BORIS

Cross BOrder RISk assessment for increased prevention and preparedness in Europe

D6.4

Lessons Learned

December 2022

Contributions by the following National Experts

Austria

Susanna Wernhart susanna.wernhart@dcna.at

Hannes Kern hannes.kern@dcna.at

Christian Resch christian.resch@dcna.at

Isabel Anger isabel.anger@dcna.at

Rainer Prüller rainer.prueller@dcna.at

Italy

Nicola Rebora nicola.rebora@cimafoundation.org

Maria Polese mapolese@unina.it

Barbara Borzi barbara.borzi@eucentre.it

Marta Faravelli marta.faravelli@eucentre.it

Gabriella Tocchi gabriella.tocchi@unina.it

Andrea Prota aprota@unina.it

Daria Ottonelli daria.ottonelli@cimafoundation.org

Montenegro

Ivana Cipranić ivanac@ucg.ac.me

Milena Ostojić milenao@ucg.ac.me

Jelena Pejović jelenapej@ucg.ac.me

Nina Serdar ninas@ucg.ac.me

Slovenia

Matjaž Mikoš matjaz.mikos@fgg.uni-lj.si

Simon Rusjan simon.rusjan@fgg.uni-lj.si

Klaudija Lebar klaudija.lebar@fgg.uni-lj.si

Mateja Klun mateja.klun@fgg.uni-lj.si

Matjaž Dolšek matjaz.dolsek@fgg.uni-lj.si

Anže Babič anze.babic@fgg.uni-lj.si

Grant Agreement number: 101004882 — BORIS — UCPM-2020-PP-AG

Project co-funded by the European Union Civil Protection

Jure Žižmond jure.zizmond@fgg.uni-lj.si

Nuša Lazar Sinković nusa.lazar@fgg.uni-lj.si

Turkey

Ela Doganay ela.doganay@tarimorman.gov.tr

Nazan Kilic nazan.yilmaz@afad.gov.tr

Filiz Tuba Kadirioğlu filiztuba.kadirioglu@afad.gov.tr

Mehmet Akif Alkan akif.alkan@afad.gov.tr

TABLE OF CONTENTS

Key words:

Civil Protection, decision models, earthquake engineering, earthquakes, exposure models, European Flood Directive, disaster risk assessment, floods, earthquakes, flood hazards, seismic hazard, flood risk, seismic risk, flood risk management, seismic risk management, hydraulic engineering, earthquake engineering, infrastructure, National Risk Assessment, population, residential buildings, hazard maps, risk maps, risk reduction, strategies, Union Civil Protection Management, vulnerability models

1. SUMMARY

The present document describes the lesson learned during the BORIS project ("Cross border risk assessment for increased prevention and preparedness in Europe – BORIS" (GA. 101004882), sponsored by Directorate-General for European Civil Protection and Humanitarian Aid Operations (ECHO). In particular are shown the lesson learned both from a methodological point of view and from an end-user perspective.

This deliverable is focused on providing a synthesis of all the choices made for developing a multi-risk approach, to combine flood and seismic risk in cross border areas, characterized by a high level of transferability and replicability to easily apply it in other cross-border areas across Europe. Moreover, the lessons learned are related to the approaches adopted

1) to obtain reliable methodologies to evaluate the single risks (earthquake or flood) and multi-risk in cross-border areas and
2) to provide results to be easily used in the pilot areas by Civil Protections and end-users involved in the Disaster Risk Management cycle. The aim is to provide a multi-risk procedure that help the end users in understanding the how the two different risks (earthquake and flood) can affect a specific area and which one is predominant.

For further details related to the approaches followed in the pilot sites activities also refer to the results reported in the deliverables D3.1 (BORIS, 2022a, focused on user requirements), D5.1 (BORIS, 2022c) and D5.2 (BORIS, 2022d) while in D4.1 (BORIS, 2022b) a detailed description of the methodology applied in BORIS is reported.

The structure of the document is the following: in section 2.1 are presented the lesson learned and limitations in the methodological approaches adopted for risks evaluation and comparison while in section **Error! Reference source not found.** the lessons learned are presented from the perspective of end-users in the pilot sites areas. I section 4 the way forward is presented while section 5 reports the final remarks.

2. Lessons learned and limitations in the methodological approach

In this section are reported the lessons learned in applying the methodological approach developed in WP4 to cross-border risk assessment, both considering the single hazards (seismic and flood) and their combination (multi-hazard), in the pilot areas (Italy-Slovenia and Slovenia-Austria).

2.1. Cross-border seismic risk assessment

To perform risk assessments in a cross-border region, harmonized models for hazard, vulnerability, exposure and consequences should be applied. Time-based risk assessment can be used to provide an unbiased risk assessment and the result can be expressed in terms of average consequences in a selected time window (e.g. average economic losses on an annual basis). Therefore, such results are directly comparable to the results of risk assessments for other natural hazards.

In the case that a hazard assessment is available for the entire cross-border area, the result can be used as a hazard model. Alternatively, a hazard model developed for a larger area can be used, such as the European Hazard Model (ESHM2020), whereas it needs to be noted that the ESHM2020 model is not as precise as the national seismic hazard models.

To perform a time-based risk assessment, an extended set of annual exceedance probabilities is needed, which is not represented by all models. For example, the ESHM2020 model provides PGA values only for return periods up to 5000 years. In such a case, interpolation and/or extrapolation of the hazard curves is required, which may result in a slight bias in the risk estimates. Future studies could focus on developing a hazard model specifically for the cross-border area under consideration. A limitation of many hazard models is that they only provide the hazard curves for rock-equivalent outcrop motion. Therefore, the effects of local ground must be considered by additional models. It is suggested to use one or more local maps with Vs30 values to account for local ground effects in the studied transboundary area. However, there is also the case that local Vs30 maps are not available and a global Vs30 map can be used.

The characteristics that can be used to assess the exposure of buildings include the material of the load-bearing structure, the number of storeys and the construction period. However, a more detailed classification can only be made if adequate data is available. Where two countries sharing a common border may have a similar historical and cultural background, so that their building stocks are similar enough to use the same building classification. However, the differences in building stocks may remain for political-economic or other reasons and in this case different building classifications can be used for the two countries. The exposure model for the housing stock could be improved by more accurate household-level data, especially for the Austrian municipalities, where some data have been based on expert judgement. Exposure data for residential buildings and population are more readily accessible than for infrastructure and other buildings, but these assets can have a significant impact on the overall seismic risk. Exposure is also dynamic, as e.g. the replacement cost of buildings is influenced by current construction costs. This limitation can be addressed by periodically repeating the risk assessment.

For a transboundary seismic risk assessment, the damage scale for exposed buildings should be aligned to obtain comparable results of the damage analysis. If the participating countries have different damage scales, a conversion to a combined damage scale is required and can be performed as described in section 3.2.3 of Deliverable 4.1 (BORIS, 2022a).

Exact vulnerability models rarely are available for the building stock of the region in which the cross-border study areas are located, as vulnerability models are usually developed for a larger area (e.g. for the entire national territory). In such cases, national vulnerability models can be used. Now, it may be the case that a national vulnerability model is only available for one of the neighbouring countries, which can be applied to the second. However, if a vulnerability model is available for both countries, a separate vulnerability model can be used for each sub-area if the building classes differ in the two neighbouring countries. However, if the buildings in the two countries are similar enough to use a common building classification, the two national vulnerability models should be harmonised. The BORIS project proposed a heuristic harmonisation approach where the vulnerability model in a cross-border area is defined as a linear combination of the two national vulnerability models. However, it is also possible that a vulnerability model does not exist for either of the two countries in the cross-border area. In such situations, global vulnerability models can be applied although these vulnerability models may be biased and the development of a region-specific vulnerability model could address this limitation.

2.2. Cross-border flood risk assessment

For the flood risk assessment in the cross-border regions, the work towards harmonization of methodological approaches in flood hazard assessment and further, flood vulnerability, exposure and risk should be intensified. The flood risk assessment procedure is standardized among the EU Member States by the EU Floods Directive (2007/60/EC), however various methods, models, platforms, and tools for each of the risk assessment elements can be find in the literature and are also applied in practice. In the following paragraphs, limitations and challenges for each of the elements of flood risk assessment, namely, hazard, exposure, vulnerability, are briefly summarized.

During the development of the BORIS methodology, one of the first challenges in cross-border flood hazard assessment was the definition of a common methodological approach that can be relatively easily applied in the two cross-border pilot sites and transferred in similar areas across Europe. The adoption of the official flood hazard maps provided by the partner countries (Austria, Italy and Slovenia) to fulfil the requirements of the EU Floods Directive (2007/60/EC) represented the best choice to ensure the replicability of the methodology. This approach also ensures that the used input data are consistent since the flood hazard maps produced in the framework of the EU Flood Directive will be continuously improved and refined by each Member State. However, this approach has some limitations and drawbacks that have been identified in scope of the BORIS project and properly considered while developing the methodology.

The first problem that we encountered while preparing the input data was the fact that neighboring countries use different flood return periods and different combinations of intensity parameters for the definition of the low, medium, and high flood hazard classes required by the EU Floods Directive. However, every project partner country uses 100-year flood return period in their national methodologies for flood hazard assessment. Therefore, this return period was identified as a good starting point for flood hazard assessment in cross-border areas. Since no additional flood hazard modelling besides the official publicly available data was done in the scope of the BORIS project, the problem of flood hazard assessment by considering different ranges of flood return periods was overcome by using a simple, yet effective interpolation procedure with 1-year return period time step. One should note that existing flood hazard maps are used as input data for this procedure, meaning that some potential hazard areas for which maps do not exist are considered not to be exposed to flood risk which is not necessarily true. Additionally, another limitation can be related to potential errors in interpretation of flood inundation modelling results while defining the flood inundation areas and flood hazard classes and further, in possible discrepancies in the flood area extension in cross border areas which should be identified a priori. However, one of the greatest advantages of this methodology is that it can be applied in similar cross-border areas in other EU countries and could provide important initial information on flood hazard which could be afterwards upgraded by more detailed flood hazard analysis.

The next part of the flood risk assessment is identification of exposed elements which includes interaction with areas exposed to flood hazard and quantification of assets (i.e., number of assets and their value). To make an exposure analysis, information about spatial distribution of assets have to be known with a certain spatial resolution. According to the data availability assessment in different project countries, in scope of the BORIS project, it was decided that for the flood exposure assessment, global data as well as local data on the exposure elements were used. This was done to improve the exposure analysis, which would be more uncertain if only global datasets were used. However, the local data from different countries had to be harmonised before further analysis to ensure consistent implementation in different countries. In case of floods, the extent of flood water and water pathways greatly depend on the topography and the vulnerability further depends on the presence of exposure elements inside the areas exposed to floods (e.g. number of people, buildings, important or critical infrastructures, etc.). Therefore, one of the possible ways for improvement of the BORIS methodology for flood risk assessment is to incorporate more detailed data on exposure elements with the consideration of possible limitations related to GDPR directive. In this way, the spatial scale of risk assessment, which was in BORIS project selected at the municipality level, could be improved. Regardless of the attractive idea to upgrade the methodology to a very detailed spatial scales, the implementation is highly dependent on the data availability and harmonization (which is potential problem in cross-border areas) and will be undoubtedly also much more demanding in terms of practical application.

Flood vulnerability describes the susceptibility of an individual element to flood damage and is dependent on the hazard intensity as well as element's characteristics. Dependence of vulnerability to specific characteristics of flood hazard events is usually described by vulnerability/damage curves. For the development of such curves, several approaches can be found in the literature resulting in relative or absolute damage functions. In the BORIS project, the evaluation of flood risk was especially focused on residential buildings and population as the most crucial vulnerability elements identified in the study cross-border areas. Since the main subject of the risk analysis for both floods and earthquakes are buildings, one should note that the developed BORIS methodology may underestimate the expected annual losses by not taking other vulnerability elements into account (e.g., cultural heritage, economic activities, environment etc.).

In the future, the methodology could be upgraded and improved by using flood hazard scenarios related also to probability of flooding instead of accounting just the selected flood hazard maps for few defined return periods. Such fully-probabilistic approach could further affect also calculation of vulnerability and consequences for different elements at risk that are defined by direct and indirect losses. If data about previous flood events and related flood damage are available, vulnerability functions could be improved by better differentiation of exposed elements and by accounting local factors more in details (e.g., construction types).

2.3. Cross-border multi-risk assessment

As discussed and explained in Deliverable 4.1 "Guidelines for cross-border risk assessment: Shared framework for single and multi-risk assessment at cross-border sites" – D4.1 (BORIS, 2022a) the multi-risk assessment within BORIS was performed within a multi-layer single risk assessment for each one of the risks impending on the transboundary area, namely seismic risk and flood risk, that were previously harmonized to allow consistent cross-border risk assessment for confining countries. The risk curves were adopted as standardization scheme within the methodology; moreover, to allow consistency in the comparing and ranking the different risks, the same boundary conditions were applied in

a) the selection of the study area and spatial scale of risk results evaluation and representation
b) the time-frame of analysis within the time-based assessment adopted to evaluate the risk curves for each risk and

c) the metric to express the risk.

Several issues and limitations in the methodology were already evidenced in D4.1 concerning in particular the spatial scale of assessment and the approach for evaluation of the consequences related to the adopted metric, namely direct economic losses and affected population, as briefly reported here.

For the spatial scale, although the optimal scale for risk analysis concerning the different hazards can be different, e.g. for flood risk the building footprint scale is preferrable while for seismic risk a larger scale can be adopted, e.g. the municipality scale, a final (uniform) scale of assessment – the municipality scale - was chosen to allow results comparability. This choice also simplifies the problem of data availability; however, as observed in D4.1, it hampers the possibility to perform more refined risk studies, allowing to determine more accurately the areas within a municipality that are most prone to the considered risks and/or to organize the response capacities in a town-level planning.

Concerning the metric for risk assessment, both seismic and flood risk allow the evaluation of consequences in terms of affected population and direct economic losses. For the affected population it is quite hard to establish a common meaning of such indicator, especially because of the different type of the hazard and its impact on the nature and built environment. As a matter of fact, in the flood risk domain the affected population is generally associated to the inhabitants residing in buildings affected by the flood hazard; on the other hand, for earthquake the effects on population are evaluated in terms of injured/deaths and displaced people (for short or long term). Collectively, all those indicators could be grouped to evaluate the "affected population" due to earthquake but the meaning of such indicator would be very different from the one for floods. While it would be theoretically possible to employ consequence model to derive expected number of injured/deaths also for floods, the level of matureness of such model is quite different from the one of earthquake since the studies devoted to evaluate the factors that determine the loss of life or injuries caused by flood events are quite scant.

Concerning the evaluation of direct economic losses, the consequence functions for earthquake and flood use different parameters. In fact, for earthquakes the monetary losses are calculated with a function that suitably considers the repair costs associated to different damage levels of the EMS98 scale while for floods the expected monetary losses are derived by simply multiplying the expected damage, roughly represented as % of (overall) damage on buildings or contents, by the replacement cost. As observed in D4.1, further efforts could be devoted towards most effective harmonization of such consequence functions, e.g. by introducing a more refined graduation of the damage scale due to flood and by assigning percental incidence of repairing each damage level with respect to the replacement (reconstruction) cost, similarly to what is done for the case of seismic risk.

In addition to the previous methodological limitations, it has to be recalled that the multi-risk assessment performed within BORIS allows comparison of risk in terms of direct economic losses evaluated with reference to the sole residential type buildings. Nevertheless, it should be reminded that damage or more generically disruption to other type of constructions, e.g. non-residential type buildings or infrastructures, lifelines or environmental assets, as well as the damage or loss of building contents, could contribute significantly to the direct losses. Therefore, future studies should attempt to also consider these elements in computation of the impact due to different hazards and for their exhaustive comparison. The full comprehensive assessment, then, should also include the estimation of indirect losses.

Besides methodological limitation, another relevant issue was encountered in the application of the methodology, in particular for the definition of a consistent integration interval for the computation of expected annual loss as area under the risk curve expressed in terms of direct economic losses. Because the portions of the risk curve providing a major contribution to overall losses are different for the two risks it was decided to extend the integration interval as much as possible to avoid omitting relevant contribution either in the short and in the long period range. However, some limitations apply, as discussed next.

The hazard curve available and employed in the calculation for seismic risk is provided for 6 return periods Tr ranging from 50 years to 5000 years (ESHM20 – Weatherill et al., 2020) while the hazard curve for flood risk (derived applying the interpolation procedure described in D4.1) provides the flood extension and depth (at relevant locations) for Tr in the range 20-300 years. Concerning the possible extension of the hazard curve for seismic risk computation in the lower period range it was decided to avoid it, since in the regions of interest, i.e. at the Italian-Slovenian border as well as Austria-Slovenia border, the PGA corresponding to Tr 50 years is lower than 0.03 g. According to (Dolce et al., 2021) 0.03 g is the minimum value of soil acceleration for which damage could be expected for any type of building type and lower PGA should not be included in calculation to avoid excessive incidence of high probability and very low consequence intensities in the computation of damage and related losses, which can bring total resulting losses to raise indiscriminately. Concerning the extension of the hazard curve for Tr> 5000 years it was deemed significant since events with low probability but high consequences such as earthquakes with Tr >5000 years could significantly contribute to overall risk. In such case, the hazard was obtained adopting the following formulation, also used for computation in the IRMA platform (Borzi et al., 2021):

$$\log_{10} p_a = -b \cdot PGA^k$$

where p_a is the mean annual frequency of exceedance of PGA and the parameters *b* and *k* are defined imposing that the curve will pass from the first and the last return period available in the given hazard curve (in this case 50 years and 5000 years).

As for the flood hazard curve it was not necessary to extend it in the lower periods range, since it already considers relatively frequent events (minimum Tr being 20 years). For what concerns the higher return periods it was hypothesized that the level of flood extension (flooded area) and flood depth considered for the maximum return period available in the hazard curve (that is 300 years) already saturate the maximum values that could be expected in the area under investigation; therefore, for higher return periods and for the limited area investigated the losses do not show relevant increase and the risk curve is almost a vertical line already in correspondence of the losses computed for Tr=300 years. Moreover the statistical evaluation over Tr=500 years are affected by a very high level of uncertainty that makes uncertain the related hazard and risk evaluations.

These assumptions for the extension of the hazard curves allowed to compute the expected annual losses referring to a consistent interval of Tr for the two hazards.

3. Lessons learned from the demonstration activity

Another important activity and result obtained by the BORIS project was that related to the demonstration activities aimed at the collection of feedbacks from national end-users involved in the DRM cycle. The process of collecting user requirements and stakeholder feedback allowed to identify and refine the functionalities of the methodology and tool. To tackle end-user needs and interests in the BORIS project, requirements have been collected in two steps in the begin of the project (D3.1, BORIS 2022a). First, the project partners defined the potential end-users for each country and identified some user requirements. In a second step, a 15-question interview guide was developed to contact 21 experts (11 male and 10 female) from five countries were interviewed. The detailed results are outlined in D3.1 (BORIS, 2022a) wherein the following points can be stated to summarise.:

- Risk maps with simple coloured representation of areas with high, low, no risk were mentioned as information's source that helps to optimize prevention and preparedness especially in cross border areas.
- Impact scenarios, that show in detail the affected assets (buildings, people, infrastructure), are considered important by most of the experts to be able to compare the risk for flood and earthquake in terms of costs and human victims to allow strategic choices for a region.
- For the emergency phase, information is required to understand where help is needed and how to plan the routes. The respondents point out that the data must always be kept up to date to be usable.

Moreover, the BORIS project foresaw stakeholder workshops and national trainings on methodologies, results presentation and an demonstration activity on the digital platform usage to ensure active exploitation of the project results through the involvement of end-users and stakeholders. BORIS stakeholders are national and local civil protection units as well as local administrations.

The first workshop organized by DCNA from Austria took place on 22-23 June 2022 in Vienna, Austria and the second workshop organized by the University of Ljubljana took place on 19-20 September 2022 in Ljubljana, Slovenia.

The stakeholders during the **Vienna Workshop** outlined:

- the advantages of cross-border harmonization and risk ranking
- the added value of the transferability of developed methodologies to other cross-border regions
- that there are occurring needs due to different data availability
- that there might be a need to integrate social aspects to risk assessment
- that it would be necessary to expanding the platform, including infrastructure data, and calculating cascading effects in the multi-risk assessment.

A detailed wrap-up of presented outcomes of the group discussion activity can be find in D6.2.

On November 11th, the **first project training** took place at Landeswarnzentrale Steiermark (Styrian warning center) with representatives of the Administration for Civil Protection and Disaster Relief from the federal state of Styria. After a project introduction and showcasing the platform, the group went into an in-depth discussion of the project results and open questions.

The presentation of the BORIS methodology and relative results stimulated a discussion from which several reflections emerged:

- The resolution of the Boris results, i.e. at the municipality level, is very suitable for the regional development of measures in the field of disaster management. However, for local planning, mayors need more detailed information about which areas of the municipality are at risk and to which extent. It was obvious to the experts why the municipality level was chosen for the analysis in the BORIS project, as most of the data is available. However, it would be seen as an interesting approach to make the risk assessment for an entire region and to overlay the municipality boundaries only later in the visualisation.
- The project is considered to provide added value, because Styria wants to go into depth in civil protection planning and a risk analysis tool could have a correspondingly supportive effect here. The usability for the municipal level could still be elaborated. Here, it is interesting for the mayor to know into which risks and appropriate preventive measures he should invest. The analysis would be particularly interesting for prevention at the household level.
- During a disaster itself, it is important from a civil protection perspective to know how many lives are affected and to be able to quickly intersect current data. In addition, the tool can help in planning with regard to the division of resources and assistance.
- Especially for cross-border regions it would be helpful if the regional and/or local responsibilities for civil protection / disaster management were directly visible in the BORIS platform. The experts expressed concern about in which way and on which level (regional or national) a tool like the BORIS platform should be implemented and how such a tool can be legally established.
- The experts pointed out that exercises (table top) are extremely valuable, particularly in civil protection, and that awareness can be created only through such activities. This should be considered in a follow-up project.

At the beginning of December, the **second project training** with the stakeholders was organized in the **Italian-Slovenian border**. In particular two days of meetings, seminars, training and field visits for a better knowledge of the Civil Protection System and its activities in the Autonomous Region of Friuli Venezia Giulia have been conducted together with the presentation of results of the EU BORIS Project for risk assessment in the cross-border area. During this workshop, there were: representatives of the University of Udine dealing with the topic of Disaster Risk Reduction (DRR) and Resilience, in particular on situational safety management, focusing on seismic risk, safety and environmental protection, securing interventions in emergency situations; several officials of Civil Protection of the Friuli Venezia Giulia Region; researcher from OGS (National Institute of Oceanography and Applied Geophysics); an official from one of the most important cross-border municipalities, Gorizia.

The presentation of the BORIS methodology and relative results stimulated a discussion from which several reflections emerged, resulting in the outline of the following lessons:

- It would have been interesting to explore in more detail the role of BORIS results in the different stages of the Disaster Risk Management (DRM) cycle: prevention, reduction, preparedness, response and recovery. Surely, BORIS is an essential tool for the prevention and preparedness, for which the probabilistic risk analyses performed could be adopted to update territorial plans for both updating urban and emergency planning, and also make them more effective, as a way of reducing damage and losses from extreme natural disasters and reducing the need for emergency aid;

- Still concerning the adoption of BORIS results it is emphasized how they are appropriate for studies for example of insurance type or otherwise to highlight the most critical municipalities for each risk and multi-risk results, but that it could be useful for stake-holders to implement the possibility of defining future scenarios or past scenarios, in addition to consider the hazard maps that are the envelope of all possible events with that return period. For the flood hazard, the future step could be the generation of all possible flood events that can affect the area of interest (as described in detail in the §4.2), in fact the hazard maps provide water levels in flood prone areas for different return periods but they do not represent flood events. A flood event or flood scenario usually affects only a portion of the country. Aim of the flood scenarios generation is the simulation of all the possible events that can affect different areas of the region with different intensities. Naturally, there are two ways of development this front: the first is to visualize the scenarios as hazard maps and the subsequent risk evaluations, but these were calculated externally to the platform; the second is to be able to implement the evaluations directly in the BORIS platform, using the hazard maps, the scenarios, the exposure models as input and thus perform the damage and loss evaluations. In order to assess damage scenarios for earthquake event directly within the platform, a tool could be set up that accepts as seismic input (i) shakemap, or (ii) epicenter of the earthquake, or (iii) geometry and characteristics of the fault that was triggered. Shakemaps are usually produced by research institutions that deal explicitly with seismic hazard (in italy this is INGV- National Institute of Geophysics and Volcanology). It is then possible to find shakemaps of past events and use them to make damage scenarios based on historical events. On the other hand, modelling seismic input with epicenter or fault also involves the selection of a GMPE (Ground Motion Prediction Equation). Damage scenarios with this type of seismic input are usually used in the planning of emergency management.
- As described in the previous section, for the cross-border flood risk assessment, the first activity was to obtain homogeneous hazard maps (for the same return periods) that can be used for risk mapping having as input not homogenous maps of flood prone areas (different return period and without the associated flood depth, see D4.1). A simplified approach to assess flood harmonized hazard curves in cross-border basins is proposed and starts from the results of the EU Floods Directive. Local stakeholders are interested in understanding if the flood hazard maps and the associated risk curves obtained with the methodology applied in BORIS can be directly compared with real time-flood hazard scenarios that can be obtained for hydrometeorological forecasting chains. However, even if the two approaches are different, event-based studies representing the local flood risk associated to specific flood events can be compared with maps produced for the EU Floods Directive. This is done with the aim of evaluating if the real-time flood hazard maps are contained within the envelope of possible flood scenarios defined by the UU Floods Directive for the same return period.
- For what concern the seismic hazard, the soil map for Italian municipalities comes fro m Mori et al. (2020) can be updated with the regional map and consider related local amplification values;
- A validation phase on different municipalities could also be proposed in the methodology, especially for the results on multi-risk being very innovative elements, comparing the losses predicted in the

platform and the historical ones occurred in the city. This can be conducted through the analysis of post-event damage data (for the seismic risk Da.D.O. (Database of Observed Damage) proposed in Dolce et al. (2017) or for the other hazards Disinventar (https://www.desinventar.net/DesInventar/inv/resultstab.jsp)) and/or by comparing with affected municipalities, such as Gorizia, which has shown interest;

- It is important to introduce and understand the effectiveness of individual measures in terms of flood mitigation impact when considering structural and non-structural solutions for flood. These types of interventions can affect the elements of the risk equation differently, especially hazard and vulnerability. For example, structural flood mitigation is where physical structures are constructed or modified to reduce the impact of flooding on individual properties or whole catchments; this type of strategy acts directly on hazard, and therefore to perform the risk assessment following the intervention it is necessary to redefine the different hazard maps for each return period. On the contrary, for seismic risk, most of the interventions affect the exposure associated with a different vulnerability.

4. Way forward and issues to be tackled

The field of risk assessment is constantly evolving. The advancements in the field include methodological developments and acquisitions of new data. The following paragraphs present the areas of progress that can benefit cross-border risk assessment as performed within the BORIS project. Some of the proposed modifications to the BORIS risk assessment approach may require additional research. In contrast, others are related to utilizing existing tools or modifications to the legal framework and administrative structures.

4.1. Seismic Hazard

One of the areas that can be improved in the future is the modelling of seismic hazard. Current hazard models partly consider region-specific data by basing the analysis on the regional seismotectonic model. However, some local effects are disregarded by using ergodic ground-motion models, which are developed based on aggregating global ground-motion data. Recently, different methodologies for developing non-ergodic ground-motion models have been proposed (e.g. Lavrentiadis et al., 2022). Such models are developed based on local ground-motion recordings and allow the introduction of systematic local effects into the seismic hazard analysis. This includes the source effects related to the average stress drop of earthquakes in the region, site effects related to the crustal velocity structure in the region, and path effects related to the inelastic attenuation of ground motions in the region. Non-ergodic ground-motion models have not yet been implemented in official seismic hazard models. However, in the upcoming years, they are expected to become more and more developed and can significantly change the estimated seismic hazard in a region. They can also be used to identify potential seismic hazard variations from one municipality to another, which cannot be captured using ergodic ground-motion models. It is therefore proposed that future efforts are directed towards improving seismic networks for obtaining ground-motion recordings, which can facilitate the development of non-ergodic ground-motion models. In addition, more focus could be put on obtaining data used to predict local soil effects on ground motions. The most feasible way forward in this area is probably to develop approximate regional

Vs30 maps. However, more comprehensive investigations of local soil conditions can provide additional data (e.g. entire Vs profiles) that allow more advanced modelling of the soil effects.

4.2. Flood Hazard

This section deals with the generation of a risk profile characterization, that can be seen a project development, as suggested by the lesson learned from the demonstration activity (§3).

To develop a risk profile, it is necessary to refer to hazard maps and the hydrological data used as input information for the hazard maps generation. The hydrological data are fundamental for the scenarios generation and the use of the same data used to derive the hazard maps assures the consistency of the results.

The flood events generation process needs to have a higher discretization of hazard maps: this because the flood generator can simulate events with all possible return periods. So the hazard map available has to be interpolated. The interpolation method starts with the computation of the total volume of water for each of the original maps. In order to obtain the maps at intermediate return periods, for each couple of consecutive original maps (e.g. 10-20, 20-50, etc.), the filling of a virtual reservoir can be simulated, in which it can be imposed that the minimum filling corresponds to the lower return period map (for example 10 years) and the maximum filling corresponds to the higher return period (for example 20 years). Then, the Return Period – Total Volume curve, previously interpolated, is imposed in order to keep the correspondence. In this way, the maps can be interpolated between the original ones, the curve of total volume (always increasing with return period) is respected, and the monotonicity of the water depth at each return period can be guaranteed for every single cell of the maps.

The next step in the risk profiling chain is the generation of all possible flood events that can affect the area of interest: the hazard maps provide water levels in flood prone areas for different return periods but they do not represent flood events. A flood event or flood scenario usually affects only a portion of the country. The distinction between flood map and flood scenario is fundamental: flood risk estimates only based on flood maps are reliable if the area of interest is relatively small but, if the area is wide, it is necessary to generate all possible flood scenarios that can affect the area of interest with their probability of occurrence. Aim of the flood scenarios generation is the simulation of all the possible events that can affect different areas of the region with different intensities. To simulate possible flood scenarios the output of the GloFAS-Reanalysis v3.0 (Harrigan et al. 2020) (discharges in different locations of the river network) was analyzed to select independent flood events. The methodology that can be employed for the events generation relies on a multivariate statistical approach that takes in input the selected events and, by preserving their spatial correlation, it is able to simulate events not yet observed both in terms of intensities as well as geographical distribution. The approach used for the events generation covers all the possible range of intensities and spatial dependencies and assures that:

- the spatial correlation of small- and large-scale events is preserved in the simulated event set;
- the statistical properties of the observed events at each location are preserved in the simulated event set.

The scenario generation process consists of two components: the first one is the event definition and selection and the second one is the probabilistic events generation. The event selection is based on a consolidated approach already applied and tested in some countries that balances the need of capturing small scale events and the limited computational resources during the flood generations process.

The entire area is divided in hydrological units: the event selection process allows to identify localized events affecting only one unit and more distributed ones affecting several units contemporary. These events, characterized by their maximum discharge over the event duration for each hydrological unit, are the basis for the probabilistic scenarios' generation.

The approach is based on a probability domain perturbation of the selected flood events via a multivariate gaussian distribution and uses a gaussian transformation in the probability domain to improve the representation of the tail dependencies and overcome boundary issues.

The algorithm consists of multiple steps:

1. each event is expressed in terms of maximum discharge during the event window: each hydrological unit has its own probability distribution of the selected events. Aim of this first step is the selection of the probability distribution that best fits the discharge sample of each hydrological unit;
2. The simulated flood event should be generated by a multivariate gaussian distribution with mean equal to the probability assigned to each discharge for all the hydrological unit (the ones calculated at step 1);
3. Each transformed event trough the inverse of the normal CDF becomes the centroid (mean) of a multivariate gaussian distribution that will be used to generate possible flood events. The covariance matrix of the multivariate gaussian is a function of the number of events and of the hydrological units;
4. The simulated samples will be anti-transformed by applying a normal cumulative distribution and then transformed back in discharges through the inverse function of each specific marginal distribution (the ones fitted in step 1);
5. Each event, expressed in terms of discharge in each hydrological unit, will be converted in return period to link the discharge to the corresponding hazard map in order to identify the flooded areas and the corresponding water levels.

The scenarios generation allows to simulate events not observed yet. The simulated event set is tested to assure that the marginal distributions (the distribution of the discharges of the selected flood events for each hydrological unit) are preserved during the simulation process.

The output of the scenario generation process is a flood event catalogue covering approximately 300 years. Each event will be characterized by its intensity expressed in terms of return period. This event catalogue, together with the hazard maps for different return periods are the input data for the risk calculation.

4.3. Exposure models

Another area where improvements can be made is the exposure model. The latter could be expanded by assets that were disregarded in the BORIS pilot applications but can significantly affect the overall risk. Such assets include non-residential buildings and infrastructures. Adding these assets can be difficult if their data is unavailable but otherwise simple.

Therefore, one of the first steps proposed for future studies is to check what data on non-residential buildings and infrastructures is currently available and include that data in the exposure model. However, the exposure model can also be improved by refining its spatial scale and level of detail. The spatial scale, as currently considered, does not allow to consider variations in the exposure throughout a municipality. Such variations can be captured if upgrading the spatial scale to sub-areas of the municipality, e.g. town compartments or census tracts, or even to the single asset level (e.g. building) level. However, improving the level of detail would require including additional exposure parameters. For example, in the case of buildings, one exposure parameter that would benefit the precision of the seismic risk assessment is the type of the load-bearing system (e.g. wall, dual, frame). The availability of such parameters would allow a more refined classification of assets, which is also necessary for establishing a more refined vulnerability model. These types of upgrades to the exposure model inherently increase the model's complexity and should therefore be made systematically and harmonized, meaning that the exposure data structures of different regions would be consistent. Moreover, the model should be systematically updated because a part of the exposure data evolves rapidly. Such developments could be done in the frame of a European exposure model that would offer standardized open data. However, refining the exposure model can be problematic from a legal point of view. Finding ways to upgrade the exposure model without violating data protection rules remains one of the issues to be tackled. As new approach, exposure should be regarded as a dynamic process, as best exemplified by rapid urbanization, depopulation of rural areas and all of the changes associated with the actual evolution of the settlements themselves. In fact, the Intergovernmental Panel on Climate Change (IPCC) state that "effective risk re-duction and adaptation strategies consider the dynamics of vulnerability and exposure and their linkages with socioeconomic processes, sustainable development, and climate change" (IPCC, 2014).

Further developments can also be made in the modelling of seismic vulnerability. The vulnerability models used in the BORIS project were defined based on national vulnerability models developed for the entire national territory, where the changes in the typology of assets are greater than in a specific region within the country. This issue could be addressed by developing region-specific vulnerability models; the Cartis approach adopted in Italy to account for local building typologies seems a useful tool to facilitate such process (Zuccaro et al., 2015; Tocchi et al. 2022). Such models would include fewer uncertainties because the asset parameters would have a lower dispersion. Consequently, the beta values of the fragility functions would be reduced, and the medians of the fragility functions would be shifted (to a lower or a higher value). A region-specific vulnerability model would be especially beneficial in the case of a cross-border risk assessment because the asset typology can differ more significantly from the national average due to the vicinity of a neighbouring country with a different cultural background. However, developing any vulnerability model is not straightforward, as no standardized approach to seismic vulnerability assessment has been developed thus far. There are several different approaches that are used in different countries, including analytical, empirical and combined approaches, which do not result in the same outcome. In the future, extensive effort is required to develop a standardized European methodology for seismic vulnerability assessment, analogously to that addressing the seismic hazard assessment. For the flood part, as for the exposure, vulnerability can be conceived with its dynamic nature, mainly related to socioeconomic change and adaptation measures.

Possibilities for future advancements can also be found in the modelling of the consequences of earthquakes. This includes introducing consequence functions for additional impact indicators. For example, the downtime of public services and businesses due to damaged assets is an important impact indicator that can be used to describe indirect seismic losses. It can also be used as a basis to further model cascading effects of earthquakes on the economy (e.g. Sousa et al., 2022). However, even the consequence function considered in the BORIS project could be further refined. Within the pilot applications (BORIS, 2022c), it was assumed that a given damage state causes the same consequences in terms of normalized economic losses, normalized casualties and unusable buildings, regardless of the regional characteristics or building typology. Further studies are needed to explore these effects.

4.4. Multi-hazard risk assessment

However, further developments can also be made to the methodology for risk assessment itself, not related to any specific model discussed in the paragraphs above. In particular, the BORIS methodology disregards the uncertainties in losses at a given earthquake and flood return period. This simplification of the risk assessment does not affect the accuracy of the expected annual losses, which are the final outcome of the risk assessment. However, by estimating the uncertainties of losses, the stakeholders would receive another valuable piece of information that can be useful in decision-making. For example, in the case of seismic hazard, the uncertainties in losses could be estimated by simulating all possible earthquake scenarios defined by the hypocentre and magnitude, estimating losses for those scenarios and aggregating the losses (e.g. Silva et al., 2014). Such an approach would be more complex than that used in the BORIS pilot applications (BORIS, 2022c), where the variation in earthquake scenarios is already considered in the seismic hazard model and does not need to be explicitly simulated in the estimation of losses.

5. Final remarks and conclusions

The approach adopted in BORIS can be seen as a “minimum standard” in facing the issue of multi-risk evaluation in cross-border areas. The approach followed was focused on the replicability and transferability of the methodological approach to other cross-border areas in Europe. For this reason, we decided to resort to the use of the most homogeneous and widely available datasets and procedures.

Starting from assessment of NRA performed in the different MS and partner countries the approach followed in BORIS was aimed at defining a set of procedural and technical standards for homogenizing risk assessments provided by different countries in cross-border areas. For this reason, all the countries within the UCPM can directly benefit from the outcomes of BORIS for what concerns the standards for comparing risk assessment procedures both considering cross-border and cross-risk situations. Also, IPA countries (as expressed by Montenegro and Turkey in deliverable D5.2) can be involved in the process as potential end-users interested in cross-border disaster risk assessment. Moreover, the approach followed in BORIS represents an example of how the NRA performed in each MS and partner country can be standardized, compared and merged for defining homogeneous single-hazard (earthquake and flood) and multi-hazard risk maps across Europe.

The methodological approach developed in BORIS can be followed by any country that is interested in sharing and comparing seismic and flood risk as well as performing simple but reliable comparison of how these two risks are affecting the same area (both in the same country or in cross border areas). Moreover, the open-source platform developed in BORIS has received good feedback, from the end-users during the different project meetings and workshops of the projects, as tool for visualizing sharing and comparing its NRA procedures, data, results and good practices.

The BORIS platform can be potentially further developed by DG-ECHO to support the NRA in each MS or to be integrated in the Disaster Risk Data Hub. The methodological and applied results of BORIS results can also be linked to other infrastructures active in the macro-region composed by countries participating to BORIS, in order to coordinate the identification of the end-users that can contribute to a standardized repository of NRA.

6. LIST OF REFERENCES

BORIS (2022a). Deliverable 3.1: Architecture of the Platform. Available at https://www.borisproject.eu/deliverables/

BORIS (2022b). Deliverable 4.1: Guidelines for cross-border risk assessment: Shared framework for single and multirisk assessment at cross-border sites. Available at http://www.borisproject.eu/wp-content/uploads/2022/06/BORIS-Deliverable-D4.1.pdf

BORIS (2022c). Deliverable 5.1: Seismic risk, flood risk and multi-risk assessment at pilot cross-border sites. Available at https://www.borisproject.eu/wp-content/uploads/2022/12/BORIS-Deliverable-D5.1-Seismic-risk-flood-risk-and-multi-risk-assessment-at-pilot-cross-border-sites_final.pdf

BORIS (2022d). Deliverable 5.2: Consolidated version of the guidelines for cross-border risk assessment. Available at https://www.borisproject.eu/deliverables/

Dolce M, Speranza E, Giordano F, Borzi B, Bocchi F, Conte C, Di Meo A, Faravelli M, Pascale V (2017) Da.D.O. – A web-based tool for analyzing and comparing post-earthquake damage database relevant to national seismic events since 1976. In: Proceedings of the 17th Italian Conf on Earthq Eng ANIDIS. Pistoia, Italy

Dolce, M., Prota, A., Borzi, B., da Porto, F., Lagomarsino, S., Magenes, G., Moroni, C., Penna, A., Polese, M., Speranza, E., Verderame, G. M., Zuccaro, G. (2021). Seismic risk assessment of residential buildings in Italy. Bulletin of Earthquake Engineering, 19, 2999–3032, https://doi.org/10.1007/s10518-020-01009-5.

IPCC, 2014. Summary for policymakers. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergov- ernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–32.

Lavrentiadis, G., Abrahamson, N.A., Nicolas, K.M., Bozorgnia, Y., Goulet, C.A., Babič, A., Macedo, J., Dolšek, M., Gregor, N., Kottke, A.R. and Lacour, M., 2022. Overview and introduction to development of non-ergodic earthquake ground-motion models. Bulletin of Earthquake Engineering, pp.1-30.

Silva, V., Crowley, H., Pagani, M., Monelli, D. and Pinho, R., 2014. Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. Natural Hazards, 72(3), pp.1409-1427.

Sousa, R., Silva, V. and Rodrigues, H., 2022. The importance of indirect losses in the seismic risk assessment of industrial buildings–An application to precast RC buildings in Portugal. International Journal of Disaster Risk Reduction, 74, p.102949.

Tocchi, M. Polese, M. Di Ludovico, A Prota, (2022), REGIONAL BASED EXPOSURE MODELS TO ACCOUNT FOR LOCAL BUILDING TYPOLOGIES, Bulletin of earthquake engineering, 20: 193–228

Weatherill, G. A., Kotha, S. R., Cotton, F., Danciu, L. (2020). Innovations in ground motion characterization for the 2020 European seismic hazard model (ESHM2020). 7th World Conference on Earthquake Engineering, Sendai, Japan, September 2020

Zuccaro G, Dolce M, De Gregorio D, Speranza E, Moroni C (2015) La scheda CARTIS per la caratterizzazione tipologico- strutturale dei comparti urbani costituiti da edifici ordinari. Valutazione dell'esposizione in analisi di rischio sismico; In: Proceedings of GNGTS (in Italian)