7 Likert scale by stakeholders, 1 minimum and 7 maximum]



6.2.2 *Different responsibilities for risk reduction at the household level*

Responsibilities for risk reduction at the household level change consistently, depending on the risk, on the country and on the availability of insurance schemes.

For example, different levels of responsibility are attributed to property owners in geological versus meteorological risk prevention. In the case of earthquakes, the level of individual responsibility is high because property owners are usually in charge of household vulnerability reduction measures (unless there are specific national policies aimed at reducing it). In the case of floods, the decisions about risk mitigation measures such as protection works, depolderisation of coastlines etc. are under the responsibility of public authorities and costs are covered collectively. Securing buildings from flood waters is often also a responsibility of the property owner (but most of the time the measures consist of water channels to better drain water and are less expensive than the measures required to secure against earthquake risk), and insurance schemes can be available - depending on the country.

However, there is a lack of options for public-private responsibility sharing, especially in cases where households are exposed to multiple risks (and if insurance schemes are not available, as is the case in some European countries).

6.2.3 *Different priorities of the agencies in charge of risk management*

The priorities of the agencies in charge of risk management are very different. Depending on the hazard and the disaster management phase they are in charge of, practitioners mention as a priority the reduction of household vulnerability (e.g., for volcanic and earthquake risk), the maintenance of protection works (e.g., for flood risk), the depolderisation of coastlines and maintenance/construction of dams (e.g., for coastal floods), the provision of detailed information to the public about emergency plans (e.g., for emergency managers), etc.
Successful multi-risk decision analytic frameworks and support tools may provide a basis for managers to reach a consensus, or at least a compromise, in terms of the actions and priorities that are to be taken. Box 5 provides insights into some current decision-analytic frameworks for multi-hazard mitigation and adaptation (excerpted from the task 6.1 report, Wenzel, 2012).

Box 5 – Insights on decision-analytic frameworks for multi-hazard mitigation and adaptation

Whereas a decision support system (DSS) is specified as an information system for the support of decisions, a decision model (DM) is characterized as a methodology or system that allows for the selection of decisions, usually from a discrete set of alternatives. The purpose of risk assessment, as a result of risk mapping, is not to take decisions, but rather to show and display the role of different risks with regards to their frequency and severity. However, there are decisions to be made in the risk assessment process when ranking different loss categories. Thus, risk assessment requires a DSS and components of a DM. DMs are even more valuable in the risk management process, as they target decisions rather than assessments.

The methodological basis of the European risk assessment process is described in the Commission Staff Working Paper "Risk Assessment and Mapping Guideline for Disaster Management" (Brussels, 21.12.2010, SEC (2010) 1626 Final). A possible methodology has been developed by the Federal Office of Civil Protection and Disaster Assistance in Germany (BBK, 2010). For any relevant risk, a set of scenarios should be designed. The frequency of the event and the severity of its impact will populate the risk matrix. The severity is expressed by an indicator variable that combines the severity of losses from five components: population, economy, ecology, infrastructure and intangible losses. As these losses can only be partially characterized in monetary terms, it is obvious that a methodology and scheme for ranking is essential. The development of this ranking scheme in a stakeholder process is the focus of the suggested decision support tool. Its theoretical base is Multi-Criteria Decision Analysis (MCDA).

As multiple objectives and criteria are relevant in risk assessment, these aspects require specific consideration. Transparent and coherent support for the solution of complex decision situations, including facilitation and communication between involved stakeholders, is the target of MCDA. An alternative approach is known as Cost-Benefit Analysis (CBA), which is frequently used for the quantitative evaluation of decisions related to risk (French, 1986, 1996, 2003). CBA requires the expression of all benefits and disadvantages of the decision process in monetary terms and the decision follows from a comparison of costs and benefits. Thus, CBA is only applicable if all relevant items can be expressed in monetary terms. However, risk assessment often involves non-monetary items. If assets such as the environment, security, cultural heritage and other intangibles, which cannot readily be expressed in monetary terms, are important, CBA is difficult if not impossible to apply and MCDA is the preferred approach. The developers of MCDA consider the fact that the subjectivity in decision making is explicitly and deliberately included, and provides a clear advantage as long as transparency and traceability of the analysis is guaranteed. In addition, by providing a sound framework for sensitivity analysis, MCDA offers valuable support for consensus finding within decision-making groups (for more information on this topic, consult the task 6.1 Report: Wenzel, 2012).

6.2.4 *Lack of interagency communication and of stakeholder involvement*

Interagency cooperation and communication are particularly difficult for risks that are managed by authorities acting at different levels (e.g., in Naples, the national level for volcanic risk and river basin area level for flood risk). For example, in Naples, the plan for volcanic emergency management has been prepared by the National Civil Protection, while hydro-geological emergency plans are under the responsibility of municipal authorities (during the fieldwork, a new law 100/2012, was enacted. Emergency plans became compulsory and all Italian municipalities had to finalise and approve them by 14 October 2012). Some practitioners also mention the lack of communication between emergency units and land-use planners (e.g., Sweden).

However, there are exceptions: for example, practitioners from the UK mention that inter-agency cooperation works well.

Multi-stakeholder participation in decision-making also takes on different shapes depending on the hazard under study. The harmonisation of these practices is therefore one of the barriers to multi-risk governance.

6.2.5 *Hazard and risk hierarchy*

Some hazards are considered as major and primary (e.g., earthquakes), with induced effects being secondary (e.g., tsunamis). Such a hierarchy refers, however, more to the process than to the intensity (e.g., a secondary hazard such as a tsunami could be a much more damaging event than the trigger).

Results reveal that present-day governance also considers this hierarchy. It results from a classification of high intensity/low frequency events (earthquakes, volcanism) in contrast to high frequency/low impact events (inland inundation and ground movement). For example, in Guadeloupe, tsunami and coastal risks were quoted, but did not appear as major risks to interviewed stakeholders.

This hierarchy leads to insufficient knowledge for some single risks. This mostly concerns secondary hazards and refers to knowledge (inundations, secondary effects of cyclones) and management (inundation, smaller tropical stormy events, coastal risks etc.), the result being an impediment to sound multi-risk approaches of those risks.

The research results also point out the incomplete knowledge on risk assessment, prevention capacity, exposed assets vulnerability and forecasting capacity.

6.2.6 *Lack of capacities at the local level*

Capacities, especially financial, but sometimes also technical and institutional, are lacking at the local level. The same is not true for the responsibilities for disaster risk management that often fall on local authorities shoulders. It is well known that responsibilities for disaster risk reduction have been transferred to the local levels without sufficient resources to implement the programmes.

Among the key problematic issues, the participants mentioned the fact that mitigation funds are diverted to response. There are also difficulties to balance the budget between short term needs and medium term multi-risk mitigation.

The lack of human resources is also sometimes an issue. Practitioners lament the lack of time, of qualified or experienced personnel (in multi-risk), leadership turnover (in some agencies) and the lack of resources for the transfer of competence and expertise (e.g., in Norway).

6.2.7 *Unsatisfactory public-private partnership*

The difficulty in communication among public agencies, working at different levels, is amplified in the cases of public and private actors. Besides the difficulties in knowledge exchange already mentioned above (see chapter 5), one of the main problematic aspects relates to the interactions between industrial and natural risks.

Indeed, industrial and technological risk management is mostly under the responsibility of private actors. However, their assessment is often not appropriately integrated into the planning handled by public authorities.

Another example regards the role of private consultants in risk assessment. Private consultants often play a key role as boundary agents between scientists and practitioners. Very often they prepare or update risk assessment for local authorities. However, in the decision making arena, private consultants frequently represent different stakeholders (from public authorities to private actors) with conflicting interests.

In this context, it is necessary to take into account that public and private actors make decisions about how to manage risk based on a variety of cultural and value-based systems. One group of actors may prioritize the guarantee of economic growth, another of high safety standards. Another group of actors in turn may prioritize cost savings over everything else, while housing availability or the preservation of private property (e.g., vs. building constraints) could be of paramount importance to others.

6.2.8 *Behavioural and cognitive biases*

The historical case analyses as well as interactions with stakeholders showed that availability heuristics and loss aversion are two major biases influencing the decision-making process. The availability heuristics bias results in giving priority to actions on the better known hazards due to historical frequency, personal experience or media coverage, which might lead to less attention to low frequency but high impact events. The loss aversion leads to the perception of necessary investments into risk mitigation measures as being more significant at present than the mitigation of the risk as being a more significant gain in the future.

6.3 *Interactions between domains*

6.3.1 *Research/practice divide*

The research/practice divide, the lack of implementation of new scientific results (e.g., on multi-risk assessment, mostly due to lack of information about new research results) and limited political awareness about the results of these assessments are problematic issues. For example, as reported by a regional civil protection officer "In Italy, there is a gap between the vast scientific knowledge available and its implementation. The main objective of scientists and researchers is to publish new research results. The main objective of practitioners is to fulfil legal requirements using effective and simple methodologies and to avoid liability in case of damages or, even worst, human life losses. It is clear that these objectives are divergent and not always easy to reconcile". In other words, reciprocal expectations can be distorted by difficulties in making new science useful for practitioners to consume, through communication failures, differences in mandates and missions, objectives and in organizational cultures between scientific and institutional communities. The director of a regional office for hydrogeological risk reduction adds to the point: "We do not need other researches on our territory whose results are not implemented by the local authorities. We already have too many and sometimes contradictory studies which often become legal proofs in the court. Attorneys will always find a study or research that proves that a certain area was exposed to high risk. As a consequence, public officials are considered responsible and can even go to prison."

In summary, Table 2 outlines the barriers that have been described in this section.

Tab. 2- Summary of the barriers to the effective implementation of multi-risk approaches identified during the research .

	Barriers in the science domain
Meta- theme	**Sub-theme**
Geological vs. meteorological hazards	• the different evolution, innovations and discoveries in science led to the development of different decision support tools and approaches to risk management across risk sectors • different methodologies and levels of uncertainty in hazard/risk assessment make the dialogue between scientists belonging to different disciplinary sectors particularly difficult
Research gaps	• lack of data, knowledge of the physical processes and models related to the cascade effects; more information needed for a quantitative check • uncertainty assessment • difficulties in combining single risk analyses into integrated multi-risk analyses (available data may refer to different time windows, different typologies of impacts are used etc.) • need of more evidence about lives and property saved by using a multi-risk (vs. single-risk) approaches • need of an overview of MR contexts at the town level
Lack of open access to database and research results	• different practices of public vs. private sector for data collection, use, access and exchange • lack of tools to exchange knowledge and target information to different audiences
	Barriers in the practice domain
Single risk centred	• lack of integrated practices for risk management (that could support

regulation and institutional frameworks	the implementation of a multi-risk approach) • cascade and domino effects usually not included in risk zoning and urban planning
Different responsibilities for risk reduction at household level	• lack of options for public-private responsibility sharing in case of households exposed to multiple risks
Different goals and priorities of the agencies in charge of hazard management	• priority identification is single-risk centred and decisions are based on the risks that could be most reduced and not necessarily the highest assessed risks
Lack of interagency communication and culture of stakeholder involvement in decision making	• cooperation and communication difficult for authorities acting at different levels • harmonisation of the practices of multiple stakeholders and decision making processes across hazards
Hazard and risk hierarchy	• resources and capacities focused on hazards considered as major (e.g., earthquakes vs. local landslides)
Lack of capacities at the local level	• lack of financial, technical, etc. capacities at the local level • mitigation funds diverted to response • lack of human resources and time • lack of qualified or experienced personnel (in multi-risk) • leadership turnovers (in some agencies)
Unsatisfactory public private partnership	• lack of communication between public private actors (especially between industrial and natural risk sector) • private consultants at the forefront in case of contradictory results of risk assessment
Behavioural and cognitive biases	• availability heuristics and loss aversion are two major biases influencing the decision-making process
	Interactions between domains
Research vs. practice divide	• problems with the implementation of new scientific or research results • divergent missions and objectives, rationalities, logic, etc.

7. Recommendations

The analysis of benefits and barriers to the implementation of a multi-risk approach formed the basis for the recommendations reported below. These recommendations aim to facilitate the process through which new knowledge generated through multi-risk assessment is taken advantage of by practitioners.

The audience for most of the recommendations and guidelines on risk assessment are usually policy makers and/or practitioners. In this case, we address our recommendations to both risk management professionals (i.e., practitioners and policy makers at the European, national, regional and especially local levels AND researchers dealing with multi-risk assessment). This reflects the two way communication process and constant dialogue between researchers and practitioners that characterised the research undertaken in WP6. At the same time, as revealed by our results (see sections 6.1.2. and 6.3.1.), there is a divergence in researcher and practitioner expectations about possible future development of multi-risk research. Efforts on both sides (broadly science and practice) need to be carried out in order to effectively implement a multi-risk approach.

7.1 Dialogue between different risk communities

Research funding institutions and national government should

- encourage knowledge exchange and dialogue between different disciplinary communities (especially geological and meteorological). To avoid or better forecast worst case scenarios, it is a priority to bridge the long-lasting gap between geological and meteorological disciplines, and also between natural and social sciences.

7.2 Development of territorial databases and platforms for knowledge exchange

Researchers, research funding institutions and private consultants should

- make databases and results available online, and make them not only user friendly, but also tailored for different types of users (or at least make a difference between the general public and practitioners).
- Develop territorial databases collecting information about multi-hazards. These databases should include demographic data, economic data on public and private dwellings, data on road and other lifelines, agriculture, as well as the environmental value of ecosystems and natural spaces. This would help with the assessments of potential or real damages in relation to single or multiple hazards, in a more integrated way.
- Conduct thorough territorial diagnosis to help assess the vulnerability of assets to the different risks. Such a diagnosis should provide a typology of the exposed elements to risk. This means that for private housing, commercial facilities, etc., the concept of multi-vulnerability has to be developed. A single house has different vulnerabilities with respect to the different hazards. Moreover, criteria to decide which scenarios would be “good candidates” for multi-risk assessment should be identified in order to help practitioners to understand where it is worthwhile to invest resources.

Practitioners at the local level in cooperation with researchers should jointly develop

- platforms that help practitioners to take action, to understand and communicate the key multi-risk contexts to their communities. More precisely, the existing organization is to be the basis for setting up a multi-risk platform, under the coordination of the local authorities. Such a transversal platform would help a more efficient exchange of information about the territory and a relevant documentation on risk management, via GIS and other NTIC.
- The more flexible and comprehensive these platforms will be in presenting and emphasising different components of risk, the more attractive they will be to users, of both the public and the private sector.

7.3 Information targeting

Researchers should:

- invest time and resources to clearly describe what benefits multi-risk assessment can provide for practitioners, taking into account their interests and needs that should be identified before starting the dissemination work.
- Bear in mind that practitioners are particularly interested in clear evidence about an increase in expected losses, and in the lives and property saved by using a multi-risk vs. single-risk approach.
- Attain the potential of MRA to fulfil the needs of different users. Practitioners are not a homogeneous group with the same tasks, responsibilities and interests. They need to be involved at time scales and levels appropriate to their interests, knowledge and skills. For example, researchers should be aware that the more specific and detailed the information is, the more useful it will be for the practitioners that want risk information about buildings and physical infrastructures that are essential to their work. Practitioners who have responsibilities for the implementation of urban planning are more interested in an overview of an area subjected to multiple risk and cascade effects.

7.4 Co-existence of single and multi-risk approaches

Policy makers and researchers should bear in mind that:

- a multi-risk approach cannot be subsidiary to a single-risk approach: both approaches have to be pursued. This comment reinforces the result of the desk studies which pointed out that the knowledge about many risks still has to be improved, or dealt with, individually, in terms of risk assessment and monitoring at least. As reported by a German practitioner: “Before a multi-risk assessment can be effectively implemented, we need a profound knowledge of single risks. We are still in the process of finalizing single risk assessment [and differences across European countries and risks are noticeable]. Also, we first have to define the multi-risk scenarios that are worthwhile assessing.” Practitioners from Hungary, UK and Guadeloupe also make the same point.
- The maturity of the different single risks assessments is quite variable, in terms of vulnerability and hazard assessment. Consequently, a multi-risk approach that integrates single-risk methods or families of methods, needs a harmonisation of methodologies, terminology and databases (see the results of WP2 “Single-type risk assessment and comparability”). A common understanding of the last issues needs to

be fostered. For example, each single risk has its own scale or unit of measure to quantify risk or damages, such as damages states for earthquake risk, and loss ratios for floods.

7.5 Development of capacities at the local level

Policy makers, especially at the national, but also at the local level, should:

- encourage the development of financial, technical and institutional capacities at the local level.
- Use multi-risk assessment to increase risk awareness of the local population by means of education and communication campaigns.

7.6 Creation of local (multi) risk commissions

Authorities at the national or local level should support:

- the creation of local multi-risk commissions, i.e., groups of local natural hazard advisors acting as liaising bodies between communities and risk management experts with responsibilities for monitoring, prevention, mitigation and implementation of MRA. This can help to bridge the gap between the domains of knowledge pertaining to the numerous actors involved in natural hazards management and improve data use and access.

7.7 Identification of new options for multi-risk responsibility sharing

Stakeholders from the public and private sector should identify:

- new options for public-private responsibility sharing especially for households exposed to multiple risks. Differences between countries are relevant (especially concerning the role of insurance schemes) and should be taken into account.

7.8 Inclusion of multi-risk assessment in urban planning

Legislators, policy makers and local technical officers should take into account that

- the implementation of multi-risk assessment requires adequate legislative frameworks. For example, the legislation concerning building constraints – and, as a consequence, urban planning – should take into account also the results of multi-risk assessment. Whether this legislation should be issued at the national or regional/lander/department etc. level depends on the institutional framework of each individual state.

7.9 Cost / risk benefit analysis

Cost/risk benefit analysis of risk mitigation measures, also for low priority risks and low probability high impact risks, as well as the availability of data, can provide argument for risk mitigation measures and help to identify behavioural and cognitive biases.

7.10 Interactions between researchers and practitioners

Practitioners and researchers should invest resources to engage in a permanent dialogue in order to:

- reach a common understanding of what risk assessment is.
- Know and understand the reciprocal expectations, preferences and needs.
- Recognize that the former concepts can be different, sometimes conflicting, and be flexible enough to reach a compromise of what the priorities are.
- Solicit reciprocal inputs as early and as regularly as possible.
- Develop strategies for obtaining reciprocal inputs during the development of multi-risk assessment.
- Ensure that sufficient time and resources are set aside to engage in a permanent dialogue.

8. Conclusion

This final deliverable of **MATRIX** Workpackage 6 “Decision support for mitigation and adaptation in a multi-hazard environment” provides a synthesis of the benefits and barriers to multi-hazard mitigation and adaptation, including recommendations for decision support.

In this document we wanted to open up a discussion on the following questions:

- What are the key benefits of a multi-risk assessment for practitioners?
- What barriers will and must researchers and practitioners confront to implement new multi-risk assessment methodologies (such as the ones developed in the MATRIX project)?
- What tools, resources and capacities can be provided to overcome these barriers?
- How can these results be translated into useful recommendations addressed to researchers and practitioners?

Our results reveal that in the present single-risk centred governance systems (reflecting risk-centred assessment systems), practitioners rarely have the opportunity to discuss multi-risk assessment. Therefore, a first key essential step to develop multi-risk governance would be to create forums for discussion at the local level ("multi-risk local commissions"). Other key catalysts for the effective implementation of multi-risk assessment are: development of territorial platforms for data and knowledge exchange between researchers and practitioners; increased interactions between the different scientific and technical communities, especially those involved in meteorological and geological risk; guarantee the co-existence of single and multi-risk approaches; inclusion of the results of multi-risk assessment in urban planning (especially in the decisions about building constraints); development of capacities at the local level (e.g., create groups of local natural hazard advisors acting as connecting bodies between communities and risk management experts); identification of new options for multi-risk responsibility sharing; and the investment of resources to favour a permanent dialogue between researchers and practitioners.

Finally, since we worked in close cooperation with practitioners from different authorities, we could also compare and confront their views. The lessons learnt through these interactions lead us to address our recommendations not only to policy makers and practitioners, but also to researchers. Efforts on both sides need to be made in order to overcome the barriers to an effective implementation of multi-risk assessment.

9. How to know more about our research?

The interested reader may contact the authors directly via the following:

In Austria *Anthony Patt, Nadejda Komendantova and Anna Scolobig* Risk, Policy and Vulnerability Program, International Institute for Applied Systems Analysis (IIASA) Schlossplatz 1 2361 - Laxenburg E-mail: patt@iiasa.ac.at komendan@iiasa.ac.at scolobig@iiasa.ac.at Website: http://www.iiasa.ac.at	**In France** *Charlotte Vinchon, Daniel Monfort-Climent, Mendy Begoubou-Valerius* Bureau de Recherches Géologiques et Minières (BRGM) Orléans and Gourbeyre E-mail: c.vinchon@brgm.fr m.bengoubou-valerius@brgm.fr d.monfortcliment@brgm.fr Website: http://www.brgm.eu
In Italy *Paolo Gasparini, Angela Di Ruocco, Alex Garcia-Aristizabal* Analisi e Monitoraggio del Rischio Ambientale - Scarl (AMRA) Naples E-mail: paolo.gasparini@amracenter.com angela.diruocco@amracenter.com alexander.garcia@bo.ingv.it Website: http://www.amracenter.com/index.html	**In Germany** *Friedemann Wenzel* Karlsruhe Institut für Technologie (KIT), Karlsruhe Hertzstr. 16 76187 - Karlsruhe E-mail: Friedemann.Wenzel@kit.edu Website: http://www.gpi.kit.edu/

Moreover, the interested reader can inspect the **project website**:
http://matrix.gpi.kit.edu/index.php

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