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Challenges in assessing and managing multi-hazard risks: A European stakeholders perspective

Robert Šakić Trogrlić[a,*], Karina Reiter[a], Roxana L. Ciurean[b], Stefania Gottardo[c,d], Silvia Torresan[c,d], Anne Sophie Daloz[e], Lin Ma[e], Noemi Padrón Fumero[f], Sharon Tatman[g], Stefan Hochrainer-Stigler[a], Marleen C. de Ruiter[h], Julius Schlumberger[g,h], Remi Harris[c,d], Sara Garcia-Gonzalez[f], María García-Vaquero[f], Tamara Lucía Febles Arévalo[i,l], Raul Hernandez-Martin[f], Javier Mendoza-Jimenez[f], Davide Mauro Ferrario[c,d,j], David Geurts[g], Dana Stuparu[g], Timothy Tiggeloven[h], Melanie J. Duncan[k], Philip J. Ward[g,h]

[a] International Institute for Applied Systems Analysis (IIASA), 2361 Laxenburg, Austria
[b] British Geological Survey, Keyworth NG12 5GG, United Kingdom
[c] Fondazione CMCC - Centro Euro-Mediterraneo sui Cambiamenti Climatici, Lecce 73100, Italy
[d] Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Venice 30170, Italy
[e] CICERO Center for International Climate Research, Oslo 0318, Norway
[f] Faculty of Economy, Business and Tourism, University of La Laguna, 38071 La Laguna, Santa Cruz de Tenerife, Spain
[g] Deltares, Delft 2629 HV, the Netherlands
[h] Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam 1081HV, the Netherlands
[i] School of Architecture, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain
[j] Istituto Universitario Studi Superiori di Pavia, Pavia 27100, Italy
[k] British Geological Survey, The Lyell Centre, Edinburgh EH14 4BA, United Kingdom
[l] Chair of Disaster Risk Reduction and Resilient Cities, Universidad de La Laguna, 38200 Santa Cruz de Tenerife, Spain

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ABSTRACT

The latest evidence suggests that multi-hazards and their interrelationships (e.g., triggering, compound, and consecutive hazards) are becoming more frequent across Europe, underlying a need for resilience building by moving from single-hazard-focused to multi-hazard risk assessment and management. Although significant advancements were made in our understanding of these events, mainstream practice is still focused on risks due to single hazards (e.g., flooding, earthquakes, droughts), with a limited understanding of the stakeholder needs on the ground. To overcome this limitation, this paper sets out to understand the challenges for moving towards multi-hazard risk management through the perspective of European stakeholders. Based on five workshops across different European pilots (Danube Region, Veneto Region, Scandinavia, North Sea, and Canary Islands) and an expert workshop, we identify five prime challenges: i) governance, ii) knowledge of multi-hazards and multi-risks, iii) existing approaches to disaster risk management, iv) translation of science to policy and practice, and v) lack of data. These challenges are inherently linked and cannot be tackled in isolation with path dependency posing a significant hurdle in transitioning from single- to multi-hazard risk management. Going forward, we identify promising approaches for overcoming some of the challenges, including emerging approaches for multi-hazard characterisation, a common understanding of terminology, and a comprehensive framework for guiding multi-hazard risk assessment and management. We argue for a need to think beyond natural hazards and include other threats in creating a comprehensive overview of multi-hazard risks, as well as promoting thinking of multi-hazard risk reduction in the context of larger development goals.

* Corresponding author.
E-mail address: trogrlic@iiasa.ac.at (R. Šakić Trogrlić).

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1. Introduction

Europe faces various natural hazards, including flooding, earthquakes, landslides, storms, volcanoes, wildfires, droughts, and heatwaves, with different degrees of exposure and vulnerabilities across the continent (Forzieri et al., 2016; Navarro et al., 2023). Between 1980 and 2020, natural hazards impacted approximately 50 million people in the European Union (EU), resulting in an average annual damage of €12 billion (European Commission, 2023a). It is increasingly recognised that these hazards and/or their impacts often overlap in space and time, necessitating a risk management approach that addresses multi-hazards and their resulting multi-hazard risks (Šakić Trogrlić et al., 2022; Ward et al., 2022; Hochrainer-Stigler et al., 2023; Kreibich et al., 2022).

Multi-hazards involve multiple individual hazards affecting a specific region and their interrelationships (UNDRR, 2016). These interrelationships include triggering (e.g., earthquake triggering landslides), amplifying (e.g., drought increasing wildfire probability), compound (e.g., simultaneous earthquake and storm), and consecutive events (e.g., two earthquakes months apart in the same region). Extensive literature discusses hazard interrelationship classifications and terminology (De Angeli et al., 2022; de Ruiter et al., 2020; Gill et al., 2022; Gill and Malamud, 2014; Hochrainer-Stigler et al., 2023; Simpson et al., 2021; Tilloy et al., 2019). In this paper, and in line with definitions presented in Ward et al. (2022), we use the term multi-hazard risk to refer to risks generated by multiple hazards and their interrelationships, also considering interrelationships at the level of vulnerability.

Multi-hazards and their impacts are not uncommon in European countries and their mounting impacts and losses present a growing challenge. For instance, Croatia experienced consecutive earthquakes in 2020 (Atalić et al., 2021; Markušić et al., 2021), and large parts of Europe experienced dry summers and heatwaves that led to droughts in 2018, 2019, and 2020 (van der Wiel et al., 2023). Indeed, the latest IPCC WG2 report indicates that compound, consecutive, and concurrent climate extremes are becoming more frequent across Europe (Bednar-Friedl et al., 2022), underlying a need for moving from single-hazard-focused risk assessment and management to innovative risk management and reduction strategies based on solid multi-hazard risk assessments.

Global and EU policies and strategies underline the importance of considering multi-hazard risks and complex impacts of multi-hazards. For instance, the Agenda 21 (United Nations, 1992) calls for multi-hazard risk research, while international disaster risk reduction frameworks, such as the Hyogo Framework for Action (UNISDR, 2005) and the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015) indicate a need for multi-hazard risk assessments and management (Scolobig et al., 2017; Ward et al., 2022; Schlumberger et al., 2022b). In the context of EU, for instance, The Commission Staff Working Paper on Risk Assessment and Mapping Guidelines for Disaster Risk Management (European Commission, 2010) indicates that multi-hazard risk scenarios should be considered as a part of national risk assessments (NRA) with the Union Civil Protection Mechanism (UCPM) (European Parliament, 2021) also outlining the importance for member states to report on their disaster risks accounting for multiple hazards as a part of the NRA process (Schlumberger et al., 2022b). As outlined by Ward et al. (2022), the move towards the multi-hazard risk approach is also apparent in the EU research agenda, with a growing number of research projects focusing on the topic.

Although there have been advancements in transitioning from single-hazard risk to comprehensive multi-hazard risk assessment frameworks, the current evaluation of natural hazards predominantly emphasizes risks for individual hazards (Komendantova et al., 2014; Kreibich et al., 2014; López-Saavedra and Martí, 2023; Schlumberger et al., 2022b; Scolobig et al., 2017; Thaler et al., 2023). As a result, natural hazard risks are managed separately, without accounting for multi-hazard interrelationships, which could lead to reduced effectiveness of risk reduction options (e.g., drought induced dike instability) or increased exposure and vulnerability because of asynergistic effects (e.g. cultivating drought resilient crops that are more vulnerable to flood effects) (de Ruiter et al., 2021).

Despite the growing understanding of multi-hazards and recognition of the need to shift towards multi-hazard risk assessment and management, there are still numerous challenges that persist. For instance, Kappes et al., (2012), based on a comprehensive review, identify the following challenges of analyzing multi-hazard risk: i) comparability of hazards due to different process characteristics, ii) dealing with hazard interrelationships, iii) analysis of physical vulnerability for multiple hazards, iii) impacts of multi-hazards, iv) visualization of multi-risk analysis. In their recent perspective piece, Ward et al., (2022) identify a lack of comprehensive understanding and overview of existing methods and tools, the absence of clear frameworks and guidelines, limited knowledge of dynamic feedback between hazards, exposure, and vulnerability, the focus on individual hazards without considering interactions or future scenarios, the limited assessment of disaster risk management measures across multiple hazards, sectors, and time horizons, and a lack of in-depth case studies. Thaler et al., (2023) argue that traditionally, risk management has been developed for single hazards and is thus challenging to adapt it to a new reality of multi-hazard and compound risks. It is becoming increasingly recognised that new forms of disaster risks management and decision-making are needed in the context of multi-hazard risks (de Ruiter et al., 2020; Hochrainer-Stigler et al., 2023; López-Saavedra and Martí, 2023; Thaler et al., 2023).

Although international policies and guidelines for disaster risk reduction and management provide a global blueprint for action (e.g., Sendai Framework for Disaster Risk Reduction 2015–2030), disaster risk management is ultimately a local affair, with local and national governments playing an important role, and in collaboration with a wider stakeholder base (e.g., private sector, civil society, citizens) (Hardoy et al., 2011; Linnerooth-Bayer and Hochrainer-Stigler, 2015; Mojtahedi and Oo, 2017). It is, therefore, crucial to engage with various stakeholders to understand their needs and identify the challenges they are facing (Adams et al., 2022; Reiter et al., 2022). To date, in research on multi-hazard risks, interaction with stakeholders on the ground (e.g., policy makers and practitioners) has been rather limited, especially in terms of understanding the challenges they experience.

In this paper, we aim to overcome this limitation of inadequate engagement with stakeholders in the contexts of multi-hazard risk and identify the challenges for multi-hazard risk assessment and management through a lens of a vast array of stakeholders impacted by or involved in risk reduction and management across Europe. Through interaction with stakeholders in five European pilots (Danube, Scandinavia, North Sea, Veneto, and Canary Islands) through a series of workshops and an additional workshop with experts on multi-hazard risks, we present different dimensions of bottlenecks experienced in the existing practice and policy in transitioning towards risk reduction and management that is fit for tackling and understanding of multi-hazard risks.

This paper is organised as follows: in Section 2, we explain the context of pilot regions, stakeholder workshops used for data collection, and our approach to data analysis. Section 3 presents five themes identified as core challenges for transitioning towards multi-hazard risk assessment in management in Europe. In Section 4, we discuss the main findings and implications of this research. Finally, the conclusions we draw from our analysis are presented in Section 5.

2. Methodology: identifying challenges through stakeholder engagement across Europe

The analysis presented in this work is derived from six workshops carried out during the HORIZON 2020 MYRIAD-EU project (www.myriadproject.eu). MYRIAD-EU aims to equip policy-makers, decision-makers, and practitioners with practical tools to develop forward-looking disaster risk management pathways based on interrelated hazards that assess trade-offs and synergies across hazards, sectors, and scales. At the core of MYRIAD-EU lie five pilots (Danube, Scandinavia, North Sea, Veneto, and Canary Islands; presented in Fig. 1), where five pilot teams, coordinated by a pilot lead, work in a collaborative co-design process with local stakeholders to tackle pilot-specific sustainability issues (outlined in Fig. 1). In this section, we first present the context of the pilots and stakeholders (Section 2.1) and then introduce our approach to stakeholder engagement, data collection through workshops, and data analysis (Section 2.2.). The general methodological approach followed in this paper is presented in Fig. 2.

2.1. The European pilot regions and stakeholders

The pilots are characterised by different spatial and decision-making scales, ranging from subnational (in Veneto and Canary Islands) to multinational (in Danube, Scandinavia and the North Sea). Their diverse bio-geographic setting and vulnerabilities together with the social, economic, and political determinants result in complex cross-sectoral, multi-scale, and multi-hazard interrelationships. A short description of the pilots, together with an example of a past multi-hazard event are given in Table 1.

For each pilot, we identified two main groups of stakeholders with different levels of commitment. First, the Pilot Stakeholder Group (PSG), whose main role is to share experiences and reflect upon the pilot's disaster risk management opportunities or challenges and provide general feedback on the solutions proposed in the project. Stakeholders in this group are selected amongst local to national level decision-makers involved in disaster risk management and climate adaptation, private sector companies, non-governmental and civil society organisations. The second group, Pilot Core Users (PCU), is formed out of local to national level decision-makers involved in disaster risk management/climate adaptation and private sector companies. In addition to the role and responsibilities of the PSG, the PCU group aims to test the MYRIAD-EU products and services and provide feedback on how to tailor them to their practical needs. Members of each group are selected by partners leading the stakeholder engagement and research at the pilot level in close collaboration with sectoral representatives involved in the MYRIAD-EU project (i.e., sectors represented are ecosystems and forestry, energy, finance, food and agriculture, infrastructure and transport, and tourism). This strategy was designed to limit stakeholder fatigue and consider different goals, levels of interest, and capacities of stakeholders.

The stakeholder identification process was guided by a set of questions and selection criteria that consider the engagement costs and benefits and the ability to foster the adoption of novel DRM services and products. Stakeholder mapping involved a stepwise process, whereby an initial pool of stakeholders (both PSG and PCU) was created from which the most relevant ones were further selected for engagement. Several indicators were used for shortlisting, such as influence, interest, level of expertise, and capacity. In the future, snowball sampling (Leventon et al., 2016), whereby current stakeholders will suggest other people, agencies, and organizations to engage with, could further our effort to gain a comprehensive understanding of the stakeholder landscape in each pilot study area.

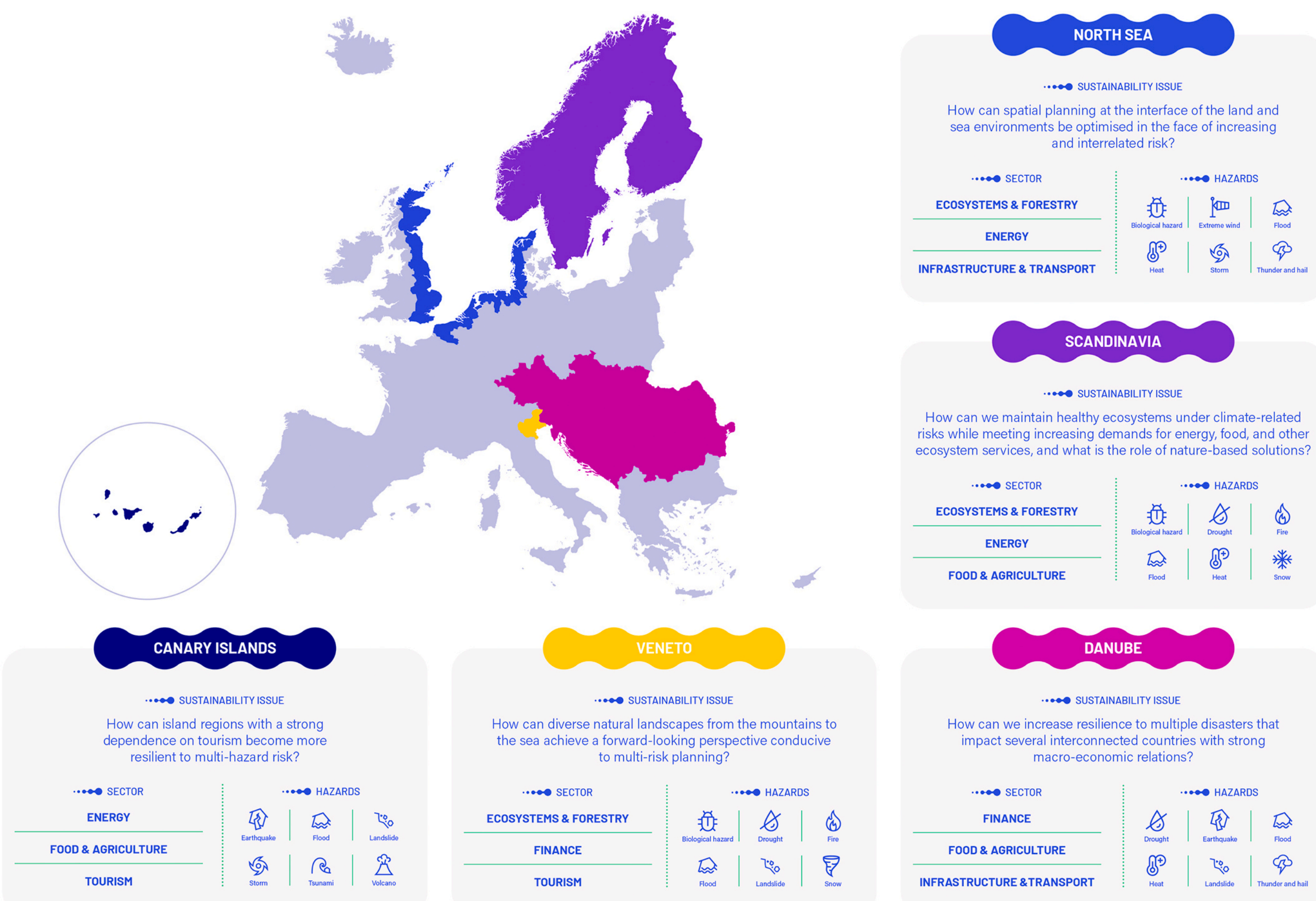

Fig. 1. Location of five MYRIAD-EU pilot regions, together with representation of unique sustainability issues, consideration of natural hazards and sectors of interest.

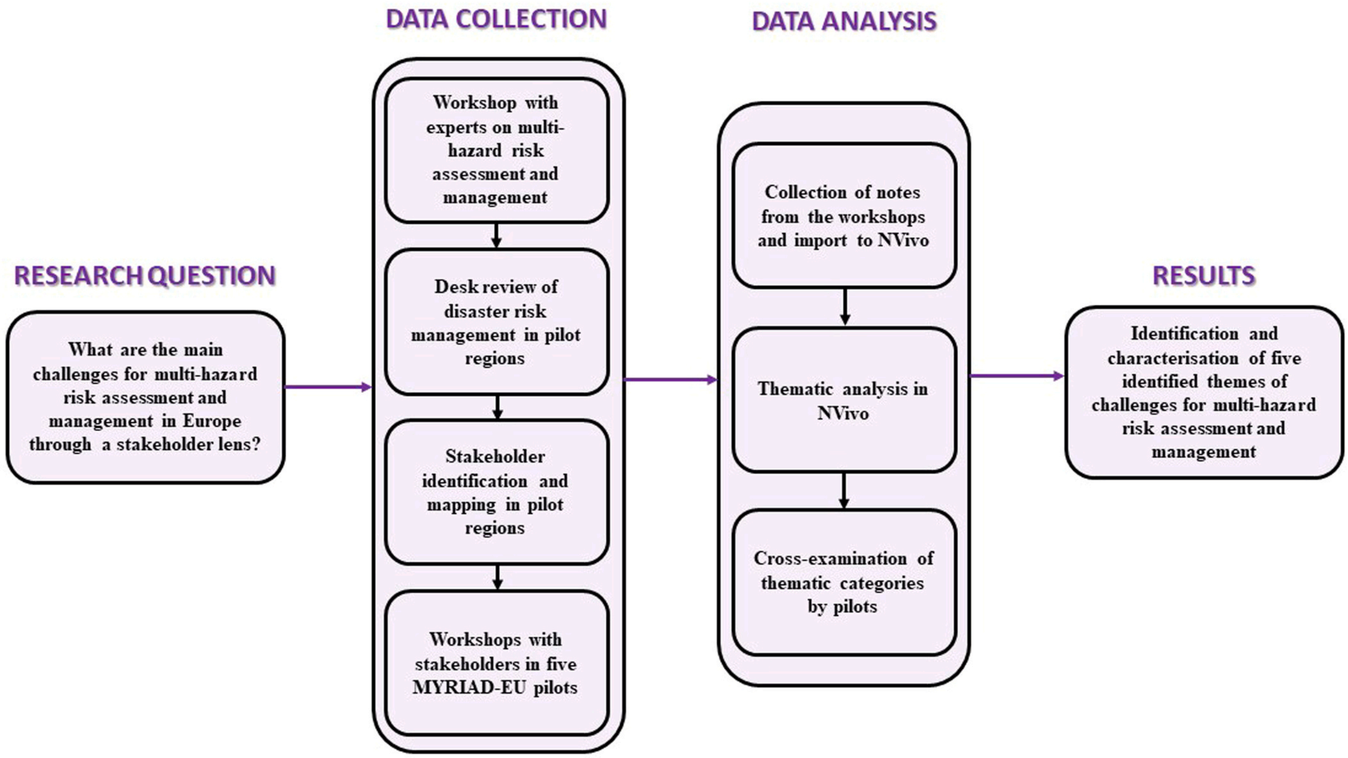

Fig. 2. General methodological approach followed in the paper.

2.2. Data collection through five pilot workshops and an expert workshop

The analysis presented in this paper is based on five workshops in MYRIAD-EU Pilots and an expert workshop. The interactive pilot workshops (n=5) were organized with a common scope and set of objectives in mind. The common scope was to collect local stakeholder perspectives on challenges and opportunities for multi-hazard risk assessment and management in pilot regions. More precisely, workshops aimed to present the project, consolidate the relationships with local stakeolders and make them familiarise themselves with the MYRIAD-EU framework for systemic multi-hazard and multi-risk management (Hochrainer-Stigler et al., 2023). Workshop results were expected to help identify the main challenges, prioritise research questions, define system boundaries and choose methods and tools to test and implement in each Pilot study. A common general agenda was co-designed by the five pilot leads and used as guidance for structuring their specific events.

However, recognizing the significant heterogeneity between the pilots and their unique stakeholder needs and landscapes, each pilot implemented a tailored approach to achieve the workshop objectives. This involved prior engagement, determining the appropriate type and number of activities, selecting the language of communication, and determining the depth of discussions. Pilot workshop participants were selected taking into account a relevant representation of expertise from pilots and different institutional perspectives on the issues discussed, as explained in Section 2.1. Workshop activities across the five pilots encompassed a range of formats and activities, including plenary presentations and discussions, round table exercises (e.g., multi-hazard and multi-risk scenario simulations), brainstorming sessions, and hands-on exercises (in break-out groups) both in person, online, and hybrid (see Table 2). These activities were generally meant to engage stakeholders in providing feedback on research direction; identify needs and priorities in relation to different types of knowledge and expertise; and mobilize interest for future interactions. Similar relevant participatory techniques are detailed in Duea et al. (2022).

For example, the Scandinavia pilot opted for an introductory meeting prior to the workshop to better understand the background of stakeholders and elicit initial reflection on disaster risk management challenges. This approach helped shape and focus the workshop agenda. The stakeholders' views and priorities on challenges in the Veneto Region were collected via guiding questions and then discussed in relation to the MYRIAD-EU objectives. A hands-on exercise aimed at synthesizing the two perspectives and analysing identified challenges in more depth. In the Danube pilot, the discussions and feedback on challenges and opportunities for multi-risk were facilitated via online platforms (MIRO and Padlet), while in The North Sea, the plenary discussions were complemented by an exercise exploring tools for multi-risk Dynamic Adaptation Policy Pathways (DAPP-MR, Schlumberger et al., 2022a). This latter approach ensured a balance between familiarization with DRM issues and multi-sector comparison within the context of the North Sea. Finally, the workshop in the Canary Islands pilot was designed using round-table exercises (6 – 8 participants per table) with the purpose of identifying, describing, and problem-solving a multi-hazard and multi-risk adaptation scenario (simulation). Two common methodologies were used to guide the general structure of discussions in the five pilots: a framework for systemic multi-hazard and multi-risk assessment and management (Hochrainer-Stigler et al., 2023) and a guidance document on collaborative systems analysis approaches (Warren et al., 2022).

In addition to the information gathered during pilot workshops in November 2022, this paper is also based on a project-wide expert workshop held in April 2022, which focused on understanding the knowledge gaps, stakeholder needs, and reflections on multi-hazard risk assessment and management. A total of 62 participants took part in this hybrid workshop. The participants included representatives from the MYRIAD-EU consortium partners (n = 37) which included both scientists and practitioners, experts in the field of multi-hazard risk (n = 17), representatives from pilots, and representatives from various sectors (n = 8). The selection of external experts involved a consultation process with researchers and resulted in a diverse group comprising academic researchers, representatives from multilateral organizations such as the

Table 1
Short description of five MYRIAD-EU pilots and examples of past multi-hazard events in the pilot.

Pilot	Short pilot description	Example multi-hazard event in the pilot
Danube	Spans 14 countries with strong economic ties. It faces diverse hazards such as floods, droughts, earthquakes, thunderstorms, landslides, and heatwaves. The Pilot prioritizes three vulnerable sectors: food and agriculture, infrastructure and transport, and finance. Resilience relies on cross-country spillover effects, regional multi-risk situations, and sector connectivity across borders.	In 2006, a significant spring flood occurred in the Danube River Basin, resulting from melting snow and heavy rainfall. The event was characterized by the rare coincidence of high water levels in the Danube, Sava, Tisza, and Velika Morava rivers, leading to an extreme compound flood event with a 100-year return period. The flood extended over a thousand kilometres, affecting multiple countries along the Danube.
Canary Islands	Heavily relies on tourism from mainland Europe, resulting in concentrated tourist activity and pressure on resources. This lack of economic diversification increases vulnerability to natural hazards. The islands' unique characteristics make them prone to interrelated hazards such as volcanoes, earthquakes, floods, hurricanes, and heatwaves, endangering rare ecosystems.	The interacting hazards from the 2021 volcanic eruption in La Palma included seismic swarms, lava flows, ashes and gases. A multi-risk scenario for all sectors and residents throughout the Canary Islands was developed for 85 days. The emergency phase persists in some touristic areas due to gas emissions, which is stressing the island's vulnerability to climate change related hazards such as wildfires, heat waves and storms.
North Sea	Exemplifies a land-sea interface region, facing space constraints and various hazards. Interactions between hazards are predicted to rise (e.g., storms impacting waves and wind, low pressure systems causing storm surges and floods). Multiple drivers shape the region's development, including renewable energy expansion, infrastructure growth, ecosystem protection and restoration, and sustainable food production.	In February 2022, the oil tanker Julietta D with 18 crew on board became adrift during storm Corrie in the Dutch part of the North Sea. The ship initially collided with another oil tanker, resulting in an oil spill. Following this, the Julietta D also collided with a transformer platform of a wind farm. Eventually, control of the vessel could be regained by establishing a tow connection.
Veneto Region	Explores the balance between land and sea activities in a diverse region with mountains, lakes, rivers, lowlands, coasts, and lagoons. Interrelated hazards such as floods, droughts, landslides, tornadoes, forest fires, and water pollution pose risks to various sectors. The pilot prioritizes ecosystems and forestry, tourism, and finance.	In March 2021, triggered by a period of around 100 days of drought, widespread fire caused significant damage in Belluno, a mountainous area of the region. Strong mountain winds propagated the fire's spread, leading to high PM10 levels across the area, with impacts across sectors and ecosystems, including disruption from visibility issues and cascading impacts to water quality and biodiversity.
Scandinavia	Focuses on climate-sensitive sectors: agriculture, forestry, and energy. Climate change is expected to intensify hazards like heavy rainfall, heatwaves, and drought. These hazards can trigger floods, forest fires, reduce agricultural productivity, and increase biological hazards. Transitioning to a low-carbon society will pose challenges to land, energy, wood, and food production.	From May to August 2018, an unprecedented multi-hazard event affected Scandinavia. A prolonged heat wave associated with several periods of drought had large impacts on several nature and sectors including agriculture and energy. In August 2023, an extreme weather event triggered flooding and landslides in Scandinavia, due to extreme rainfall. These events impacted society in many ways, for example damaging infrastructures and disrupting transportation.

Table 2
Summary of attendance, activities, and approaches for five pilot workshops and an expert workshop.

Pilot	Workshop technique/ activity	Number of participants	Profile of participants
Danube	Online plenary and break-out group discussions facilitated through MIRO and Zoom	20	Regional organizations, governmental agencies, nongovernmental representatives, scientists
Canary Islands	In person round table exercises (multi-hazard, multi-risk scenario simulations) and semi-structured discussions	22	Regional organizations and governmental agencies, sectoral representatives, scientists
North Sea	In person semi-structured discussions and hands-on exercise	11	Governmental agencies, research institutes, sectoral representatives, scientists
Veneto Region	Hybrid workshop combining plenary semi-structured discussions and hands-on exercise in break-out groups	23	Regional organizations, governmental agencies, nongovernmental sectoral representatives, scientists
Scandinavia	Pre-workshop scoping meeting followed by in person semi-structured discussions and presentations	4	Governmental Agencies, regional council representatives, scientists
Expert workshop	In-person roundtable exercises and online facilitation using MIRO and Padlet	62	MYRIAD-EU experts, sectoral representatives, multi-hazard and multi-risk researchers, international organizations

World Bank and the United Nations Office for Disaster Risk Reduction, and stakeholders of MYRIAD-EU pilot projects.

During the workshops, detailed notes were taken by organizing teams. These notes served as a basis for the analysis in this paper, which was done using thematic analysis. Thematic analysis, as described by Kiger and Varpio (2020), is a technique used to identify, analyze, and report patterns (themes) within data. This method involves coding, which is often a fundamental activity in qualitative data analysis (Weston et al., 2001). Coding entails attributing meaning to specific elements of text, such as words, phrases, sentences, or paragraphs (Gläser and Laudel, 2013), enabling researchers to define the content (Elliott, 2018). For thematic analysis, we used six stages as recommended by Nowell et al., (2017): 1) data familiarisation through critical reading of workshop notes, 2) generation of initial codes in NVivo, 3) searching for themes with revision of codes, grouping into sub-themes, and generation of initial themes 4) reviewing the initial themes through discussion with pilot leads, 5) defining and naming themes, and

6) producing the report of thematic analysis. We based our approach on grounded theory (Charmaz, 2014), meaning that the research team started the workshops with no preconceived ideas of which challenges are important for stakeholders, thus allowing these to emerge through data analysis resulting in five identified themes of challenges. In the present research, the five major themes are presented and discussed in detail in the results section (Section 3).

3. Challenges for multi-hazard risk assessment and management in Europe

Fig. 3 provides an overview of the five identified themes of challenges from the workshops, along with the associated codes of challenges. Identified themes were created by merging the identified codes, following the thematic analysis, as described in Section 2. Each of the challenge themes is presented in detail in the subsequent sections by elaborating on specific codes of challenges.

3.1. *Governance of multi-hazard risk*

UNDRR (2016) broadly defines disaster risk governance as the system comprising various institutions, mechanisms, policies, legal frameworks and related arrangements that serve the purpose of guiding, coordinating, and overseeing disaster risk reduction efforts and associated policy domains. Risk governance needs to be multi-scalar and multi-sectoral and requires the involvement of various actors (including authorities, public servants, media, private sector, and civil society) across scales (from local to global) (Djalante and Lassa, 2019; UNDRR, 2023). Our findings reveal that various aspects of disaster governance are a key identified theme of challenges for multi-hazard risk management efforts in Europe.

Jointly addressing and managing the risk of different hazards and especially taking into account their interrelationships requires a coordinated and cooperative approach between different actors and agencies and across different scales (i.e., from local to global). However, discussions in the six workshops indicate that fragmentation and siloed working are hindering a move towards multi-hazard risk assessment and management. As noted during the workshops, different hazards are often the responsibility of individual agencies (e.g., ministries) within the governmental system. For instance, in the Scandinavia pilot, flooding is a responsibility of one directorate (Norwegian Water Resources and Energy Directorate) while sea level rise falls under the realm of another (The Norwegian Coastal Administration). In the Danube Region, flood risk management is coordinated by a regional agency (i.e., the International Commission for the Protection of the Danube River), while no clear mandates for drought risk management are in place across the basin. In the Veneto Pilot workshop, participants expressed a concern that the lack of definition of responsibilities and roles in the context of multi-hazard risk translates to fragmented decision-making and siloed risk management approaches.

As participants across different workshop emphasised, fragmentation also occurs at the level of risk assessment, especially at the regional scale, as different countries use different approaches for assessing and mitigating risks. This variation poses challenges for conducting comprehensive regional assessments when addressing single hazards, and becomes even more complex when considering multiple hazards. Furthermore, the issue was raised in different pilots that existing policy and legislative frameworks remain single-hazard focused, with no clear legal responsibilities for multi-hazard risks. This fragmentation becomes more severe at regional levels, such as in the Danube, Scandinavia, and the North Sea pilots, due to varying legislative, policy, and institutional arrangements among different countries. As pointed out by some participants in the Danube Region workshop, tackling the issue of multi-hazard risks would require international cooperation; however, they felt that political issues and bureaucracy delay decision-making.

Siloed approaches and fragmentation in governance are also partly created due to a lack of coordination and communication between different institutions. This coordination problem occurs across scales. For instance, as indicated in both the Veneto Region and the Canary Islands, disaster risk management requires significant coordination efforts by all administrations, which is missing. Furthermore, as highlighted in the Danube Region and the North Sea Pilot, the coordination among various stakeholders in risk management becomes even more complex when it extends to the international level and involves multiple countries. This complexity arises from the involvement of multiple layers of institutions and governance structures, adding further challenges to effective coordination.

Other governance challenges identified by stakeholders across workshops include, for instance, a lack of institutional capacity for multi-hazard risk management. In the Danube Pilot, it was noted that multi-hazard risk management would require new ways of adaptive management with shared strategies and resources; however, the

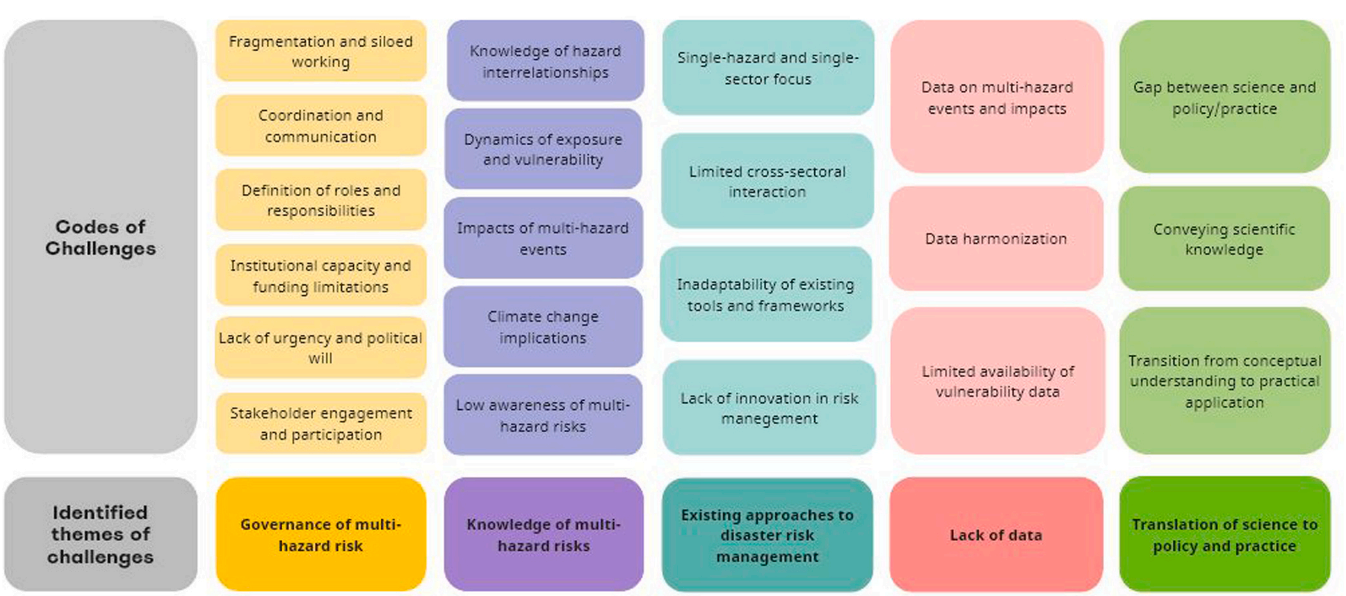

Fig. 3. : Summary of the findings of the thematic analysis of the five pilot workshops and an expert workshop.

institutional capacity to adapt and maintain new ways of management is limited. In the Canary Islands, participants noted that the institutional capacities are already challenged in the implementation of the existing single-hazard-focused policy frameworks such as the Flood Directive, raising concern that multi-hazard risk management could further overwhelm the existing institutional capacities. Furthermore, a concern was raised in different pilots that the funding for disaster risk management is already stretched and limited and that the current architecture of available funding is not conducive to tackling multi-hazard risk issues. Lack of funding was also seen to be related to changing political priorities as policy and decision makers were lacking focus on issues that go beyond their electoral cycles, including multi-hazard risk governance. In some cases, as recognised in the North Sea pilot, there is simply a perceived lack of urgency and political will for disaster risk management in general.

A final challenge in terms of the governance of multi-hazard risks pertains to stakeholder engagement. This was evident in the North Sea workshop, where it became apparent that there is limited interaction among various sectors involved in risk management. Currently, there are scarce opportunities for these sectors to convene on a shared platform and engage in discussions about their respective concerns and priorities. Similarly, in the Veneto pilot workshop, participants pointed out that different types of stakeholders (e.g., government, private sector) lack interaction. The current system is characterised by single initiatives, resulting in missed opportunities for potential synergies. As further mentioned during the workshop with experts on multi-hazard risk assessment and management, there is a lack of cooperation between the private and public sectors in natural hazard risk reduction and management, with initiatives in the private sector often missing. Moreover, there is a lack of citizen participation in risk governance, with perceptions and priorities for risk reduction often differing between various actors (e.g., citizens and local authorities).

3.2. *Knowledge of multi-hazard risks*

The second major theme of challenges identified is related to the general lack of knowledge on multi-hazard and multi-hazard risks, which can be conceptualised as more of a technical, scientific challenge.

During the expert workshop and across pilot workshops, participants highlighted a lack of knowledge of hazard interrelationships and how these occur in space and time (i.e., spatiotemporal characterisation of hazard interrelationships). Some of the questions currently not answered in the pilots include: where do clusters and hotspots of multi-hazards occur in a given region, and what are the different spatial and temporal interdependencies between different hazards? Although progress is made in terms of understanding different interrelationships between hazards, they remain difficult to describe quantitatively, ultimately limiting the extent to which they can inform risk assessment and management.

As shown in the workshops, this lack of clarity is not limited to the domain of knowledge about hazards, it also extends to our understanding of the exposure and vulnerability in the system impacted by multi-hazards, especially in terms of the dynamics of exposure and vulnerability (e.g., changes in exposed elements at risk and determinants or conditions leading to different degrees of loss during a multi-hazard event such as an earthquake followed by a flood). In the Veneto Region, it was noted that integrating the analysis of multi-hazards with information on vulnerability and exposure is inherently challenging and often lacks appropriate data sources and analysis tools. Moreover, during the expert workshop, participants noted a lack of knowledge of accounting for potential adverse effects of risk management across different hazards.

Furthermore, our analysis shows that the impact of multi-hazard events is poorly understood at present. During the Danube region workshop, participants noted that risk-based and informed management requires more comprehensive characterisation of impacts for different combinations of hazards and different return periods- information that is lacking at present. As noted in the Canary Islands, a lack of understanding of the direct and indirect impact of multi-hazard events (including both tangible and intangible impacts, see Hochrainer-Stigler et al., 2023), hinders the effective management of these events. As discussed by stakeholders, although there is an increasing understanding of hazards (also including their future projections), this is often not translated to an enhanced understanding of their potential impacts, and therefore, of possible risk reduction options.

Climate change and its implications for our understanding of multi-hazards and multi-hazard risks featured an important role in discussions. Generally, participants across different workshops pointed out that climate change is likely to influence different climate-related hazards (e.g., storms, floods, heatwaves, droughts) and by extension, hazard interrelationships. However, there are large uncertainties involved, including a lack of understanding of how the existing hazard interrelationships will change in time and which new interrelationships will emerge. As explained by stakeholders in Scandinavia, climate projections are ensemble-based and provide sparse information on the spatial and temporal distribution of different hazard scenarios. In the Veneto Region, participants noted that recent trends show an increase in the frequency and intensity of extreme events, but most research is focused on single-hazard future risk estimation, and it is not yet clearly understood how multi-hazard risk interactions are reflected in future risk scenarios. However, participants felt that understanding the propagation of risks along different future climate projections is key for the development of adequate adaptation strategies and for informing risk managers and institutions.

Concerning the modelling efforts, participants of the expert workshop emphasised the challenge of uncertainty characterisation in multi-hazard and multi-risk assessments. This includes uncertainty characterisation in the modelling of multi-hazard risk scenarios (e.g., coupling different hazard models, modelling exposure and vulnerability and their dynamics) and uncertainty of climate change impacts on single hazards and hazard interrelationships.

While this challenge theme primarily concerns technical knowledge (e.g., tools, methods, and approaches for assessing the risk of multi-hazards), it also includes discussions on low awareness and lack of knowledge of various stakeholders on the very nature of multi-hazards and multi-hazard risks, namely, multi-hazard interrelationships and dynamic risk drivers (i.e., dynamics of exposure and vulnerability, synergies and synergies in risk management of different hazards). As elaborated during the expert workshop, this could be partly due to a lack of conceptual clarity on the very concept of multi-hazard risk management, such as, at times, unclear definitions of hazard interrelationships with an often overlap between different descriptors (e.g., between the ''multi-hazard'' and ''compound hazard'' communities, see Tilloy et al., 2019). However, as elaborated during the North Sea workshop, low levels of perception of multi-hazard risk can also be explained by the fact that some sectors in the pilot (e.g., shipping and energy) have so far seen marginal impacts from hazard events. Therefore, even though impacts are projected to increase, it is challenging for these stakeholders to start considering multi-hazard risks and focus their planning on the future, whilst they are dealing with more pressing issues, such as spatial planning constraints in the North Sea.

3.3. *Existing approaches to disaster risk management*

Another theme of challenges identified based on the inputs gathered during the six workshops relates to the fact that the current approaches to disaster risk management across pilots are not conducive to the assessment and management of multi-hazard risks. Overall, participants argued that there is a very limited implementation of approaches that address multi-hazard risks (e.g., multi-hazard early warning systems, land use management which reduces impacts of both floods and droughts), as they largely remain focused on tackling risks from single hazards. By disaster risk management approaches in this challenge theme, we refer to a wide range of risk management options (e.g., structural measures such as flood walls and non-structural measures such as policies, land zoning and early warning systems) as well as current processes of conducting risk assessments (e.g., processes and usage of tools) and selecting risk management options.

Across pilots, it became evident that stakeholders in charge of risk management are used to planning and making decisions based on single hazards and single sectors. For instance, in the Canary Islands, stakeholders had limited awareness of the significance of interactions and interdependencies in multi-hazard risk scenarios. Their planning approach predominantly focused on single hazards and direct risk scenarios. As found in this pilot, this can lead to overinvestment in hard infrastructure for adaptation to flooding (as a single-hazard focused approach) because of recent past events and can even lead to an increase in risk through increasing exposure and creation of new risks (e.g., landslide and heatwave risks).

In the existing practice, there is also limited cross-sectoral interaction, as emphasised by the stakeholders in the Canary Islands workshop. Dependencies and cross-sectoral connections are not considered in risk assessments, leaving certain sectors, such as tourism, highly vulnerable to multi-hazards. For example, tourism destinations relying on desalinated water do not have water deposits for emergency periods, leaving tourism operations highly exposed to energy and other disruptions in water supply. Moreover, evidence of past events suggests that the recovery period for tourism flows after a disaster depends extremely on how other sectors have been impacted.

Furthermore, as pointed out during the expert workshop, existing tools, methods, and frameworks are not easily adaptable to multi-hazard risk assessment, as these are still very much focused on single-risk assessments and focused on specific sectors. For instance, there are few methodologies in development (North Sea Pilot), with stakeholders in Scandinavia questioning the usability of existing tools beyond academia for non-academic users and bringing to light that if a tool is already used by institutional stakeholders, it is difficult to change it. Furthermore, although new tools might be interesting, participants in Scandinavia reported they will be used only if minimal effort is needed in using them or understanding them, emphasising a need for better knowledge transfer.

Finally, participants in the Danube workshop pointed out that multi-hazard risk management will require engaging with innovative approaches to risk management, which is limited at present. This was true even in the context of single-hazard risk management. For instance, stakeholders in the Danube gave an example of nature-based solutions (NBS) for flood risk managementwhich is still not implemented widely enough despite being recognised as a potential solution for flooding issues in the region (e.g., by the International Commission for the Protection of the Danube River), as the preference is often given to traditional grey infrastructure. Yet, NBS are increasingly widely regarded as innovative solutions in disaster risk management (Ruangpan et al., 2020; Tyllianakis et al., 2022). In the Canary Islands workshop, the stakeholders involved in risk management were not aware of the multiple benefits of NBS, particularly when future climate scenarios were discussed.

3.4. Translation of science to policy and practice

During the expert workshop, participants identified an apparent gap between academic research on multi-hazard risk assessment and management and its translation into policy and practice (particularly informing multi-hazard risk management and decision-making). This was further echoed in the pilot workshops. For instance, stakeholders in the North Sea workshop mentioned limited science-policy interaction between governmental, sectoral and research stakeholders, with a gap apparent in both directions (i.e., science informing policy and practice, and policy and practise informing science). It remains challenging to convey the science of multi-hazards and multi-hazard risks to non-experts in industry and government. These stakeholders, which are often instrumental in the implementation of risk management on the ground, often lack knowledge and understanding of scientific concepts; for instance, how hazards overlap in time and space (i.e., hazard interrelationships). Furthermore, as noted by the North Sea workshop participants, researchers often lack skills in effective science communication, further hindering the translation of science to policy and practice. The Danube pilot stakeholders also emphasised that a transition from a conceptual understanding of multi-hazard risks to practical application presents a challenge in their region. In the Canary Islands workshop, stakeholders expressed a low level of awareness of multi-hazard risk research and its importance, indicating a need for more knowledge transfer and collaboration spaces. Finally, stakeholders in the Scandinavia Pilot raised that the latest scientific tools are often developed with no consideration of their usability for end-stakeholders (i.e., decision-makers and risk managers).

3.5. Lack of data

Final identified theme of challenges was related to the lack of data for understanding and managing multi-hazard risks. For instance, there is a paucity of data on past multi-hazard events and their impacts. During the expert workshop, participants pointed out a big gap in terms of the availability of impact data, noting a lack of case studies on past multi-hazard events. These types of events are not currently well captured in disaster databases such as EM-DAT or Desinventar, so it is challenging to get a good picture of multi-hazard scenarios and their impacts. Workshop participants in the Canary Islands, Veneto, North Sea and the Danube made a similar observation. Even when case studies are available, these are often not peer-reviewed and published (i.e., available in grey literature), with limited efforts to scale up learnings from case studies.

As discussed throughout workshops, a coherent approach for modelling multi-hazard risks is hindered by the fact that data for different hazards and impacts often have different spatiotemporal resolutions and need to be harmonised, which is a large undertaking, as explained during the expert workshop. The data on vulnerability are even more challenging, as these datasets are often missing or difficult to obtain (i.e., not openly available). Data for understanding the dynamics of exposure and vulnerability are particularly scarce, as these are most often available as static data.

4. Discussion

Recent experiences show that multi-hazards and their resulting impacts are challenging conventional risk management strategies (Simpson et al., 2021; Thaler et al., 2023), with a clear need for the transition towards multi-hazard risk assessment and management (Ward et al., 2022). Based on the interaction with different types of stakeholders in five European pilots, and discussion with experts, this paper set out to describe challenges for the assessment and management of multi-hazard risks in Europe. In doing so, we identified five themes of challenges:

1. Governance of multi-hazard risk
2. Knowledge of multi-hazard risk
3. Existing approaches to disaster risk management
4. Translation of science to policy and practice
5. Lack of data

Fig. 4 shows the prominence of identified themes of challenges per workshop (i.e., the number of codes assigned to a specific theme per workshop). All themes were mentioned in all of the pilots, except the complexity of translating science to policy and practice, which was not coded in the Canary Islands and Veneto Region. Furthermore, we observe that the themes of challenges of governance and knowledge of

	WORKSHOP					
THEME OF CHALLENGES	Canary Islands	Danube	North Sea	Veneto Region	Scandinavia	Expert workshop
GOVERNANCE OF MULTI-HAZARD RISK	2	13	8	3	3	4
KNOWLEDGE OF MULTI-HAZARD RISKS	6	5	3	5	4	4
EXISTING APPROACHES TO DISASTER RISK MANAGEMENT	5	2	3	1	1	3
TRANSLATION OF SCIENCE TO POLICY AND PRACTICE	0	1	3	0	2	2
LACK OF DATA	1	1	1	1	1	1

Fig. 4. : Prominence of identified themes of challenges per workshop. Each of the rows presenting a workshop is conditionally formatted using a scale bar indicating which theme was most prominent in discussions. Numbers associated with the bars present the number of codes assigned to challenges during thematic analysis.

multi-hazards risks had the most prominence in workshops, indicating that these are the two core groups of challenges. It is worth noting that the nature of the challenges mentioned in the workshops was influenced by: a) the participant selection for the workshops (i.e., discussion with different stakeholder profiles might have yielded additional challenges), and b) the unique sustainability issues in the pilots (presented in Section 2). For instance, in the Danube Region, where the focus was on regional risk management, participants were primarily representatives of organisations with regional interests, reach and influence, which meant that discussions were often revolving around the challenges of regional disaster risk governance and associated challenges. On the contrary, in the Veneto pilot, the spatial scale was much smaller, and discussions were of a more technical nature.

Our findings indicate that challenges for multi-hazard risk management can have an implication across different phases of the disaster risk management cycle (Alexander, 2002) , including in mitigation and prevention (e.g., lack of multi-hazard risk assessment), preparedness (e.g., lack of knowledge of the spatial-temporal occurrence of multi-hazards), response (e.g., lack of communication and coordination across actors at different levels), and recovery (e.g., asynergies introduced in risk management of different hazards due to siloed working practices). Furthermore, it shows that the challenges identified are multi-faceted and manyfold, and require advancements across different spheres, including policy development and planning, changes in risk financing, cross-sectoral and participatory initiatives, information sharing, development of new scientific tools and approaches, and better data for risk assessments and risk-informed decision-making. Based on this, we propose that these challenges are interconnected and cannot be tackled in isolation. For instance, certain aspects of lack of knowledge on multi-hazard risks (e.g., socio-temporal characterisation of multi-hazard risks) can be partly explained (among other factors) by a lack of data of past impacts and occurrences of multi-hazard events, which can in turn be associated with siloed institutional practices (i.e., governance-related challenges). Furthermore, while recent studies have asked for a better scientific understanding of multi-hazard interrelationships and dynamics of risk components (i.e., exposure and vulnerability) (de Ruiter and van Loon, 2022; Simpson et al., 2021), which might result in more accurate multi-hazard risk assessments, this will have limited impact on decision-making and risk management on the ground without proper translation of science to policy and practice. Translating scientific knowledge into action is inherently complex, as shown for instance in research on climate change (Livingston and Rummukainen, 2020; Naustdalslid, 2011). Even with the latest scientific findings informing policy and practice, the impact would still be limited if the governance structures and processes that would allow for better interagency collaborations are not put in place (e.g., clear responsibilities, and shared budgets). A recent report on the Mid-Term Review of the Sendai Framework for Disaster Risk Reduction 2015–2030 identified governance gaps as one of the key bottlenecks for reaching the goals and targets of the framework (International Science Council, 2023). Our workshops were designed to identify the main challenges faced by European stakeholders for moving towards multi-hazard risk assessment and management, and did not dwell into connections between challenges, which we argue is an important frontier for further research and development of multi-hazard risk management strategies.

Previous research on challenges for multi-hazard risk assessment and management primarily focused on the risk analysis/assessment aspects (e.g., Kappes et al., 2012; Kreibich et al., 2014; Wang et al., 2020). However, much less emphasis was put on the governance of multi-hazard risks, which is a relatively recent area of disaster risk governance (Komendantova et al., 2014). Scolobig et al., (2014), for instance, analyse multi-hazard risk governance in Naples and Guadeloupe and identify interagency communication and cooperation and science-informed policymaking as core challenges. In their follow-up research in Italy and Guadeloupe, they further find that a lack of clear responsibility in the context of multi-hazard risk is hindering progress (Scolobig et al., 2017). Building on these findings, our research further explores governance failures and uncovers additional governance challenges. For instance, Alam and Ray-Bennett (2021) identify as core dimensions of good disaster risk governance the following: accountability, participation, collaboration, transparency, information sharing, communication, shared decision-making, leadership, and shared resources. Our results indicate that in the context of multi-hazard risk governance in Europe, there are various issues across all of these dimensions (e.g., no clear responsibility for multi-hazard risk leading to the lack of accountability and lack of stakeholder participation).

The importance of scale is another aspect that featured strongly in our results. By scale, we refer both to spatial and governance scales (e.g., local, national, to regional), and scale of risk analysis when considering multiple hazards, their interrelationships, and the progression of exposure and vulnerability in multi-hazard risk scenarios. For the latter, challenges of risk assessment and management become more complicated and complex when moving from single to multi-hazard risk. Transitioning from single to multi-hazard risk, for instance, requires data and methods harmonisation (Wang et al., 2020), and the consideration of synergies and asynergies of risk management measures (Ward et al., 2020; de Ruiter et al., 2021). In terms of multi-hazard risk governance, it requires collaboration and cooperation between institutions that typically do not engage with each other, policy development and guidelines to steer the cooperation, and identification of clear responsibilities. All of these become increasingly complex when thinking of multi-hazard risks as regional issues, as our experiences from the Danube, North Sea, and Scandinavia pilots show. For instance, in these pilots, participants pointed out the complexities of risk management at the regional scale, including a number of institutions with a stake in risk management, different priorities between countries, and complex institutional and policy landscapes. Yet, disaster risk management is inherently a transboundary issue as natural hazards know no political borders (Booth et al., 2020). In the context of multi-hazard risks, this becomes even more prominent; for instance, the Danube Basin experienced compound flooding in 2002, while eastern and central Europe experienced concurrent heat and drought extremes in 2015 (Niggli et al., 2022). It is therefore evident that multi-hazards and resulting risks need to be dealt with from a regional perspective, especially when considering the indirect and cascading impacts of these events (e.g., on critical infrastructure or supply chains) (Hochrainer-Stigler et al., 2023).

Findings from our cross-European study highlight the importance of considering path dependency when dealing with multi-hazard risks, echoing recent work by Thaler et al., (2023) which argues that path dependence in risk management effectively hinders the management of multi-hazard risk in practice. Hanger-Kopp et al., (2022); p.2) define path dependency as ''*a process that has the property of staying on a particular path so that past decisions and contingent events pre-determine what further steps may be taken. Technologies, policies, or governance modes are locked-in. Self-reinforcing mechanisms contribute to their reproduction and diminish the range of likely alternatives.*'' A vast majority of the challenges identified in our study can be seen through the lens of path dependency. Stakeholders' adherence to traditional approaches, limited innovation in risk management practices (e.g., for nature-based solutions), the need for transitioning to new tools, and siloed institutional structures all reflect the influence of path dependency. As explained by Thaler et al., (2023), path dependencies frequently serve as a core obstacle to effectively adjusting to evolving risks in the future, consequently impeding the implementation of sufficient measures to reduce disaster risks. Based on the obstacles identified through the workshops, we argue that path dependency could be a crucial hurdle in moving from single to multi-hazard risk management, especially in terms of governance and the current practice of disaster risk management.

A need for multi-hazard risk management is increasingly gaining traction, and the scientific community is developing promising efforts and tools that could assist in overcoming some of the challenges. For instance, Gill et al., (2022) developed a handbook of multi-hazard, multi-risk definitions and concepts, aiming to bring conceptual clarity and provide clear definitions of core terms used in multi-risk assessment and management. Recently, a collaborative toolbox for multi-hazard risk assessment and management was developed (www.disasterriskgateway.net) as an information crowd-sourced platform that can enhance the knowledge of current terminology, concepts, and approaches for multi-hazard risk assessment and management. Furthermore, several frameworks for multi-hazard risk assessment and management have been recently proposed. For instance, Hochrainer-Stigler et al., (2023) present a conceptual six-step framework based on systemic risk thinking (e.g., Renn, 2021; Sillman et al., 2022) to aid the assessment and management of multi-hazard risks across scales, while Cremen et al. (2023) introduce a decision support environment for risk-informed development in urban areas, applicable to a range of natural hazards and across different decision contexts. In the context of planning under deep uncertainty, Schlumberger et al., (2022a) propose the Dynamic Adaptive Policy Pathway for Multi-Risk (DAPP-MR), guiding the development of forward-looking disaster risk management pathways that account for interrelationships between hazards and sectors. Further examples of recent development are the new open-source tool for characterising the spatiotemporal occurrence of multi-hazards proposed by Claassen et al., (2023) and the reclassification of historical datasets from EM-DAT from single to multi-hazards by Lee et al. (2024) , which could both bring much-needed clarity to the types of hazard interrelationships relevant to a certain geography. Moreover, there is a growing literature on various aspects of multi-hazard risk assessments, such as applications of different methodologies in specific geographical contexts (e.g., Tocchi et al., 2023, Mladineo et al., 2022), characterisation of vulnerability and associated dynamics in multi-hazard scenarios (Drakes and Tate, 2022; Albulescu and Armas, 2024), and enhanced understanding of multi-hazard impacts (Gentile et al., 2022). Multi-hazard thinking is also strongly featured in the EU Mission on Adaptation to Climate Change (European Commission, 2023b), where scientists work directly with up to 100 regions in Europe, supporting their risk assessments and adaptation planning. Similarly, there is a growing plethora of EU-funded projects focusing on multi-hazard risks, including PARATUS (www.paratus-project.eu) and TheHuT (www.thehut-nexus.eu). These initiatives could be a useful step in facilitating the translation of science into practice.

While technical understanding of multi-hazard risk assessment and management is a crucial step in changing practice on the ground, our paper argues that engagement with stakeholders in this process from the very onset is of paramount importance. As shown by our results, it allows for the identification of priority challenges, thus exposing links is the system where changes are most needed (e.g., establishing cross-institutional collaborations, increasing research funding for different aspects of multi-hazard risk assessment and management). However, it also serves as an avenue for raising awareness on the topic and creating a platform for bringing different actors together; for instance, in the Canary Islands and North Sea pilot, participants in the workshop pointed to a low awareness of the issues of multi-hazards and associated risks. On the other hand, it also aids in refining the objectives and tools for research teams, thus tailoring research towards outcomes grounded in locally specific priorities and needed solutions.

In this paper and our workshops, we focused on natural hazards in the context of multi-hazard risks. However, natural hazards cannot be viewed in isolation and often coincide with other types of threats, as their impacts compound. It is imperative also to take these into account when assessing multi-hazard risks. Examples include health emergencies such as the COVID-19 pandemic (Terzi et al., 2022) or conflict (Thalheimer et al., 2023). Furthermore, disaster risk management planning needs to be integrated into broader development objectives at national and sub-national levels (Lucatello and Alcántara-Ayala, 2022); for instance, a synergistic approach to implementing the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals (Roberts et al., 2015). Therefore, approaches for multi-hazard risk management should deliver multiple dividends beyond saving lives and avoiding losses, including unlocking economic potential and generating development co-benefits (Rözer et al., 2023; Surminski and Tanner, 2016).

5. Conclusions

While a need for moving from single-hazard to multi-hazard risk assessment and management is increasingly recognised, implementation of this shift in practice is challenging due to a relative novelty of the concept of multi-hazard risks and general complexity of risk management in a multi-hazard setting (e.g., due to a complex stakeholder landscape). Moreover, there is a general lack of understanding of stakeholders' views and needs on the ground in relation of multi-hazard risk assessment and management. To overcome this gap, and based on stakeholder engagement through five workshops (n=80) conducted across five European pilots (Danube, Scandinavia, North Sea, Veneto, and Canary Islands) and an expert workshop (n=62), this paper identifies five themes of challenges generated through a stakeholder lens. Prime challenges are related to the governance of multi-hazard risks and knowledge gaps hindering the very understanding of underlying multi-hazard risk creation processes. In addition, existing risk management approaches, inadequate translation of science to policy and practice, and lack of data significantly impede multi-hazard risk management. The challenges identified in this paper bring novel and rich insights into our understanding of obstacles for multi-hazard risk assessment and management in practice, especially in terms of drawing the attention to governance aspects of a problem, as knowledge to date primarily focused on the risk analysis and assessment aspects (i.e., ''technical'' challenges).

We argue that these challenges are inherently linked and cannot be tackled in isolation. Our paper further shows that multi-hazard risk assessment and management are influenced by the issue of scale, where risk analysis and governance get more complex when hazard interrelationships are considered and multi-hazard risk is viewed from a regional perspective. Furthermore, our results indicate that path dependency poses a significant hurdle in transitioning from single to multi-hazard risk management, specifically in governance and the prevailing approach to disaster risk management.

This paper focused on identifying challenges for multi-hazard risk assessment and management through a stakeholder's lens. However, it also highlights some of the emerging opportunities. For instance, it showcases the importance of including stakeholders' views to identify bottlenecks in current practices that hinder transition to multi-hazard risk management, raise general awareness of multi-hazard thinking, and to inform research agendas. In going forward, we identify promising approaches for overcoming some of the challenges, including emerging approaches for multi-hazard characterisations, common understanding of terminology, and comprehensive frameworks for guiding multi-hazard risk assessment and management. We argue for a need to think beyond natural hazards and include other threats in creating a comprehensive overview of multi-hazard risks, as well as promoting thinking of multi-hazard risk reduction in the context of larger development goals. Finally, we argue that the identified challenges shed light on the frontiers and directions in which improvements are needed, thus offering a valuable contribution to the existing knowledgebase.

CRediT authorship contribution statement

Dana Stuparu: Methodology, Writing – review & editing. **Melanie J. Duncan:** Methodology, Writing – review & editing. **Julius Schlumberger:** Methodology, Validation, Writing – review & editing. **Robert Šakić Trogrlić:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Timothy Tiggeloven:** Methodology, Writing – review & editing. **Marleen C. de Ruiter:** Methodology, Validation, Writing – review & editing. **Sara García-González:** Data curation, Methodology, Validation, Writing – review & editing. **Roxana L. Ciurean:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Remi Harris:** Data curation, Methodology, Validation, Writing – review & editing. **Phillip J. Ward:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Karina Reiter:** Data curation, Formal analysis, Investigation, Writing – review & editing, Methodology, Writing - original draft. **Tamara Lucía Febles Arévalo:** Data curation, Methodology, Validation, Writing – review & editing. **Silvia Torresan:** Data curation, Investigation, Methodology, Validation, Writing – review & editing. **María García-Vaquero:** Data curation, Methodology, Validation, Writing – review & editing. **Stefania Gottardo:** Validation, Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Investigation, Methodology, Project administration. **Javier Mendoza-Jiménez:** Data curation, Writing – review & editing. **Lin Ma:** Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Raúl Hernández-Martín:** Data curation, Writing – review & editing. **Anne Sophie Daloz:** Data curation, Investigation, Methodology, Validation, Writing – review & editing. **David Geurts:** Data curation, Methodology, Validation, Writing – review & editing. **Sharon Tatman:** Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Davide Mauro Ferrario:** Data curation, Validation, Writing – review & editing. **Noemi Padrón-Fumero:** Data curation, Investigation, Methodology, Validation, Writing – review & editing. **Stefan Hochrainer-Stigler:** Methodology, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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