The communication strategy for the release of the first European Seismic Risk Model and the updated European Seismic Hazard Model

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Abstract. To design user-centred and scientifically high-quality outreach products to inform about earthquake-related hazards and the associated risk, a close collaboration between the model developers and communication experts is needed. In this contribution, we present the communication strategy developed to support the public release of the first openly available European Seismic Risk Model and the updated European Seismic Hazard Model. The backbone of the strategy was the communication concept in which the overall vision, communication principles, target audiences (including personas), key messages, and products were defined. To fulfil the end-users' needs, we conducted two user testing surveys; one for the interactive risk map viewer and one for the risk poster with a special emphasis on the European earthquake risk map. To further ensure that the outreach products are not only understandable and attractive for different target groups but also adequate from a scientific point of view, a two-fold feedback mechanism involving experts in the field was implemented. Through a close collaboration with a network of communication specialists from other institutions supporting the release, additional feedback and exchange of knowledge was enabled. Our insights, gained as part of the release process, can support others in developing user-centred products reviewed by experts in the field to inform about hazard and risk models.

Short Summary. For the release of (cross-country harmonised) hazard and risk models, a communication strategy co-defined by the model developers and communication experts is needed. The strategy should consist of a communication concept, a user testing, expert feedback mechanisms, and the establishment of a network with outreach specialists. Here we present our approach for the release of the European Seismic Hazard and Risk Models and provide practical recommendations for similar efforts.

Keywords: communication concept; communication products; user-centred design; hazard and risk maps; feedback loops

1 Background

How should we render scientifically-developed models relevant and useful for society? The short answer is that model developers, communication experts, and societal stakeholders must collaborate on and co-design the products (Pohl et al., 2021). The comprehensive answer is presented in this paper, offering an illustrative example of the communication strategy developed and implemented through a transdisciplinary approach to support the launch of the European seismic hazard and risk models. This strategy consisted of the preparation phase (communication concept, end-user testing, expert feedback rounds, outreach specialist network), the public release (information materials and model data, events, distribution channels), and the rework processes (requests, follow-ups).

This communication strategy was used for the public release of the latest generation of the seismic hazard model for Europe and the first European seismic risk model, which are currently the only harmonised, peer-reviewed, fully open access datasets in this domain that are available at the European level. Elaborated and documented by research teams across Europe, they offer all interested users a valuable reference upon which to base mitigation decisions for future earthquakes in the Euro-Mediterranean region. These models are critical input for professional users involved in the definition and/or implementation of seismic design codes, as well as those elaborating transnational insurance solutions or disaster risk mitigation strategies. However, to be able to make a difference and improve Europe's preparedness for earthquakes, political and societal support is required. Therefore, the models' launch targeted a broad set of audiences.

Our insights and recommendations in this paper thus can support other institutions or groups in charge of releasing regional, national, European or international hazard and risk models and their related products to interested users, the scientific community, and society.

1.1 The European seismic hazard and risk models

The European Seismic Hazard Model 2020 (ESHM20; Danciu et al., 2021) is an update of the earthquake hazard assessment in the Euro-Mediterranean region, following the 2013 (Wössner et al., 2015) and the 2002 (Jiménez et al., 2001) models. The hazard assessment is based on the knowledge of past earthquakes, geology, tectonics, and site-effects based on the local soil conditions. To develop the updated hazard model, state-of-the art procedures were consistently used for the entire pan-

European region, avoiding country-border limitations on data, source delineation or model implementation. In several regional workshops, feedback from scientists and experts were gathered, and public webinars were organised to inform the wider scientific community about the ongoing efforts; thus giving them the chance to provide feedback, review, and contribute with insights of local knowledge. The probabilistic ground shaking estimates across the region indicate that the countries with the highest chances of experiencing significant ground shaking due to earthquakes are Turkey, Greece, Albania, Italy, and Romania (Danciu et al., 2021). Further, the ESHM20 (Danciu et al., 2021) is the basis to inform different applications such as the European seismic design code (EC8; Eurocode 8, 2023) or the first open-access European seismic risk model (Crowley et al., 2021). The European Facilities for Earthquake Hazard and Risk (EFEHR) Consortium will continuously update these models, in collaboration with the Global Earthquake Model (GEM) Foundation and the European Plate Observing System (EPOS).

The European Seismic Risk Model 2020 (ESRM20) is the first harmonised, openly available and reproducible seismic risk assessment for Europe (Crowley et al., 2021). Earthquake risk consists of four factors: earthquake hazard, site amplification, vulnerability, and exposure. The model shows that, as expected, the highest risk and thus the most severe consequences are expected in urban areas situated in regions with a high earthquake hazard, including the cities of Istanbul, Catania, and Athens (Crowley et al., 2021). Moreover, many European countries have not yet developed a national earthquake risk model (Crowley et al., 2021), thus policy makers can use the insights from the ESRM20 to inform their disaster management plans and define prevention measures (e.g., retrofitting, insurances). The model will continue to be updated based on future improvements of the component models and feedback from the scientific and professional risk communities.

1.2 The process for the release

Developing as well as updating seismic hazard and risk models is primarily a scientific task. Making the results accessible to a wider audience is, however, a joint effort of model developers and stakeholders, IT specialists, as well as communication experts. We based our approach for the launch of the two models (i.e., ESHM20 and ESRM20) on the schema depicted in Figure 1.

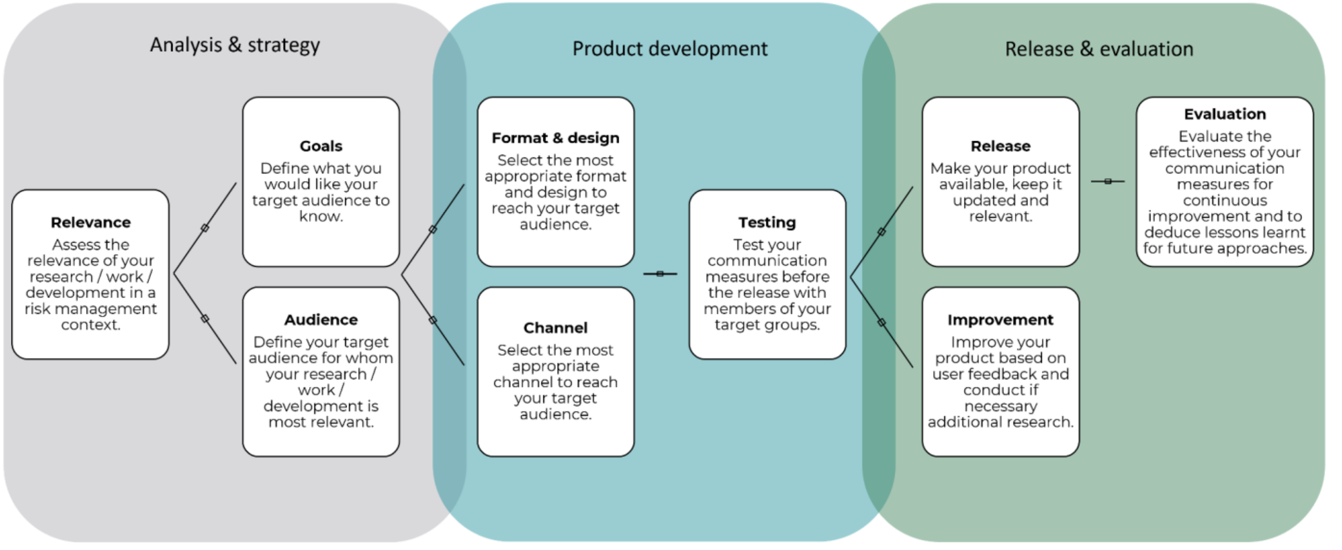

Figure 1: Flowchart visualising the principle process steps to adhere to when designing communication products; adapted from Marti et al. (2020).

An interdisciplinary core team structured the work accordingly and jointly developed the strategy as well as the communication products. The progresses and different product versions were regularly presented to a larger group of experts in seismic hazard and risk assessment, who provided detailed feedback. The virtual meetings were planned thoroughly, allowing the assimilation of feedback from such a large group as efficiently as possible. We often worked with virtual collaboration tools and regularly conducted short surveys inviting everyone to contribute.

The first step of the schema foresees assessing the relevance of the information to be distributed. As illustrated in the introduction, political and societal support is needed to advance earthquake mitigation strategies which are informed by the results of the models. In the following, the subsequent steps leading to the launch of the models are shown.

1.2.1 The communication concept

Besides the data and models that are openly available on a public Gitlab repository (https://gitlab.seismo.ethz.ch/efehr), further products were needed for the public release of the model (e.g., maps; Figure 5). To this end, the model developers at the EUCENTRE and the Swiss Seismological Service (SED) at ETH Zurich, and the communication team at SED joined forces and developed products tailored to the target audiences' needs and knowledge; thus, this core team was responsible for the corporate communication (Christensen and Cornelissen, 2013) by managing all communications related to the ESHM20 and ESRM20.

The basis of these efforts was the elaborated communication concept, which follows the theoretical frameworks of Zerfaß and Piwinger (2014). In this concept, we defined the communication strategy, the realisation plan, and the controlling and evaluation mechanisms. Regarding the controlling mechanism, we on the one hand checked to what extent the formulated objectives are achieved through the realised communication activities (result control), and, on the other hand, whether the project is on schedule or if actions are necessary (process control); see specific examples later in the paper.

More precisely, the communication concept defined the overall vision, the communication principles and goals, the target audiences, the products, and the dissemination channels and activities. Regarding the target audiences, we created the so-called "Personas". Personas are characters that represent a subgroup for whom specific communication products are designed and created. The definition of the Personas includes the professional background, interests, expertise, and specific use of the product (Smith, 2012). This concept has already been used in other contexts where international communication products were developed (Getto and Amant, 2015). Regarding the communication goals, we identified which goals address end-users' hazard and risk awareness, their attitudes, and their actual behaviours (Bruhn and Herbst, 2016).

1.2.2 The design and testing of the products

To design user-centred products, testing is indispensable (Dallo et al., 2022a; Karjack et al., 2022; Marti et al., 2023; Schneider et al., 2022). The earthquake hazard and risk maps of Europe were two of the main products that were also integrated into many other products (e.g., flyers, posters). Maps are commonly used to communicate spatial hazard and risk but are only an appropriate format if they are well designed (Marti et al., 2019; Schneider et al., 2022). Experiences show that colour scales are often chosen based on subjective preferences and not empirical evidence (Thompson et al., 2015).

The consequences of unsuitable colour scales are manifold: i) manipulation or distortion of data (Crameri et al., 2020), ii) inaccessibility for people with a colour-vision deficiency (Crameri et al., 2020); iii) impossible colour discriminability (Bujack et al., 2018); iv) misunderstandings of the actual hazard especially by non-scientific users (Dasgupta et al., 2020); and v) loss of meaning when printed in black and white (Crameri et al., 2020). Thus, the colour scale is a critical element on the map especially because it is considered pre-attentive, which means that the eye extracts information intuitively and rapidly (Sherman-Morris et al., 2015).

But there are solutions for these challenges. Crameri et al. (2020) offer various colour palettes that are colour-blind-friendly such as the batlow-palette. Robertson and O'Callaghan (1986) further recommend using linear progressions in colour lightness across the entire scale in order to guarantee perceptual uniformity (i.e., a unit increase in data value corresponds to a unit increase in the perception of change between colours). Schneider et al. (2022) additionally provide a criteria-based framework for the design of hazard maps demonstrated by the design of the German seismic hazard map (Grünthal et al., 2018). However, for cross-country maps one must also take into account that what people associate with specific colours is cultural-specific (Wang et al., 2014).

Besides the colour scale, also the map-related elements such as the legend, title, or textual explanations matter. For example, Edler et al. (2020), from a cartographic perspective, recommend positioning the legend on the right side of the map since this can lead to a faster processing of the information. Further, to increase end-users' trust and confidence in the products, the source should be indicated and well visible (Sullivan-Wiley and Short Gianotti, 2017; Wood et al., 2018). Moreover, pictograms and icons trigger people to take action and allow persons not speaking the language in which the information is written to grasp the context (e.g., key messages, or what they should do) (Dallo et al., 2022b). Further, people prefer a combination of textual and visual information (Becker et al., 2018; Dallo et al., 2020), which also ensures that people with different cognitive abilities can look at the format that is understandable for them.

For the ESRM20 and ESHM20, we decided to test the interactive risk web viewer and the risk poster including the corresponding map. For both products we conducted an online survey, once with professional users and once with students from European universities. We argue that the insights from the surveys are also valid for the wider public since several studies have shown that well educated and trained people (e.g., non-technical audiences) have no advanced abilities in interpreting scientific graphs (McMahon et al., 2015; Maltese et al., 2015).

1.3 The scope of the paper

Figure 2 shows the overview of our communication strategy for the public release of the ESRM20 and ESHM20; from the preparation phase over the release to the rework process. In this paper, we focus on the preparation phase namely the communication concept (section 2), the user testing (section 3), the expert feedback mechanisms (section 4), and the networking with outreach specialists (section 5).

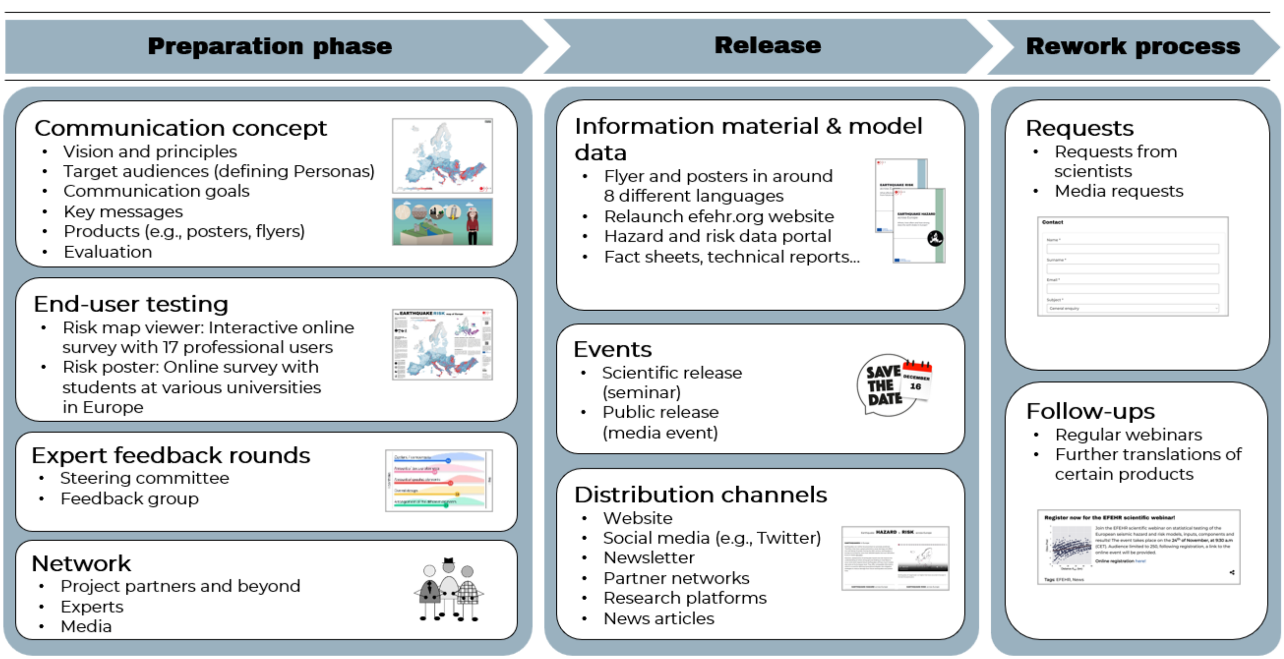

Figure 2: Overview of the communication strategy for the public release of the ESRM20 and ESHM20.

2 The communication concept

As mentioned in section 1.2.1, our communication concept followed the structure of Zerfaß and Piwinger (2014). In the following, we describe the core elements of the concept.

2.1 Vision and principles

As a first step, it is crucial to define the vision and the principles of the project in order to guarantee that all project members work towards common goals and communicate according to the same principles. This allows one to build a shared overall vision of what should be achieved with the release of the models. The overall vision of the project was to *provide cross-border harmonised hazard and risk models for Europe*. Regarding the principles, we, for example, committed to: i) communicate transparently and openly; ii) guarantee consistency and continuity; iii) provide comprehensive knowledge on earthquake hazard and risk; and iv) support cooperation among the internal project group and foster engagement with external stakeholders.

2.2 Target audiences and personas

The second step was the definition of the target audiences of our communications. As the models were of great interest to many stakeholders, we first compiled a list with all of them. Together with the involved partners, we then categorised the target audiences into four groups, each of which we defined a persona for (Figure 3). Personas are fictional characters representing a subset of the target audiences (Getto and Amant, 2015); summarising typical requirements (e.g. interests) of the subset as comprehensively as possible (Smith, 2012). In our case, we summarised their interests and needs regarding the release of the earthquake hazard and risk models. The benefit is to reduce complexity, better tailor the products to the target audiences' needs, and to re-check decisions throughout the product designing process.

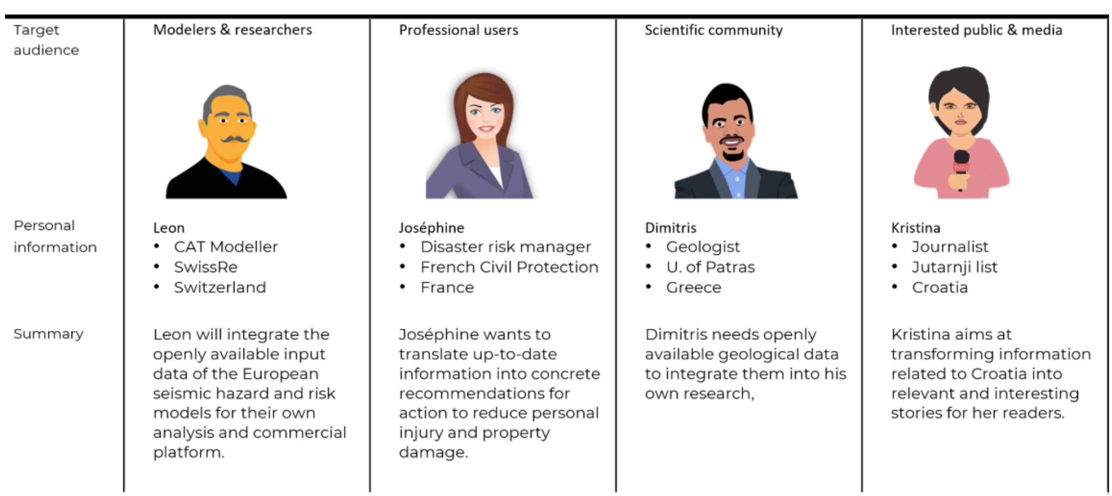

Figure 3: The four personas who represent the target audiences of the ESRM20 and ESHM20; Icons created by pixabay.

2.3 Communication goals

We defined 15 communication goals that indicated what we aimed to achieve with our communication efforts. The goals were further grouped into three dimensions that build on each other: knowledge (=cognitive-oriented), attitude (=affective-oriented), and behaviour (=conative-oriented) (Bruhn and Herbst, 2016); see Figure 4. This differentiation makes sure that not only general information is communicated but that the target audiences' perception and actual use of the products are addressed by the communication efforts.

Figure 4: The communication goals aligned to the three dimensions knowledge, attitude, and behaviour; adapted from Bruhn and Herbst (2016).

2.4 Key messages

The next step in the communication concept was to derive key messages based on the target audiences and communication goals (Röttger, 2016). Insights from the testing (see section 3) served as valuable inputs in the definition of the messages. In total, we defined a set of 33 key messages whereas five of them were defined as overarching key messages; e.g.

"*The 2020 European seismic risk model is the first openly available earthquake risk assessment at a European level presenting the potential consequences earthquakes may have on the built environment*."

The other 28 key messages were clustered into eight sub-topics i) importance of the models; ii) hazard model; iii) risk model; iv) relation to national models; v) joint development; vi) access to data; vii) citation; and viii) additional materials. The key messages were used to integrate the content, thus to ensure that the messages are consistent across different products or platforms. However, not all these messages were always used in each product. Depending on the context (e.g., product, communication goals, and target groups), different aspects were emphasised content-wise and therefore only particular messages used.

The key messages were aligned with the communication goals to ensure that all goals are addressed. To this end, we checked which communication goals are reached by each of the eight key message sub-topics. For example, one communication goal was to have two clear citations – one for the risk model and one for the hazard model – which researchers and the media should use to refer to the models. This is crucial to measure the impact of the models. One related key message thus was:

"*Whenever making use of scientific products or when distributing visualisations of Europe's earthquake hazard and risk models, please cite the respective technical reports: [citation risk & citation hazard]*."

This key message was indicated on each communication product and mentioned in several places on the EFEHR website, but also on the map viewers of both hazard (hazard.efehr.org) and risk (risk.efehr.org) web-services. By doing so, it allowed us to minimise the problem that emerged for the release of the ESHM13 (Wössner et al., 2015), where the model was cited in various ways and, thus, it was impossible to measure the outreach of the model and acknowledge the developers appropriately.

2.5 Products

Next, the products for the public release of the two models were defined. The development of these products was iterative; the core team always created a first draft, collected feedback from the feedback groups or did testing, and then adjusted and finalised the products. In Table 1, we provide an overview of all products with a short description and their primary target audiences, and in Figure 5 we show the final risk and hazard map of ESRM20 and ESHM20, respectively. All products are available on the EFEHR website (www.efehr.org/explore/Downloads-information-material/; June 2023). Some products, such as the detailed technical reports or the fact sheets are available in English, and others such as the official poster or flyer are available even in several languages (e.g., English, German, French, Italian, Greek, Portuguese, Romanian). Partner institutions in the respective countries provided the translations.

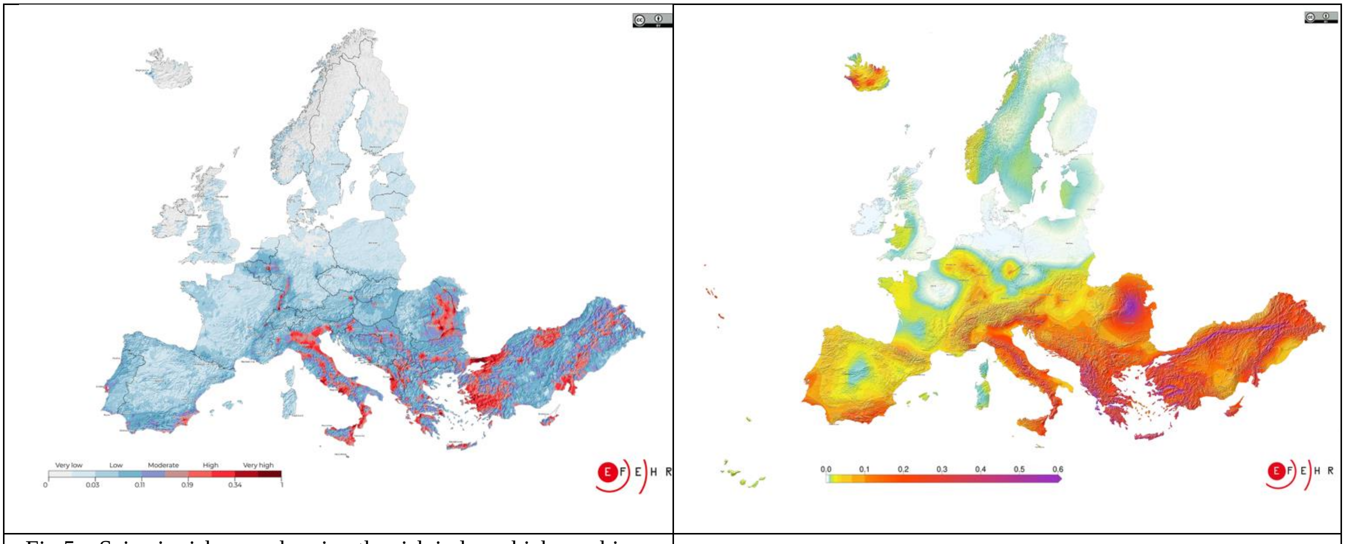

Fig 5a: Seismic risk map showing the risk index which combines the average annual economic loss and the average annual loss of life.

Fig 5b: Seismic hazard map showing the expected level of ground shaking [Peak Ground Acceleration]

Figure 5: The European seismic risk and hazard map [www.efehr.org/explore/Downloads-information-material/]

Table 1: Overview of the products and their target audiences (Figure 3) for the public release of the two models, which are available under http://www.efehr.org/explore/Downloads-information-material/

Products and communication measures	Description	Target audiences (Personas)
Corporate Design	This measure includes the creation of a corporate design manual, in which the typography and colour selection are defined. The various communication products are then designed on this basis, which leads to a common appearance and appealing presentation of the products.	- All
Re-design EFEHR website	The website and information provided through this communication are a central pillar for all communication activities, i.e. one entry point for all target audiences. Therefore, the EFEHR website appears in a modern, minimalistic design, and consists of different sections dealing with different aspects of seismic hazard and risk.	- All
Detailed (technical) report [Hazard and Risk]	A long report which contains various contextual information about seismic hazard and seismic risks in Europe, describes the models and the datasets used to build those models as well as the methods (technical descriptions). Furthermore, the main results are presented.	- Modellers and researchers - Scientific community
FAQ	Compilation of information on particularly frequently asked questions, available on the EFEHR website. Further questions can be continuously added to the list.	- All

Brochures [Hazard and Risk]	Two brochures (A5 format) that give a brief overview of the earthquake hazard and risk in Europe. The brochures also inform about the models and link to the EFEHR website.	- Interested public and media
Posters [Hazard and Risk]	Two posters, one for seismic hazard and one for seismic risk, present the results of the models. The main maps (one for seismic hazard and one for seismic risk) are the key elements of the posters. Explanatory texts and additional maps and illustrations support the understanding of the posters' content.	- Modellers and researchers - Professional users - Scientific community
Explainer video	A video explains the key aspects of the seismic hazard and risk models as well as the difference between hazard and risk. The video lasts about 5 minutes and is a valuable complement to the written information material. [https://www.youtube.com/watch?v=5h2MvidnXCw; June 2023]	- Professional users - Interested public and media
Fact sheets [Hazard and Risk]	The fact sheets have a length of around 5 pages (A4 format). They provide a general overview over the seismic hazard and risk models, indicate key results, describe all components of the models as well as the underlying methodology.	- Professional users - Scientific community
Press release	A common communication tool measure to reach the media is through press releases. The press release is available in English, German, French and Italian. It was shared with the partner institutions and translated into multiple languages (e.g., Portuguese, Greek, Romanian). In consultation with the core team, partner institutions could enrich the text with additional information regarding their research efforts contributing to the models' development or specific information on the seismic hazard or risk in their country.	- Interested public and media
Material for web and social media posts	For common and consistent communication, texts and visuals for news articles and content for social media posts were provided in German, French, Italian and English and shared with the communication managers of the partner/ supporting organisations.	- All
Interactive map viewer for professionals	Experts can discover and interact with the seismic hazard and risk models on online map viewers. The map viewers allow them to extract the information needed for their context.	- Modellers and researchers
Interactive map viewer for the general public	To discover earthquake hazard and risk across Europe, a map viewer for a more general public is also available. Users can choose between various layers to see and compare the different levels of earthquake risk at any location in Europe.	- Interested public and media - Scientific community
Virtual media event	To promote the public release of the models, a media event was held, offering journalists to get first-hand information about seismic hazard and risk assessment and the opportunity to ask questions directly to the researchers.	- Media

2.6 Evaluation

To control the usefulness and effectiveness of our communication efforts, we had various evaluation mechanisms. On the one hand, we collected the web statistics and compared them with previous years (e.g., website visitors, product downloads). For example, we had on average 1,880 website visitors per month in 2021 and about 1,000 more in 2022 (2,890 visitors per month).

In Figure 6, the increase after the public release at the end of April 2022 is visible; with a total of 7,721 visitors in May. Even in the months following this peak due to the release, the numbers remained at a higher level than before. Furthermore, the EFEHR website is highly accessed after severe events; such as the devastating Türkiye-Syria earthquake on February 6th 2023 demonstrated, when more than 32,000 persons accessed the EFEHR website.

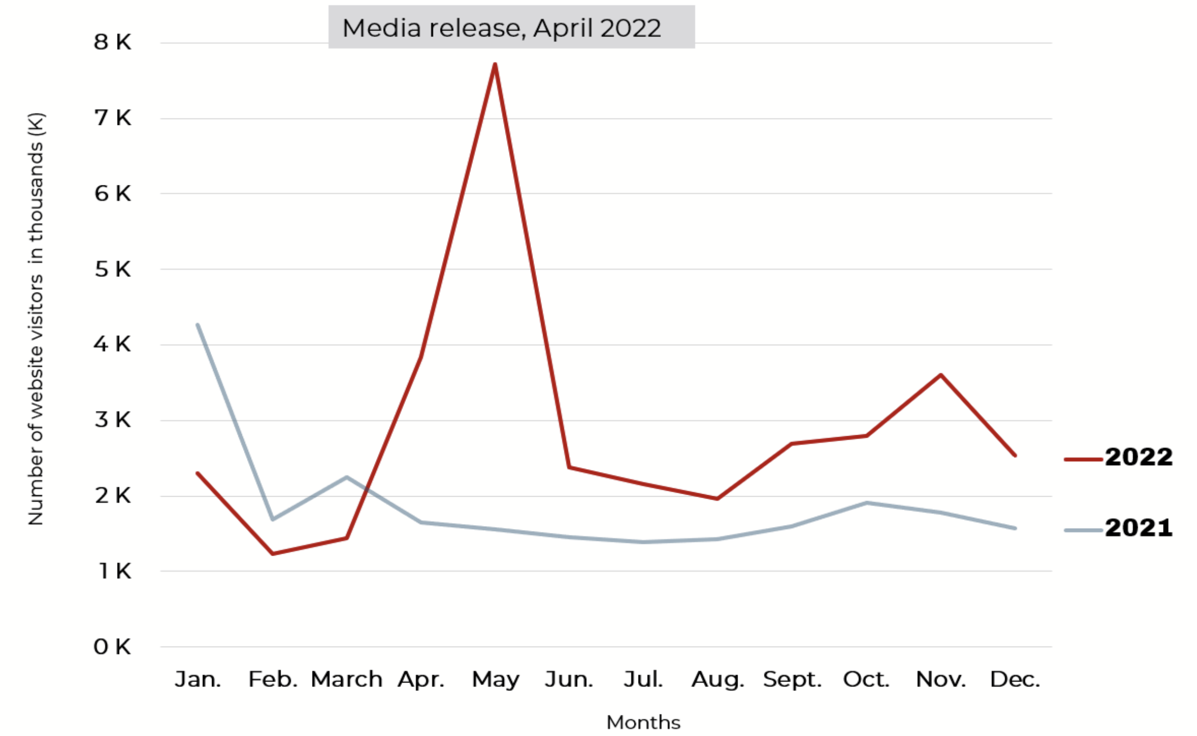

Figure 6: Number of visitors on the EFEHR website in 2021 (blue) and 2022 (red)

On the other hand, we have collected the news articles which provide information about the models. To this end, we prepared a joint Excel file where the outreach specialists from our established partner network (see section 5) were asked to add their articles and those they came/come across. Our outreach efforts worked well, as the various articles in newspapers or online magazines (~37), articles on websites or newsletters (~14), as well as numerous posts on social media channels, and a few TV/radio interviews showed (as at November 2022). The news articles were published by different media outlets across Europe, e.g. EuroNews, NZZ Switzerland, Express UK, Greek Reporter, SOL Portugal, Critic National Romania, or ANSA Italy.

3 User testing – the two online surveys

We decided to test two different products, the interactive risk web viewer for professional users (risk.efehr.org) and the official risk poster with a special focus on the risk map. For both products, we conducted an online survey to assess the correct comprehension, perceived usefulness, and design and content preferences. For the risk poster, we further did a between-subject experiment to identify which colour-scale and shading work best. In sections 3.1 and 3.2, we describe the two testing studies in detail and summarise the main practical insights.

The hazard web-platform and hazard map were not tested within this effort. However, the hazard poster consists of the same design elements as the risk poster; thus applying the lessons learnt from the user testing described below. In addition, the hazard map was adapted to the colour bar recommendation, and reviewed and approved by the feedback group.

3.1 Web viewer of the risk model

In December 2020, we conducted an interactive online survey with 17 professional users of the risk web viewer (Figure 7), representing researchers, civil engineers, cat risk modellers, and civil protection (Fig. S1 in Supplement). The aim of the survey was to assess the user needs with respect to the information presented on the web viewer; i.e. its relevance, usability, understandability, user-friendliness, and completeness.

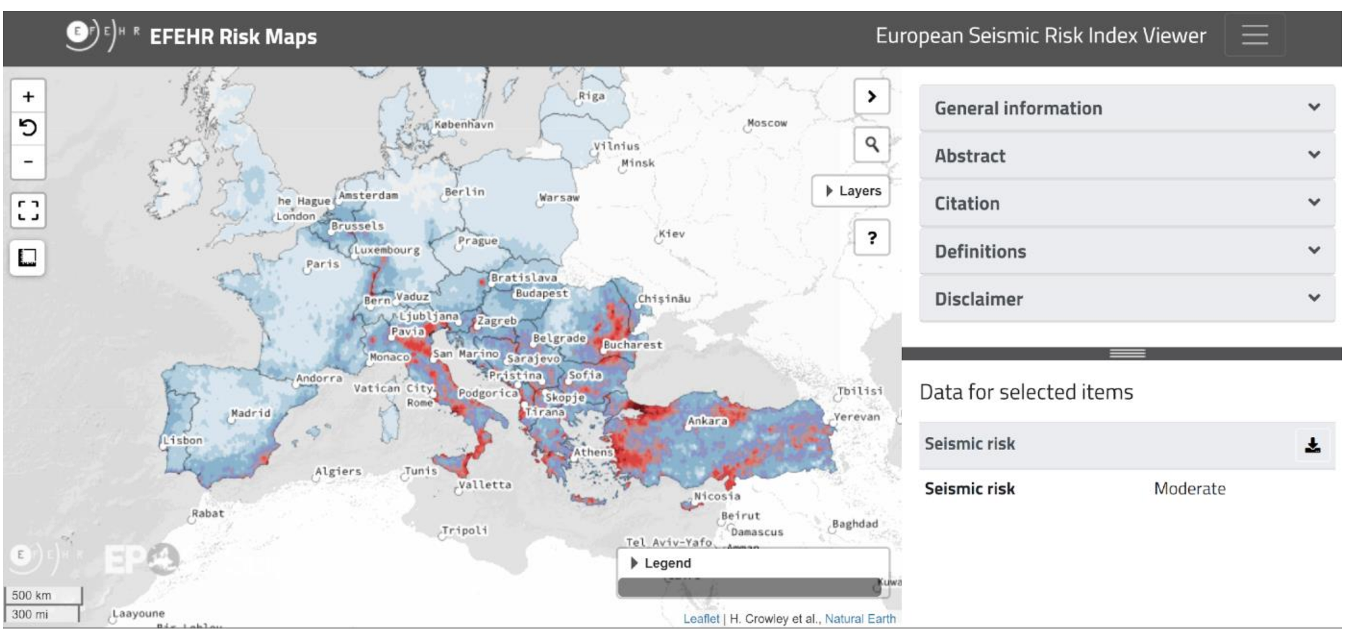

Figure 7: EFEHR interactive seismic risk map viewer [https://maps.eu-risk.eucentre.it/map/european-seismic-risk-index-viewer/#4/52.64/5.05]

In four question blocks (QB), we assessed the user needs. In QB1, before seeing the beta version of the web viewer, participants had to indicate what information they would expect on the map viewer. This allowed us to validate if participants' expectations were in line with the actual content. In QB2, we assessed participants' correct interpretation of the information provided, map and layer preferences, and additional information needs. In QB3, we let them evaluate the design, and, in QB4, they had the chance to provide final comments. The entire questionnaire is listed in Supplement S1. The survey was set up with Unipark at ETH Zurich, and the results were statistically analysed with the Software SPSS.

In Table 2, we summarise the practical implications from the survey results that we used to improve the clarity of the web viewer and the additional information requested by the users. Overall, the two primary benefits of the ESRM20 are the enhancement of existing services/products and the development of new ones as stated by the participants (Fig. S2 & S3). All descriptive results are listed in Supplement S2.

Table 2: Summary of the practical implications for designing an interactive web viewer for risk models. All descriptive results are listed in Supplement S2.

Issues	Description	Empirical basis [Supplements]
Preferred information	- Direct and indirect economic losses - Number of casualties, fatalities and people in need of help - Damages on physical assets (e.g., infrastructure) - Hazard and exposure (population and building) data - Fragility and vulnerability models for residential and commercial buildings - Social vulnerability or resilience indicators - Building stock information (differentiation between commercial, industrial, and residential buildings) - Uncertainties associated with the models	S2.2, S2.5, S2.10
Map preferences	- Map of average annual loss (M EUR) preferred over Map of average annual loss ratio (per mile) preferred over Map of the 200 years return period loss (M EUR) - Direct access to hazard and exposure map - Mapping of social vulnerability indicators - Map of the distribution of buildings' collapse risk - Ability to download maps as .csv - The risk results covering both economic losses and fatalities should be provided together in the same interactive map viewer	S2.7, S2.8
Resolution preferences	- Gridded map (e.g., 1km x 1km) preferred over National level preferred over NUTS19 (administrative unit) - Resolution: countries, cities and municipalities - The risk results for all levels of resolution should be included in the same map viewer so that all information is together.	S2.7
Layer preferences	- Populated places and density of the population - Significant earthquakes (according to the NCEI WDS database) ☐ By clicking on the event, detailed information about an event should pop up. - Active and major faults - Return periods: 50, 200 and 500 years - Relevant infrastructure and lifelines - Shaded relief not desired	S2.9
Perceived purpose of the risk model	- To give estimates of risk levels at various return periods of the mapped economic exposure.	S2.3

	- To provide an overall view of seismic risk in Europe and to compare seismic risk in the different EU countries. - To guide the development of public and private risk mitigation strategies of all sorts, such as deployment of wide-scale structural upgrading campaigns. - To compare with and improve existing vendor models of European seismic risk. - To provide easy access to specific risk metrics for the whole Europe accompanied by the data and models used for its development. - To raise awareness within the scientific and engineering communities. - To provide reliable data that can be quickly found. - To homogenise the seismic hazard maps along the boundaries of the European countries. - To increase awareness of seismic risk in Europe at the levels of both the government and the public. - To estimate the number of displaced people and potential casualties, as part of the national disaster management plans (preparedness phase).	
Design evaluation	- The web viewer was overall rated as easy to navigate, attractive, clear, informative and useful. - Only the topographic layer was not well visible and had to be adjusted. - The use of clear and understandable legends are important, i.e. provide the same information in the legend and the information box. - Further information (pop-up windows) must be intuitively found, i.e. using clear icons. - When having an information box, one should ensure that it is clear at first glance how to open and close it.	S2.6, S2.11

3.2 Risk poster and risk map

We conducted an online survey with 83 students across Europe to test the risk poster in July 2021. The aims were to assess i) if the communication goals are reached with the information on the poster; ii) if the risk information on the poster is understood correctly, perceived as useful and well designed, and complete; and iii) what influence the design (colour-scale) and participants' characteristics – numeracy skills, colour-blindness, field of study, university, age, gender, and living place – have on these factors.

We developed three versions of the risk map with three different colour-scales (see Figure 8). We thus tested three versions of the risk poster by replacing the map in the middle (Table S8), whereas all the other poster elements stayed the same. To test which version works best, we conducted a between-subject experiment, thus participants were randomly assigned to one of the three poster versions but responded to the same questions. The same was done for the risk map only.

The survey consisted of three question blocks (QB). In QB1, participants saw one of the three risk poster versions (between-subject experiment), and we assessed participants' first impression, correct interpretation, personal use, and design preferences. In QB2, participants then only saw one of the three risk map versions (between-subject experiment), and we again asked about their first impression, correct interpretation, and design preferences. Furthermore, we tested different shading and contour variations by always showing two maps side by side and letting participants choose which one they prefer. In QB3, we assessed participants' characteristics to analyse if these have an influence on their preferences, perceived usefulness, and correct interpretation. The entire questionnaire is listed in Table S9.

In total, 83 students with a mean age of 30.8 (SD=10.2) filled in the survey. 59% of the participants were female and 41% male, and the majority lived in Switzerland, Romania, Italy, or France. The majority has either a Master's degree (37.3%) or a Bachelor's degree (27.7%), mainly in the fields of engineering (44.6%), earth sciences (16.9%), geophysics (7.2%), architecture (7.2%), or environmental sciences (6.0%). All characteristics are listed in Table S10. The sample characteristics did not differ significantly across the experimental groups (Tables S11 & S12).

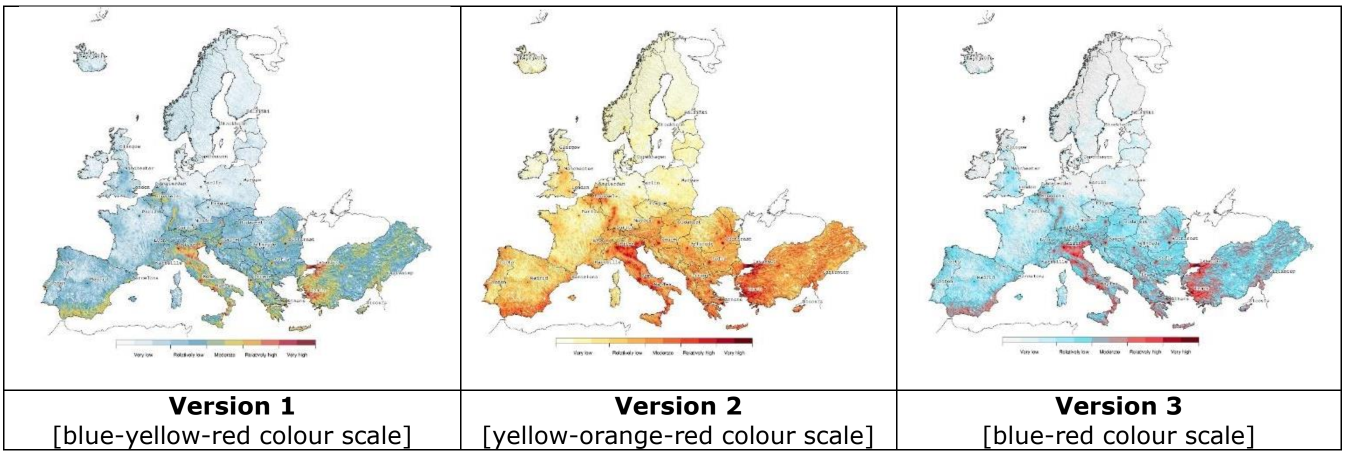

Figure 8: The three risk map versions we tested alone and integrated in the poster. The feature that was varied was the colour scale.

In Table 3, we summarise the main practical implications that we used to adjust the map and poster design to the users' needs, preferences, and comprehension skills. Overall, the participants correctly grasped from the risk posters that earthquakes pose a serious threat to Europe and that certain regions in Italy, Greece, and Turkey face especially high earthquake risk (Supplement S6.3). When looking only at the risk map, participants recognised that Southern Europe (including Italy and Turkey) is most affected (Supplement S6.10). Further, they indicated that they learned something new about earthquakes in Europe, which shows the successful knowledge transfer via the risk poster (M=3.46, SD=1.12; Supplement S6.8). Moreover, the majority is also motivated to share the gained information with their colleagues (M=3.39, SD=1.14; Supplement S6.8). All descriptive results of the survey are listed in Supplement S6.

Regarding the design, we here discuss the aspects relevant for the final choice of the colour scale and risk index. First, our decision is ground in choosing a colour scale that ensures that people correctly interpret the map (Table S14 in the Supplement). Second, with the selected colour scale, people better understood that although the house next door might be located in a differently coloured area, this does not indicate a lower seismic risk per se (e.g., influence of building type). An effective visual technique for conveying this information involved incorporating a gradient or fading of colours. Third, we explicitly state on the poster and other products that the map illustrates a risk index, representing the average annual economic loss and the average annual loss of life. In the case of the Swiss earthquake risk map, we went one step further by clearly indicating the risk index and its two underlying components in the legend too, a measure proven to improve public comprehension of the map (Dallo et al., 2023).

Table 3: Practical implications for designing comprehensive, useful, and well perceived risk maps and posters. All descriptive results of the survey are listed in Supplement S6.

	Issues	Description	Empirical basis [Supplements]
Earthquake risk poster	Information needs	- List of factors driving high risk levels desired (e.g., specific building constructions, urban vs. rural areas). - The Azores and Portuguese archipelagos should be depicted on the map. - Information about secondary hazards preferred (e.g., tsunami, landslides).	S6.5
	Content	- It must be clearly explained which losses the risk index combines (e.g., normalised value of both economic loss and fatalities). - The components of seismic risk should be explained to ensure the readers understand the difference between the risk index of the risk map and the components of the overall risk model. - The explanations on the poster ensured that people understand that even though the house next door might be located in a differently coloured area, this does not indicate a lower seismic risk per se (e.g., influence of building type). - A reading example (such as in our case for the city of Istanbul) facilitates the interpretation of the visual information. - The uncertainties behind the risk estimates should be emphasised. - Information about secondary hazards such as tsunamis would be appreciated.	S6.4, S6.5, S6.6, S6.9, S6.17
	Perceived purpose of the earthquake risk poster	- To raise awareness for the human and financial losses earthquakes may cause in Europe. - To increase people's knowledge about seismic risk in Europe. - To facilitate the more regular update of building codes.	S6.8, S6.17
	Disclaimers	- It should be clearly stated if the model can be used for commercial purposes or not. - Not all are familiar with the licensing icons (e.g., CC BY 4.0). - A clear indication of the funding resources is needed.	S6.4
	Design evaluation	- The risk poster was overall rated as useful, trustworthy, reliable, understandable, and clearly structured. Thus, our design can serve others as a template to develop similar posters. - Only the topographic layer was not well visible and, consequently, was adjusted. - The use of clear and understandable legends is important, e.g. provide a legend title 'THE EARTHQUAKE RISK INDEX MAP' to indicate what the scale is. - Further information (pop-up windows) must be intuitively found, i.e. using clear icons.	S6.7

Earthquake risk map	Map preferences	- The preferences for the colour scales only differed slightly, therefore our choice for the final scale was based on the correct interpretation and risk perception of the map. - The versions with hill shades were clearly preferred. - There were no clear preferences for smoothing or no smoothing. However, if the smoothing effect is used, it should be combined with hill shades. - The smoothing effect helps to avoid clear borders of risk cells. - The qualitative labels of the risk categories should be combined with numerical values, i.e. what does high or moderate mean in terms of losses (e.g., expected fatalities or amount of economic losses within 50 years). - The capitals of all countries should be displayed to facilitate geographical orientation.	S6.13, S6.14, S6.15, S6.16, S6.17
	Design evaluation	- The risk maps were overall rated as informative, useful, trustworthy, understandable, and appealing. - For marking the location of cities on a map not a dot but a circle should be used. Because the dot may cover the colour and lead to misinterpretations. - No region should be coloured white since an earthquake can happen everywhere, and otherwise people wrongly interpret that certain regions have no seismic risk. Thus, also the lowest level of the risk scale should be ‘very low’ and not ‘no risk’.	S6.11, S6.12, S6.13

4 Expert feedback rounds

The model developers and the communication experts built the core team (the authors), and took the lead in the product development and the scientific as well as public release of the models. Meetings were held bi-weekly and in the final phase even weekly to, among others, discuss preliminary product versions, the status of the project plan, and prepare presentations for the wider expert group and release.

To guarantee high-quality products, we created two expert groups namely the ‘feedback group’ and ‘steering committee’. The feedback group consisted of persons who were involved in the development of the hazard and risk models, most of which are also part of the EFEHR Executive Committee. The steering committee contained four persons (i.e., EFEHR’s Consortium Chair, SERA and RISE project coordinators, GEM’s Secretary General). We met monthly with both groups, and they had the chance to give their inputs to all products. To this end, we had a collaborative online repository where they could provide feedback in parallel while seeing what the others had already commented on or changed. For the feedback rounds during the meetings, we used *Mentimeter* (https://www.mentimeter.com), which allowed us to directly show their preferences and opinions, discuss disagreements, and take final decisions in which direction to go. Moreover, since not all were able to join every meeting, we always sent the meeting notes and presentations to everyone, collected written feedback or offered bilateral meetings if needed.

5 Networking with outreach specialists

In preparation for the public release of the model, three issues were relevant. First, we had to establish a network with outreach specialists of project partners and beyond. We used our personal networks and actively reached out to other stakeholders and the media.

Second, we created a virtual media kit to share various communication materials (e.g., press release, high-resolution maps) with the journalists, so that they could use them for their news articles or TV contributions. This media kit was also provided to all outreach specialists of our established network.

Third, we appointed so called EFEHR ambassadors. These "EFEHR ambassadors" were earthquake hazard or risk experts from different European countries who were available to answer media requests in the respective language of the country and who were familiar with local conditions. These contact persons received instructions and information materials (e.g., key messages, key facts) to be ready to answer specific questions, making sure that they communicated consistent information.

6 Conclusions

6.1 Key practical recommendations

Figure 9 provides an overview of practical recommendations for the design of (inter)national outreach activities to support the release of updated or newly developed hazard and risk models. To this end, each step of the communication strategy is relevant: i) the preparation phase including the communication concept, end-user testing, expert feedback rounds, and the outreach specialists network; ii) the release of the information materials and model data at events and via the distribution channels; and iii) the rework process to answer requests, offer trainings and webinars, and evaluate the outreach activities.

Thereby, the backbone of a communication strategy is the communication concept, in which the vision, communication goals, target audiences, key messages, products, and communication measures are defined. To reduce complexity when aiming at targeting a wide range of target audiences, we recommend the use of personas. Personas represent typical characteristics of the target audiences. The communication concept should further be flexible and adjustable since new insights (e.g., from product testing) may emerge throughout the process, and, consequently, communication goals or key messages may have to be revised.

The testing of key products is seen as an indispensable part of the communication strategy to ensure that they fulfil end-users' needs and preferences. Consequently, best practices in communicating seismic hazard and risk information need to be adopted, evaluated, and considered for the product design. To this end, model developers and communication experts must closely collaborate, and consider inclusive design approaches. Such an iterative design process is elaborate and time-consuming, two factors that must be accounted for when defining resources and timelines.

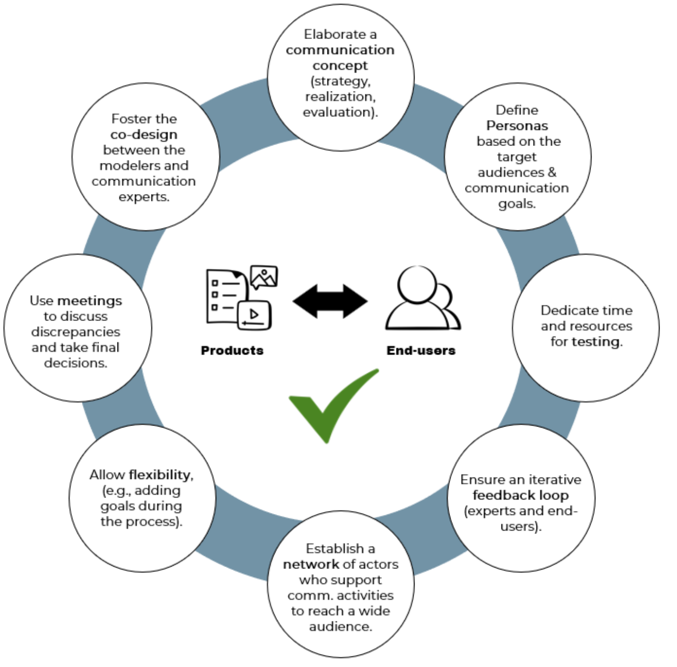

Figure 9: Overview of practical recommendations (in the circles) on how to achieve products accessible for and effectively used by the end-users; Icons created by smashingstocks – Flaticon.

Additionally, to ensure that the products are also coherent and correct in terms of content, feedback from experts in the respective fields is needed. A challenge thereby is to find the right balance between expert requirements and user needs. To support joint decision taking, we used an interactive tool during meetings with the experts, which allowed us to visualise (different) viewpoints and come to an agreement. To obtain written feedback, we recommend using a virtual platform, where experts can in parallel add comments, observe what others have already changed, and directly react to certain aspects.

With a clear strategy, an interdisciplinary team, and the involvement of the target audiences, communication products can be designed that are valuable and useful to support decision taking. Thereby, it is important that not only the technical data, but also all outreach materials are openly available and easily accessible, which we for example ensured via the EFEHR website for the European seismic hazard and risk models. We are convinced that the chosen approach is not only useful in this context, but could be applied to any domain, where complex scientific findings should be made accessible to diverse target audiences.

The effectiveness of the approach's transferability is, for instance, demonstrated through its successful application in developing Switzerland's first publicly available earthquake risk model (Dallo et al., 2023; Marti et al., 2023) or in redesigning the seismic hazard map for Germany (Schneider et al., 2022). A transdisciplinary approach is currently also used by the United States Geological Survey (USGS) to design products for aftershock forecasts in various countries (Schneider et al., 2023). They have already used user testing for the evaluation of the rapid impact assessment they release after significant earthquakes

(Karjack et al., 2022). This approach is also partially utilized and under consideration for the future development of socially relevant assets within the framework of the European Plate Observing system (EPOS; Marti et al., 2022).

6.2 Closing words

This paper provides insights on how to co-define a communication strategy – including a communication concept, user testing, and expert feedback mechanisms – for cross-country hazard and risk models to ensure user-centred, high-quality products for the target audiences (scientific community and societal stakeholders). The insights from our strategy should support future efforts on national but also international levels such as the ongoing process to develop European operational earthquake forecasts (Han et al., 2023) and international aftershock forecasts (Schneider et al., 2023). We emphasise that a close collaboration between the model developers and communication experts as well as an iterative development process is key to the success and the long-term relevance of the models; which, in our case, was again proven by the high access rates of the ESHM and ESRM products after the devastating Türkiye-Syria earthquake on February 6th 2023.

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Author contributions

We use the CRediT Contributor Roles Taxonomy to categorise author contributions. **Conceptualization** (communication strategy and user-testing): ID, MM (lead), NV, HC, LD, JD, SZ. **Resources** (developing communication products): MM, NV, HC, LD, JD, SZ. **Feedback on communication products**: ID, FC, DG, RP, JS, CB, AAC, OJK, PM, MP, VS, GW, SW. **Methodology** (communication concept and related issues): MM, NV, HC, LD, JD. **Investigation** (user testing: data collection and analysis): ID. **Writing - original draft**: ID, NV. **Writing – review & editing**: MM, HC, JD, LD, SZ, FC, DG, RP, JS, CB, AAC, OJK, PM, MP, VS, GW, SW. **Funding**: DG, SW. **Project investigators**; DG, SW.

Core team leading the communication strategy and doing the user-testing: ID, MM, NV, HC, JD, LD, SZ. Steering committee: FC, DG, RP, JS, SW. Feedback group: AAC, OJK, PM, MP, VS, GW.

Declaration of Competing Interests

The authors declare no conflicts of interest.

Appendix A. Supplementary material

The supplementary material associated with this paper can be found in the online version at DOI: 10.3929/ethz-b-000612048.

References

Becker, J. S., Potter, S. H., McBride, S. K., Gerstenberger, M., and Christophersen, A.: Effective communication of Operational Earthquake Forecasts (OEFs): findings from a New Zealand workshop, GNS Science, Te Pū Ao, 2018.

Bruhn, M. and Herbst, U.: Kommunikation für Nonprofit-Organisation, in: Handbuch Instrumente der Kommunikation, edited by: Bruhn, M., Esch, F.-R., and Langner, T., Springer Fachmedien Wiesbaden, Wiesbaden, 605–622, https://doi.org/10.1007/978-3-658-04655-2_29, 2016.

Bujack, R., Turton, T. L., Samsel, F., Ware, C., Rogers, D. H., and Ahrens, J.: The good, the bad, and the ugly: a theoretical framework for the assessment of continuous colormaps, IEEE Transactions on Visualization and Computer Graphics, 24, 923–933, https://doi.org/10.1109/TVCG.2017.2743978, 2018.

Christensen, L. T. and Cornelissen, J.: Bridging corporate and organizational communication: review, development and a look to the future, in: Organisationskommunikation und Public Relations, edited by: Zerfaß, A., Rademacher, L., and Wehmeier, S., Springer Fachmedien Wiesbaden, Wiesbaden, 43–72, https://doi.org/10.1007/978-3-531-18961-1_3, 2013.

Crameri, F., Shephard, G. E., and Heron, P. J.: The misuse of colour in science communication, Nat Commun, 11, 5444, https://doi.org/10.1038/s41467-020-19160-7, 2020.

Crowley, H., Dabbeek, J., Despotaki, V., Rodrigues, D., Martins, L., Silva, V., Romão, X., Pereira, N., Weatherill, G., and Danciu, L.: European Seismic Risk Model (ESRM20), EFEHR Technical Report 002, V1.0.1., https://doi.org/10.7414/EUC-EFEHR-TR002-ESRM20, 2021.

Dallo, I., Stauffacher, M., and Marti, M.: What defines the success of maps and additional information on a multi-hazard platform?, International Journal of Disaster Risk Reduction, 49, 101761, https://doi.org/10.1016/j.ijdrr.2020.101761, 2020.

Dallo, I., Stauffacher, M., and Marti, M.: Actionable and understandable? Evidence-based recommendations for the design of (multi-)hazard warning messages, International Journal of Disaster Risk Reduction, 74, 102917, https://doi.org/10.1016/j.ijdrr.2022.102917, 2022a.

Dallo, I., Marti, M., Clinton, J., Böse, M., Massin, F., and Zaugg, S.: Earthquake early warning in countries where damaging earthquakes only occur every 50 to 150 years – The societal perspective, International Journal of Disaster Risk Reduction, 83, 103441, https://doi.org/10.1016/j.ijdrr.2022.103441, 2022b.

Dallo, I., Schnegg, L. S., Marti, M., Fulda, D., Papadopoulos, A. N., Roth, P., Danciu, L., Valenzuela, N., Wenk, S. R., Bergamo, P., Haslinger, F., Fäh, D., Kästli, P., and Wiemer, S.: Designing understandable, action-oriented, and well-perceived earthquake risk maps – the Swiss case study. [under review in *Frontiers in Communication*]

Danciu, L., Nandan, S., Reyes, C., Basili, R., Weatherill, G., Beauval, C., Rovida, A., Vilanova, S., Sesetyan, K., Bard, P.-Y., Cotton, F., Wiemer, S., and Giardini, D.: The 2020 update of the European Seismic Hazard Model: Model Overview, EFEHR Technical Report 001, v1.0.0, https://doi.org/10.12686/A15, 2021.

Dasgupta, A., Poco, J., Rogowitz, B., Han, K., Bertini, E., and Silva, C. T.: The effect of color scales on climate scientists' objective and subjective performance in spatial data analysis tasks, IEEE Transactions on Visualization and Computer Graphics, 26, 1577–1591, https://doi.org/10.1109/TVCG.2018.2876539, 2020.

Edler, D., Keil, J., Tuller, M.-C., Bestgen, A.-K., and Dickmann, F.: Searching for the 'Right' legend: the impact of legend position on legend decoding in a cartographic memory task, The Cartographic Journal, 57, 6–17, https://doi.org/10.1080/00087041.2018.1533293, 2020.

Eurocode 8: Eurocode 8 – Design of structures for earthquake resistance – Part 1-1: General rules and seismic action, European Committee for Standardization (CEN), FprEN 1998-1-1 (draft), 2023.

Getto, G. and Amant, K. St.: Designing globally, working locally: using personas to develop online communication products for international users, Commun. Des. Q. Rev, 3, 24–46, https://doi.org/10.1145/2721882.2721886, 2015.

Grünthal, G., Stromeyer, D., Bosse, C. et al. The probabilistic seismic hazard assessment of Germany—version 2016, considering the range of epistemic uncertainties and aleatory variability. Bull Earthquake Eng 16, 4339–4395, https://doi.org/10.1007/s10518-018-0315-y, 2018.

Han, M., Mizrahi, L., Dallo, I., and Wiemer, S.: Sequence-specific updating of European ETAS model: Application to the 2023 Türkiye-Syria earthquake sequence, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17634, https://doi.org/10.5194/egusphere-egu23-17634, 2023.

Jiménez, M. J., Giardini, D., Grünthal, G., SESAME Working Group. Unified seismic hazard modelling throughout the Mediterranean region. Bollettino di geofisica teorica ed applicata 42(1-2), 3-18, 2001.

Karjack, S., Brudzinski, M. R., and Shipley, T. F.: Assessment of the general public's understanding of rapidly produced earthquake information products ShakeMap and PAGER, Seismological Research Letters, 93, 2891–2905, https://doi.org/10.1785/0220210318, 2022.

Maltese, A. V., Harsh, J. A., and Svetina, D.: Data visualization literacy: investigating data interpretation along the novice—expert continuum, Journal of College Science Teaching, 45, 84–90, 2015.

Marti, M., Stauffacher, M., and Wiemer, S.: Difficulties in explaining complex issues with maps. Evaluating seismic hazard communication – the Swiss case, Natural Hazards and Earth System Sciences, 19, 2677–2700, 2019. https://doi.org/10.5194/nhess-19-2677-2019

Marti, M., Stauffacher, M., and Wiemer, S.: Anecdotal evidence is an insufficient basis for designing earthquake preparedness campaigns, Seismological Research Letters, 91, 1929–1935, https://doi.org/10.1785/0220200010, 2020.

Marti, M., Haslinger, F., Peppoloni, S., Di Capua, G., Glaves, H., and Dallo, I.:. Addressing the challenges of making data, products, and services accessible: an EPOS perspective. Annals of Geophysics, 65(2), DM212, https://doi.org/10.4401/ag-8746, 2022. Marti, M., Dallo, I., Roth, P., Papadopoulos, A. N., and Zaugg, S.: Illustrating the impact of earthquakes: Evidence-based and user-centered recommendations on how to design earthquake scenarios and rapid impact assessments, International Journal of Disaster Risk Reduction, 90, 103674, https://doi.org/10.1016/j.ijdrr.2023.103674, 2023.

McMahon, R., Stauffacher, M., and Knutti, R.: The unseen uncertainties in climate change: reviewing comprehension of an IPCC scenario graph, Climatic Change, 133, 141–154, https://doi.org/10.1007/s10584-015-1473-4, 2015.

Pohl, C., Klein, J. T., Hoffmann, S., Mitchell, C., and Fam, D.: Conceptualising transdisciplinary integration as a multidimensional interactive process, Environmental Science & Policy, 118, 18–26, https://doi.org/10.1016/j.envsci.2020.12.005, 2021.

Robertson, P. K. and O'Callaghan, J. F.: The generation of color sequences for univariate and bivariate mapping, IEEE Computer Graphics and Applications, 6, 24–32, https://doi.org/10.1109/MCG.1986.276688, 1986.

Röttger, U. Einsatz der Public Relations im Rahmen der Unternehmenskommunikation. In M. Bruhn, F. R. Esch, & T. Langner (Hrsg), Handbuch Instrumente der Kommunikation. Grundlagen, innovative Ansätze, praktische Umsetzungen (2. Aufl.). Springer Reference Wirtschaft Wiesbaden, 2016.

Schneider, M., Cotton, F., and Schweizer, P.-J.: Criteria-based visualization design for hazard maps. Natural Hazards and Earth System Sciences, 23(7), 2505–2521. https://doi.org/10.5194/nhess-23-2505-2023, 2022.

Schneider, M., Wein, A., van der Elst, N., McBride, S. K., Becker, J., Castro, R., Diaz, M., Gonzalez-Huizar, H., Hardebeck, J., Michael, A., Mixco, L., Page, M., and Palomo, J.: Visual Communication of Aftershock Forecasts Based on User Needs: A Case Study of the United States, Mexico and El Salvador. https://doi.org/10.31219/osf.io/5qam4, 2023

Sherman-Morris, K., Antonelli, K. B., and Williams, C. C.: Measuring the effectiveness of the graphical communication of hurricane storm surge threat, Weather, Climate, and Society, 7, 69–82, https://doi.org/10.1175/WCAS-D-13-00073.1, 2015.

Smith, J.: Defining and applying Personas to UX Design, Web Design Envato Tuts+, 2012.

Sullivan-Wiley, K. A. and Short Gianotti, A. G.: Risk perception in a multi-hazard environment, World Development, 97, 138–152, https://doi.org/10.1016/j.worlddev.2017.04.002, 2017.

Thompson, M. A., Lindsay, J. M., and Gaillard, J. C.: The influence of probabilistic volcanic hazard map properties on hazard communication, J Appl. Volcanol., 4, 6, https://doi.org/10.1186/s13617-015-0023-0, 2015.

Wang, T., Shu, S., and Mo, L.: Blue or red? The effects of colour on the emotions of Chinese people, Asian Journal of Social Psychology, 17, 152–158, https://doi.org/10.1111/ajsp.12050, 2014.

Wössner, J., Danciu L., Giardini, D. et al. The 2013 European Seismic Hazard Model: key components and results. Bull Earthquake Eng 13, 3553–3596, https://doi.org/10.1007/s10518-015-9795-1, 2015.

Wood, M. M., Mileti, D. S., Bean, H., Liu, B. F., Sutton, J., and Madden, S.: Milling and public warnings, Environment and Behavior, 50, 535–566, https://doi.org/10.1177/0013916517709561, 2018.

Zerfaß, A. and Piwinger, M. (Eds.): Handbuch Unternehmenskommunikation: Strategie - Management – Wertschöpfung, Springer Fachmedien Wiesbaden, Wiesbaden, https://doi.org/10.1007/978-3-8349-4543-3, 2014.