Executive summary:

SHARE successfully delivered a Euro-Mediterranean wide probabilistic seismic hazard assessment across multiple disciplines spanning from geology to seismology and earthquake engineering. The project built a framework for integration across national borders, compiled relevant earthquake and fault data, and developed a sustainable, high-impact authoritative community-based hazard model assembled by seeking extensive expert elicitation and participation through multiple community feedback procedures.

SHARE has established a quality-controlled computational infrastructure that enabled to deliver all products that are of key interest to the seismological and engineering community as well as for the public and policy makers. SHARE spearheads regional scale hazard assessment programs releasing an unprecedented range of products: large data resources are freely available to stimulate research and a large range of hazard results is ready to be used in multiple engineering applications and decision making processes.

As input to the new hazard mapping, SHARE introduced new standards and databases, including a new European historical and instrumental catalogue (SHEEC), a new database of active faults with over 64'000 km of mapped faults, a full-logic tree of ground-motion prediction equations covering the main tectonic regions, a new model of maximum magnitude for the whole region, a new regional reference geodetic mapping, three independent models expressing the expected recurrence of earthquakes in the future (based on different combinations of area sources, distributed seismicity and larger events concentrated on faults), new procedures for expert elicitation and the description of aleatory uncertainty.

SHARE produces a legacy of more than sixty time-independent European seismic hazard maps (ESHMs) spanning spectral ordinates from PGA to 10 seconds and exceedance probabilities ranging from 1 to + 1/10'000 yearly probability. The hazard values are referenced to a rock velocity of vs30=800m/s at 30m depth. SHARE models earthquakes as finite ruptures and includes all events with magnitudes MWgreater than=4.5 in the computation of hazard values. SHARE introduces an innovative weighting scheme that reflects the importance of the input data sets considering their time horizon, thus emphasizing the geologic knowledge for products with longer time horizons and seismological data for shorter ones.

Single-site hazard products such as uniform hazard spectra and disaggregation are available for locations on-land at a spacing of about 10 km summing up to more than 120,000 sites. The products reflect essential information including all uncertainties that contribute when assessing seismic hazard and are suitable to serve as reference for engineering applications as well as for insurance purposes. The wealth of output products is available through a web portal that provides access to mapped and single site hazard information. All products as well as the input data are accessible and documented on the SHARE website and the portal. The SHARE portal will be integrated in the European facility for earthquake hazard and risk (EFEHR), the European access point for hazard and risk information of the European earthquake data and products portal (see http://www.seismicportal.eu online).

The SHARE products will impact the assessment of seismic hazard by setting a European and worldwide standard. SHARE proposes new pathways to develop the next European seismic zonation map and also proposes parameters essential for new seismic design practices. On the European Community level, long lasting impact is expected by serving as reference model for the Eurocode 8 revisions, owing to the participation of the CEN/TC250/SC8 committee members in the project. At global level, the procedural implementation already is serving as guideline for other regional projects within the Global Earthquake Model (GEM) initiative.

Project context and objectives:

Seismic hazard assessment is one of the key products seismology offers to society. SHARE targeted an unprecedented approach to harmonize probabilistic seismic hazard assessment for the Euro-Mediterranean region given the many scientific and technological developments since the last project on this scale (SESAME, UNESCO-IUGS International Geological Correlation Program Project 382). The project was initiated timely connected with worldwide and regional initiatives, such as the global earthquake model (GEM) and the earthquake model for the Middle East (EMME) project, to support the use of highest standard in assessing seismic hazard around the globe and to comparatively understand the relative level of seismic hazard. In particular for the region of the European Union, it was important to establish the project SHARE to serve a new reference model for the revision of the European building code EC8. A close cooperation was envisioned and implemented to ensure the SHARE results to be applicable for the current version of the EC8, but also to prepare for the requirements of future revisions of the building code.

Within the projects lifetime, several tragic destructive earthquakes occurred within Europe and worldwide (e.g. L'Aquilla, Italy, 2009; Haiti, 2010; Van, Turkey, 2010; Christchurch, New Zealand, 2011; Tohoku, Japan, 2011, Lorca, 2011; Emilia-Romagna region, 2012) causing large numbers of fatalities. These disastrous earthquakes causing many fatalities and long-lasting economic issues remind of the socio-economic relevance and emphasize the need to reassess seismic hazard periodically respecting the latest scientific knowledge.

SHARE focused on time-independent seismic hazard assessment and delivered appropriate input to mitigate seismic hazard and risk. It is simple to state that earthquakes do not kill people; rather collapsing structures or secondary effects such as tsunamis, landslides, fires, etc. are the final causes of fatalities. However, it is essential to understand the primary problem, the earthquake likelihood and the ground shaking effects, and then use this information appropriately to mitigate the risk by reducing the vulnerability of society. A regional program is capable to strongly contribute to hazard and risk mitigation and to safer living conditions in the Euro-Mediterranean region. The generated foreground from SHARE is therefore planned to be scientifically exploited within other on-going projects funded by the European Commission that target to assess single risks, systemic risks or the risk related to multi-hazard components.

In case of an actual earthquake situation, seismologists are often overwhelmed with new data and the flood of interest by the public, the media and policy makers. SHARE results support the capabilities of the scientific community to communicate the seismic hazard, to put the hazard into perspective regionally and to compare to other hazards, relevant for long-term planning of disaster relief actions on the national and European scale.

SHARE has defined its hazard model to cope with the uncertainties in the earthquake process itself and with the uncertainty and deficiencies in the ability to measure and model the earthquake source processes as well as the ground shaking. The basic datasets, although they have greatly improved in the last decades, are still sparse, non-uniform and inhomogeneous as well as partly not freely available. These shortcomings have been targeted within the project and the spirit of having transparent, reproducible and freely accessible datasets and software has been promoted. From this perspective, it is to be noted that the results of this project may be seen as one additional milestone to understand seismic hazard, however, seismic hazard assessment needs to be understood as a dynamic entity with changing outcomes due to increase knowledge over time.

SHARE uses the method of probabilistic seismic hazard assessment (PSHA) for the Euro-Mediterranean region, the only method to generate a scientifically sound estimate of ground shaking potential on a large scale including all uncertainties. For specific places of interest, such as the locations of critical infrastructures, this method serves as the first step and should be supplemented by deterministic assessment of seismic hazard. The scenarios earthquakes that contribute most to the seismic hazard at a site are found by disaggregation and is then used in deterministic modelling. The combination of both methods is of specific interest for risk assessment.

This SHARE model is more complex than previous models and reflects various views on the earthquake process in the way a probabilistic model should reflect the scientific state-of-the art. SHARE has followed an approach in which homogenization and harmonization were guiding principles; thus, the SHARE hazard model results cannot replace site-specific hazard assessment for which more local data and knowledge is available or reassessment on the national scale. Here we only want to point to one issue: the smallest magnitude in the SHARE European Earthquake Catalog is MW=3.5, which is a large cut-off for many low-seismicity regions in the Mid- and Northern Europe. During the project it was not possible to include smaller magnitudes; thus, specific attention should be paid to such issues in future assessments. SHARE, however, clearly outlined procedural guidelines for future projects on a regional and national scales and was intended as a guiding reference model.

Considering the identified areas of socio-economic relevance, the existing challenges and present limitations of Probabilistic Seismic Hazard Assessment, SHARE addressed the following specific objectives:
- SHARE builds a framework for integration across disciplines, by involving participants, competences and experts spanning all fields from earthquake engineering to geology to engineering seismology, and for integration across national borders, to compile earthquake data and assess seismic hazard without the burden of political constraints and administrative boundaries. An authoritative community model will be assembled by seeking extensive expert elicitation and participation, and through community feedback.
- SHARE pursues best practices and highest standards in all aspects of seismic hazard assessment, from data collection to the computational framework.
- SHARE covers the northern Euro-Mediterranean area from the mid-atlantic ridge in the West to eastern Turkey. We do not consider Northern Africa nor the Near East and Red Sea areas.
- SHARE develops an appropriate computational infrastructure as well as rigorous procedures to qualify, evaluate, and, if possible, test all components of the hazard, as a basis for longevity and continuous improvement of a dynamic model ready to incorporate the most recent developments from science and engineering.
- SHARE maintains a direct connection to the Eurocode 8 applications and the definition of the Nationally Determined Parameters, through the

participation of the CEN/TC250/SC8 committee in the definition of the output specification requirements and in the hazard validation.
- SHARE produces direct outputs for risk assessment, enabling the European participation in the Global Earthquake Model program initiated by the OECD.
- SHARE focuses on effective dissemination of hazard tools and results recognizing the various needs of different user and consumer groups.

Project results:

SHARE scientists implemented the proposed strategy that forced all scientists in the seven workpackages to strongly collaborate. Defining engineering requirements at the beginning of the project served as a guide to assemble appropriate databases and gather scientific and technical knowledge for the selection of ground motion prediction equations as the basis for the assessment of earthquake occurrence probabilities and the calculation of ground shaking parameters. These models, cross-checked for their consistency, were then combined within three different approaches to model the earthquake activity in the assessment of seismic hazard. The proposed hazard model was then translated to the quality-controlled computational infrastructure and the results were handed back to the engineering partners to create risk scenarios and to propose products of European wide impact.

SHARE provides an unprecedented resource of scientific input data and hazard model results that is publicly available in particular for the scientific and engineering community for further developments. We emphasize that in particular the wealth of input/raw data is of enormous value for scientific developments on the Euro-Mediterranean scale, prone to boost scientific research and result in applicative products for mitigating seismic hazard and risk within Europe.

Seismic hazard results, i.e. exceedance probabilities of a ground motion intensity measure within a specified period, are now available for five different return periods and for at least twelve different spectral periods. The hazard model consists of 60 mean hazard maps, compared to the output of one map by the SESAME project (UNESCO-IUGS IGCP No. 382) for PGA and an exceedance probability of 10% in 50 years. In addition, SHARE generated results that:
1) represent the uncertainties of the hazard maps in terms of multiple standard deviations;
2) show detailed site specific information such as hazard curves and uniform hazard spectra for each of the more than 120,000 sites on-land;
3) show disaggregation of the hazard computation to understand at the specific sites which magnitude earthquakes at what distances are the largest contributors to the hazard. This product is of immediate interest for engineering procedures when selecting appropriate time-series for building design.

SHARE thus sets new standards in the output of hazard results that were available in Europe only in a few countries.

Progress in the definition of earthquake sources and activity rates

The main results consist of data compilations and data elaborations. Three major databases at the state-of-the-art were compiled, geographically complete as much as possible for entire Europe, homogeneously collected and authoritative. They comprise a fundamental legacy and will become a European reference in the forthcoming years. We foresee that they will be used in the future for SHAs at various scales and other research purposes. The databases are:
1) the new SHEEC earthquake database (see http://www.emidius.eu/SHEEC online), which for the critical window of 'earthquakes before 1900' features a) a consensus, full list of events, and b) full parameters for the 645 larger (M = 5.8) events;

2) the new homogenized European seismic source zone model (SSZM), featuring over 400 source zones, carefully tailored to accommodate differences and inconsistencies across national boundaries (see http://www.SHARE-eu.org online);
3) the first pan-European database of active faults and seismogenic sources (see http://diss.rm.ingv.it/SHARE-edsf/index.html online), which includes about 1,128 fully-parameterized seismogenic sources, for a total fault length of nearly 64,000 Km (98 sources and 8,500 Km at the beginning of the project).
WP3 has also supplied a number of elaborations, including:
- a European-scale finite element strain model that implemented the largest faults studied within SHARE, the subduction interfaces, realistic rheology, and a crustal structure with varying thickness. The integration of the subduction zones and the faults allowed an unprecedented level of detail for the Central Mediterranean (Apennines and Dinarides);
- a set of activity rates for all seismogenic source zones encompassing the entire area covered by SHARE, calculated using a common statistical approach that employs a penalized maximum likelihood procedure (Task 3.7);
- a set of commonly derived activity rates for the based on the assessed geological parameters of single fault sources;
- a set of Mmax independently calculated using the SHEEC catalogue for the zone of the final seismic zonation model, for all sources of the seismogenic source model and for 44 'superzones' encompassing the entire are covered by SHARE separated due to their primary tectonic regime;
- a simplified 3D geotectonic model suitable for calibrating the ground motion prediction equations to be used in the different tectonic setting of Europe.

Progress in strong ground motion modeling

SHARE produced a first consensus ground motion model for the Euro-Mediterranean region on the basis of a rock velocity of vs30=800m/s. From the very large number of existing ground-motion predictions equations (GMPEs), a pre-selection of the most relevant ones following exclusion criteria by Bommer et al. (2010) was performed. Provided the updates large SHARE strong motion database, a testing procedure has been combined with standard expert analysis to compare the performance of each model against the SHARE database. This methodology, the ground motion logic-tree structure and logic tree weights are described in Delavaud et al. (2012). This procedure is innovative and closely follows requirements for SSHAC-level 3 formal expert elicitation.

SHARE has achieved progress along two directions in the definition of new site amplification factors: (1) keeping the EC8 site classification criteria unchanged and proposing the corresponding 'optimal' spectral shapes and/or amplification factors (Pitilakis et al, 2013), (2) exploring new tracks for new site classification, and proposing site amplification factors accordingly (Sandikkaya et al., 2013).

SHARE made considerable progress in understanding European wide proxies to site conditions. Correlations between vs30 and topographic slope were examined; the results show that the method only provides an information gain for class B (rock) and to a certain extend for class C (stiff soil) in stable areas (Lemoine et al, 2012). SHARE thus concluded that vs30-slope correlations proposed by Wald & Allen (2007) are only useful for smaller scale SHAs in active parts of Europe and only in the absence of more detailed information. Thus, SHARE sticks to provide only rock hazard.

The engineering seismologists within SHARE used the synergies with the hazard modeling team and presented work on the influence of hazard estimates when using GMPEs with erroneous source-to-site distance metrics. A key point is to use the same metrics in the computation of the hazard and in the derivation of GMPEs (Bommer and Akkar, 2012). New ways of physically sound predictive ground motion models based on fully data driven approaches are developed (Derras et al., 2013) and also include predictive equations for alternate ground motion parameters such as Arias intensity and strong motion duration, both of special interest by the engineering community. The new models in development also target larger ranges of spectral ordinates.

Progress in seismic hazard assessment

SHARE has achieved regional harmonization of a probabilistic hazard assessment program at a level never reached before on the European scale. During the course of the project, more than fifty workshops have been held across Europe to collect data and provide the participants with the modeling intentions and preliminary results of the PSHA. The project has benefitted from the enthusiasm of the wider seismological, geological and engineering community and leveraged this by including much more expert expertise as was expected at the beginning of the project. SHARE thus has worked across national boundaries and multiple disciplines disregarding traditional administrative and disciplinary borders existent in the previous programs.

We implemented a formal procedure to involve expert elicitation when building of the hazard model. As guideline, we used the recommendations of the Senior Seismic Hazard Analysis Committee (SSHAC, NUREG-2117), yet could not on all levels implement the formal procedures equally. The strong ground motion modeling work-package used a defined strategy to prepare the ground motion prediction equation logic-tree (Delavaud et al., 2012). The seismic source logic-tree has been assembled involving the wider community and several feedback rounds. The modeling team organized two Model Review workshops in 2013 and similarly prepared for the final meeting of SHARE, thus having feedback on the source model three times. Each time, material was provided before the workshops so that appropriate preparation time was given. The topics were then discussed with consortium members and external experts and the conclusions were implemented in the modeling procedure. The WP leaders and the modeling team functioned as mediators in this procedure.

The SHARE model explicitly treats uncertainties, epistemic and aleatory, by using the logic-tree approach. This is implemented by within the GMPE logic–tree and the logic-tree of the source model. For the first time, a European wide model considers three views on the stationary process of earthquake activity:
1) an Area Source (AS) Model,
2) a model that combines activity rates based on fully parameterized faults imbedded in large background seismicity zones, the Fault-Source & Background (FSBG) Model, and
3) a kernel smoothed model that generates forecasts based on fault slip and smoothed seismicity (SEIFA).

These three principal models show the various models for seismic activity in the European region. Uncertainties are handled with different approaches for the distinct tectonic regimes: for example, the maximum magnitudes within the tectonic regimes are assessed differently using either a global analogue approach for stable continental regions (EPRI, 1984) in contrast to a observation driven approach in active tectonic regions. SHARE implemented a weighting scheme of three source model options that reflects the base data used to build each one. The AS-model is given the largest weight for the various exceedance probability levels and the weight increases with decreasing exceedance probability levels. We increase the weight of the FSBG-model for decreasing exceedance probability levels due to the importance of the geologic information for the estimation of activity rates. The contribution of the SEIFA model decreases with decreasing exceedance probability levels because SEIFA itself considers the contribution of seismicity stronger than the fault information. For exceedance probabilities larger than 10% in 50y, believe that the SEIFA-model and the AS-model should be equally weighted. We define the combination 0.5 AS-model, 0.2 FSBG-model, and 0.3 SEIFA-model as the average weighting scheme used to generate hazard curves.

We model the Cyprus, Hellenic and the Calabrian arc for the first time as complex fault sources for the interface seismicity of the subduction zone. The inslab seismicity is modeled as volumes at depth. A particular limiting factor in the definition of the activity rates within subduction zones is the large uncertainty in determining focal depth of events which could only be addressed by ad-hoc definitions. The differentiation between crust, interface and inslab seismicity is included in all three source model option and the implementation is the same for the AS- and the FSBG-model. The SEIFA-model takes another approach following its own conceptual setup.

SHARE produces a legacy of more than sixty time-independent European Seismic Hazard Maps (ESHMs). The range of products result from the availability of ground motion prediction equations spanning many spectral ordinates and the range of hazard curves that were calculated (10-1y-10-4y). The hazard values are referenced to a rock velocity at a depth of 30m, vs30=800m/s. SHARE integrates hazard values starting from a minimum magnitude of MW=4.5; all events are treated as extended ruptures, defining the extent of the rupture with the appropriate scaling relation of Wells and Coppersmith (1994). The implementation then uses the correct distance metrics of the ground motion prediction equations.

The maps illustrate the probability to exceed a level of ground shaking in terms of the peak ground acceleration in a fifty years period. On the left, the illustrated levels of ground shaking are expected to be exceeded with a 10% probability in 50 years, on the right it is expected that the level of ground shaking is only exceeded with a 2% probability in 50 years. This corresponds to return periods of 475 years and 2475 years.

SHARE has used its leading role as a regional program of the Global Earthquake Model (GEM) to strongly collaborate in the development of a quality controlled computational infrastructure to calculate seismic hazard. GEM has developed OpenQuake as its hazard engine and benefitted from the feedback of the first large application with a complex model as prepared in SHARE. OpenQuake has constantly improved in this process and for the final computations, SHARE could use feature not existing before to adequately treat extended sources for the generation of hazard results. SHARE ensures that the version of OpenQuake will remain available to be able to reproduce the results. It should, however, be noted that OpenQuake will be further developed implementing additional features and / or modifications to increase speed and handling of model concepts. In particular, we expect that the pre-processing software tools will replace parts of what was written specifically for SHARE.

Progress in the definition of engineering requirements and applications

A key achievement has been to ensure the compatibility of the SHARE hazard output specifications with the Eurocode 8 application requirements. This has been undertaken by conducting annual review meetings with the CEN/TC250/SC8 Committee. A specifications document for the outputs of the SHARE project was drafted together with the CEN/TC250/SC8 Committee at the beginning of the SHARE project (Deliverable D2.1) and SHAREd with the other project partners responsible for the ground motion and hazard modeling to ensure compatibility.

The hazard outputs in terms of UHS for return periods used in current design codes in Europe (primarily 475 years) were used to estimate risk maps in terms of fatalities and economic losses for a number of locations in Europe: Lisbon, Italy, Marmara Region, Thessaloniki. These risk maps were compared with the risk maps obtained using the current state-of-the-art hazard assessments in those case study areas. The resulting comparative risk maps help present the impact that the use of SHARE hazard in these regions could have on risk mitigation efforts.

The results in terms of hazard curves and UHS were used to derive zonation maps at periods of interest in the construction of EC8 elastic design spectra and scaling parameters. These maps were then discussed with a number of European engineers at a final meeting and European-wide zonation maps were suggested.

Recommendation for the EC8 committee are based on a critical review of seismic hazard practice from around the world, considered the use of loss assessment for the calibration of seismic design codes and a fresh look at the minimum capacity of buildings designed without seismic actions. The preliminary recommendations are divided in three levels that represent short-term, mid-term and long-term perspectives. Short-term implies a direct use of the SHARE outputs, while both mid- and long-term asks for more research to implement actions on the SHARE results.

WP2 – Engineering requirements and applications

Main scientific and technological results

The main achievements from the research and development in WP2 can be broken into four key areas: Engineering Requirements, Engineering Applications, European Zonation, and Recommendations to Eurocode 8 Committee.

Engineering requirements

A key achievement of WP2 has been to ensure the compatibility of the SHARE hazard output specifications with the Eurocode 8 application requirements. This has been undertaken by conducting annual review meetings with the CEN/TC250/SC8 Committee. A specifications document for the outputs of the SHARE project was drafted together with the CEN/TC250/SC8 Committee at the beginning of the SHARE project (month 8)

and SHAREd with the other project partners responsible for the ground motion and hazard modelling. The engineering requirements of SHARE were summarised as follows:
- Hazard maps for a range of return periods between 25 and 5000 years for the median (from the logic tree) of PGA at a reference bedrock level.
- Hazard maps for return periods between 25 and 5000 years for median spectral ordinates (acceleration and displacement) on type A ground (reference bedrock) for a range of period ordinates (those covered by all GMPEs in logic tree)
- Hazard maps, for aforementioned return periods, of median F0, TB, TC, at a reference bedrock level.
- Hazard maps, for the aforementioned return periods, for values of median PGV and median PGD (or appropriate proxies).
- Maps, for the aforementioned return periods, of median TD (if possible) at bedrock level.
- Zonation Map for Europe based on PGA (EN 1998-1 3.2.1 (1)P, EN 1998-1 3.2.1 2), corresponding to the no collapse requirement (EN 1998-1 3.2.1 3).
- Zonation map for Europe considering both PGA and spectral shape PSHA disaggregation in terms of PGA and spectral ordinates (i.e. for the results of the maps of output 2). Note, the surface-wave magnitude (Ms) is needed as output of the disaggregation, though this may be obtained from a conversion of Mw.
- Estimation of 'k-value' (a parameter to allow for the scaling of hazard to intermediate return periods) for median hazard, and indication of uncertainty and applicable return period range.
- Portal with access for engineers to the above output (details to be determined between WP2 and WP6).
- Proposals for new spectral shapes for EN 1998 for both acceleration and displacement spectra.

Engineering applications

The outputs of WP5/6 in terms of UHS for return periods used in current design codes in Europe (primarily 475 years) were used to estimate risk maps in terms of fatalities and economic losses for a number of locations in Europe: Lisbon, Italy, Marmara Region, Thessaloniki. These risk maps were compared with the risk maps obtained using the current state-of-the-art hazard assessments in those case study areas. The resulting comparative risk maps help present the impact that the use of SHARE hazard in these regions could have on risk mitigation efforts.

European zonation

The UHS and hazard curves of WP5/6 in SHARE (as specified by WP2) were used to produce zonation maps of F0, TB, TC, TD, k-value, ASI and VSI. These maps were discussed with a number of European engineers in a final meeting, and Europe-wide zonation maps for defining UHS were proposed.

Recommendations to Eurocode 8 Committee

In order to make recommendations to the EuroCode 8 Committee on the future of seismic actions in design codes in Europe, the following activities were undertaken:
- A critical review of recent seismic hazard practice in many countries including US, New Zealand, Japan, Italy and Canada was undertaken, leading to Deliverable D2.2.

- Deliverable D2.3 considered the use of loss assessment for the calibration of seismic design codes.
- Deliverable D2.4 looked at the minimum capacity of buildings designed without seismic actions, to understand the level of hazard below which zonation is not needed (as a detailed description of the seismic actions for design would not be needed).

The preliminary recommendations from these deliverables, which were discussed with a number of European engineers in a final meeting, are as follows:

Short-term (using directly the outputs of SHARE)
- The two spectral shapes (Type I and Type II) anchored to PGA could be removed and replaced by zonation maps of F0, TB, TC and TD such that spectral shapes can vary with location and return period.
- Should the latter not be adoptable immediately, it is recommended that Ms is replaced by Mw.
- Better guidance should be provided on the estimation of the controlling scenario (from disaggregation at the period of vibration of the structure of interest).
- The k-value suggested within EC8 should be revised, and possibly based on the outcomes of SHARE. An upper and lower bound return period that can be estimated with these k-values should also be reported in EC8.

Mid-term (with more research, building upon outputs of SHARE)
- New vertical spectral shapes need to be derived for EC8, building upon the outputs of WP4.
- A zonation-based approach should be removed, and the UHS provided and used directly (through a web-portal).
- Amplification factors and site classification table in EC8 could be updated based on the research from WP4.
- Deeper geological characteristics could be accounted for in the site amplification.
- Further consideration on the use of the epistemic uncertainty could be given. For example, could the maps of fractiles be considered for the definition of importance factors?
- Displacement spectra require more attention, and the current informative annex should be revised.

Long-term (with more research, building upon outputs of SHARE)
- Risk targeted seismic design actions should be further investigated for application within EC8.
- The possible use of aggregate hazard analyses, rather than site specific, for design actions (Malhotra, 2008) requires further consideration.
- A new paradigm for the future of seismic design codes which considers the influence of design choices (in terms of stiffness, strength and ductility) on the aggregate losses to urban areas has been proposed. Future research in this direction is of merit.

WP3 – earthquake sources and activity rates

Main scientific and technological results

WP3 has been the biggest of the entire SHARE project, involving 13 out of 18 participating institutions and 38% of the global manpower, 80% of which was concentrated in Task 3.1 and 3.2. These two tasks resorted extensively to expert elicitation, which allowed them to bring in a huge amount of data from the entire continent in a relatively short time. Most if not all of the nearly 100 experts involved responded enthusiastically, showing that this form of involvement is highly rewarding at both a scientific and personal level, in addition to being very cost-effective.

It should be noted that WP3 benefited from an extraordinary and unprecedented amount of co-funding from national and other sources. Perhaps for the same reason WP3 forced a difficult but necessary circulation of ideas and models on how to go from science to practical results for Society.

Much of the activity of WP involved technical meetings and workshops organized on a regional basis by the institutions in charge of gathering data for each given area. Nearly 30 of such meetings have been held in addition to the general project assemblies. Some of these meetings were dedicated to the exchange of expertise and data with scientists operating in other projects and initiatives similar to SHARE, such as:
- BSHAP, funded by NATO and devoted to the seismic hazard of the Balkans,
- EMME, funded by the industry and devoted to the seismic hazard of the Middle East,
- EMCA, mostly funded by GFZ and devoted to the seismic hazard of the Central Asia,
- IberFault, funded by the Spanish government to investigate seismic hazard in Iberia.

All the goals of WP3 have been met as originally planned. Most of the Deliverables were released on time with a few exceptions. A delay in the elaboration of the European earthquake database (T3.1) triggered further delays in the elaboration of the Seismic Source Zone model (T3.4) and in the determination of Mmax (T3.5), which ultimately somewhat delayed the calculations of activity rates (T3.6). These delays resulted from the very structure of WP3, where '...many partial projects with numerous interconnections go on in parallel whereas ideally, they would have been dealt with in a sequential manner...', as stated by the Scientific Advisory Board (SAB) report following the 2nd Annual meeting in Oslo, 15-17 June 2011. For WP3 task leaders there was no other choice than follow the SAB advice to '...always favour the quality of the results and not the respect of deadlines....'.

Throughout the entire project WP3 has operated in close connection with the other WPs, with special emphasis on those dedicated to hazard calculations. In fact, although all of the activities were planned to be completed by the end of the second year, the combination of the initial delays with the need to interact with the other WPs during the hazard model building phase has forced the scientists in charge of some of the tasks to extend their involvement up to the very end of the project, investing on SHARE much more time and efforts than originally planned.

Joint efforts with other WPs included the creation of a simplified 3D model of homogeneous geotectonic zones of Europe, assembled jointly by scientists of Task 3.2 and of WP4. This regionalization has been used in a logic-tree approach for selecting the most appropriate Ground Motion Predictions Equations (GMPEs) for each individual area (Delavaud et al., 2012, JOSE). Throughout the second half of the project WP3 and WP6 scientists cooperated to ensure full and seamless compatibility of the parameter scheme adopted in the realization of the database of active faults and seismogenic sources with OpenQuake standards, both for crustal and for subduction fault sources.

Scientists working in WP3 have really strived to gather the largest possible amount of data, set new standards for their analysis and representation and bring the input data for SHARE at the same level as that reached in the countries that are most advanced in the practice of seismic hazard assessment. The Scientific Advisory Board has acknowledged these achievements and circumstances, stating that 'The data bases and maps developed within the project exhibit the highest quality presently possible in the field of seismic hazard assessment on a pan-European scale...', and added that 'It's only a pity that no more time and money is available in order to deepen in particular the interpretation of the results.

In the following the project results will be described on a task by task basis.

Task.3.1. European earthquake database

This task was completed in April 2011. The database was supposed to be delivered in 2010, but the project coordination requested that the tools for assessing earthquake parameters from macroseismic data points be further improved, with special emphasis on selecting the 'most reliable method' and on the calibrations against instrumental data in various European areas. The complexity and the critical implications of this request imposed a delay of 4 months for releasing the relevant deliverable ('Updated European earthquake catalogue, with homogeneous magnitude calibration', D3.2).

The new SHARE reference database is called SHEEC (SHARE European Earthquake Catalogue) and is composed by two parts:
1) SHEEC 1000-1899, compiled using the methodology developed in the frame of the project NERIES, module NA4. These procedures are described in detail in the SHEEC website (see http://www.emidius.eu/SHARE/task3_1/ online). The final list contains 4482 events. Only earthquakes with initial M presumably larger than 3.5 were considered, but the choice of such a low threshold is applicable only in selected areas of Northern Europe. This part of the catalogue was compiled by INGV-Milan and has been published in 2012 (Stucchi et al., 2012);
2) SHEEC 1900-on, compiled using the methodology developed by GFZ for the compilation of the 'Central, Northern and North Western European Catalogue' (CENEC; Grünthal et al. 2009). This part of the catalogue was entirely compiled by GFZ.
The catalogue now covers the area ranging from Ireland to Western Turkey, 30° East. Notice that the seismicity of the Azores and North Africa is explicitly not included.

A number of practical decisions concerning the catalogue were made at the Model Building Workshop held in Zurich on 17-19 May 2011. Most of these decisions involved updates, such as
1) for Greece, Turkey and the Aegean SHEEC includes the catalog by Makropoulus (AUTH);
2)SHEEC merges with the EMME catalog in the region up to longitude 32° east;
3) KOERI exchanged data with INGV and GFZ (both for before and after 1900) and took care of the region east of 32° working closely with Task 3.1 scientists on an appropriate catalog update;

4) the catalogues published by IGN (2010) and Pelaez et al (SRL, 2007) were included to cover the Maghreb region; 5) INGV-Milan took care of the seismicity of the Azores and Iceland, before 1900;
5) uncertainties were defined for events after 1900, in part taking them from original GFZ catalogues.

Task 3.2. European database of active faults and seismogenic sources

The database of active faults and seismogenic sources was implemented following the design illustrated by Basili et al. (2008, Tectonophysics). Guidelines on how to compile records to be incorporated in the database were released right after agreeing on this design at the beginning of the project. In September 2009, a technical report with these guidelines was made available to all partners (Basili et al., 2009, http://diss.rm.ingv.it/dissDocs/ RT108.pdf). A critical review of fault source definitions used in the INGV and USGS databases of seismogenic sources (Haller and Basili, 2011, SRL) was also taken into account.

Task 3.2 partners agreed upon a regional subdivision of the SHARE area to be covered. A scientist in charge was designated in each region to act as database manager by promoting and validating the flow of data in a common repository. Software tools were distributed among managers to facilitate the manipulation of database entries.

Different data collection strategies were adopted in different regions to accommodate the different needs, data availability and skills, and local scientific legacy. Several formal and informal meetings were organized to establish a common ground and compare strategies for homogenizing data. They also served for collecting input from a large number of elicited local experts. Most of the partners and local experts recommended as a key for the success of this Task that the database be kept alive after the end of the project in a long-term perspective and that INGV should host the public version of the database. These actions also promoted the development of regional fault-source datasets and, occasionally, dedicated public databases across Europe, such as QAFI for Iberia (http://www.igme.es/infoigme/ aplicaciones/qafi/; Garcia-Mayordomo et al., 2012, Journal of Iberian Geology), GreDaSS for Greece (http://eqgeogr.weebly.com/seismogenic-sources-in-greece.html; Caputo et al., 2012, Annals of Geophysics) and other ongoing initiatives for NW Europe (Vanneste et al., 2013, BSSA), eastern Europe (Kastelic et al., 2012, Marine and Petroleum Geology), central Mediterranean area (Basili et al., 2013, NHESS). These publications also provided a form of peer review for most of the material conveyed into the SHARE database. A special case had to be made for the Anatolian region, where most of the data was supplied by the sibling project EMME. In this case, it was necessary to adapt fault data that were independently compiled following different guidelines, recommendations and timelines.

The final release of the database consists of 1,128 crustal fault sources, for a total length of nearly 64,000 km, and three subduction sources. Alongside the database, input files for the hazard engine have been especially tailored. They consist of a file with a selection of the used parameters including the homogeneous reassessment of the maximum magnitude that can be released by each single fault source; the background area where minor seismicity is distributed around fault sources; and a file with a geometric discretization of the fault-source surfaces at depth for the use of faults within the smoothed-seismicity approach (for parameters see D6.6). Discovery and delivery of spatial data has been made available through a dedicated website hosted on an INGV web server. This website provides Database navigation through map viewing and record listing, as well as seamless download of relevant files for offline desktop usage.

Task 3.3. European crustal strain rates

The activity has been developed by collecting all finite-element geodynamic models available for Europe, collecting the necessary operational datasets, and building three models of strain and slip rates: one at the European scale, one for Fennoscandia, and one for the Dinarides. Modeling the Dinarides represented a step towards introducing the subductions within the entire European model.

As for the datasets, all crustal thickness, heat flow, stress and geodetic data available in the literature were explored. In order to verify the reliability of the datasets, two unified end-member models covering the whole SHARE study area have been built: one based on the assumption of isostasy and one that integrates the crustal structure, but without any faults and subduction zones. The resulting finite element model implements the largest faults studied within SHARE, the subduction interfaces, realistic rheology, and the crustal structure with varying thickness. The integration of the subduction zones and the faults allowed detailing the model in the Central Mediterranean (Apennines and Dinarides).

The models were calibrated with the main datasets available in mid-2011. The outputs of the models include the strain rates, the slip rates, the anelastic velocities, and the principal stress directions. As for the Dinarides, the earthquake activity rates were determined, and their dependence on the model characteristics and seismological parameters was studied.

To provide a uniform and independent control of the finite element models, the stress orientations between data clusters were determined by modifying and extending the analysis technique used by Bird and Li (1996) by adding an additional constraint governing the probability algorithm. This technique was used to create a map of the maximum horizontal compressional stress orientations in the greater European region (including Europe, Turkey and Mediterranean Africa). The method provides a means of reproducing significant local patterns in the stress field. Several mountain ranges in Europe display 90° changes in the orientation between their crests (which often experience normal faulting) and their foothills (which often experience thrust faulting). This pattern constrains tectonic stresses to a magnitude similar to that of topographic stresses.

Task 3.4. Seismic Source Zones

A new seismic source zone model (SSZM) for seismic hazard has been constructed for the SHARE region. The model stretches from the Mid-Atlantic Ridge and Iceland in the west, to Romania and Turkey in the East.

The model was constructed from existing and local models; some of the zones were then modified. New areas not present not present in SESAME are Iceland and, for what concerns intermediate seismicity, the Cyprean Arc. Improved homogenization of the SSZM has been made with focus to geological and seismological boundaries. The whole SHARE area is covered with 423 source zones. The new SHARE model show major changes compared to previous European studies.

In total eight workshops all over Europe were held in order to build a community model with experts from 27 European countries. During the period of assessing the activity rats, the WP5 modeling team modified the area source model with the objective of homogenizing the model and to complete it: 1) At the eastern / south-eastern border of Turkey, area sources from the EMME-project were used; 2) In many areas, the earthquake data did not support the provided area sources, many of them being empty. Thus, area sources were merged to leading to better constrained activity rates.

Task 3.5. Homogeneous determination of maximum magnitude

This Task released on schedule its main product (Deliverable 3.3), but its activity was critically slowed down by the already mentioned delays in the delivery of the earthquake catalogue and of the seismogenic source zone model, and by the unavailability of the seismogenic sources until the end of May 2011. Nevertheless, preliminary models based on a transparent and reproducible procedure, including choices made by expert judgment, were presented at every meeting, thus allowing the entire Mmax set to be quickly recomputed as soon as improved data became available.

The Mmax model was released in June 2012 following several rounds of interaction with scientists of nearly all the other tasks of WP3. Mmax was independently calculated based on the SHEEC catalogue for the final seismic zonation model, for the seismogenic source model and for the 44 'superzones' encompassing the entire are covered by SHARE. The calculation of Mmax in the superzones followed the construction of a logic tree and was based on the following general criteria
- the minimum value (Vmin) of the distribution was anchored to the maximum magnitude (including the relevant uncertainty; Mobs + Unc) observed in the earthquake catalogue;
- the maximum value (Vmax) of the distribution was set equal to the previous values incremented by 0.6;
- a fixed minimum value was defined according to the tectonic type of superzone (6.6 in the active regions; 6.5 in the SCRs);
- in a few cases the range of the distribution was incremented to 0.9 in order to include the magnitude expected by fault information.

Task 3.6. Earthquake activity rates

This Task released on schedule its Deliverable 'D3.7 – Logic tree of earthquake activity rates', and was intended to provide estimates derived from the data supplied by Tasks 3.1 , 3.2 and 3.5. Similarly to Task 3.5, the activities of Task 3.6 were somehow slowed down by the delays in the delivery of some of the input data.

A preliminary survey of current practices in Europe and North America showed that the consensus of informed opinion is that the 'best practice' for estimating activity rates from seismicity data is the maximum likelihood approach derived ultimately from the work of Weichert (1980), which allows joint estimation of activity rates and b-values, together with the uncertainty distribution, taking into account maximum magnitude (with uncertainty) and variable catalogue completeness.

Task 3.6 established procedures for computing magnitude-frequency distributions for each zone based on the SHEEC catalogue and on the seismic zonation model. All procedures were automated to a reasonable extent, so that values could be recalculated with the least effort following updates in the input data. Overall the activities of Task 3.6 tackled three fundamental issues:

Catalogue completeness: Completeness was assessed with historical considerations and expertise of the WP3/5 scientists. The completeness was given in large superzones (McModel1 in D6.6). Whenever these completeness levels, assessed for the large superzones where inadequate for fitting a Gutenberg-Richter type distribution, completeness values were modified by often increasing the completeness magnitudes (McModel2, D6.6).

Maximum magnitude: Maximum magnitudes were taken from Task 3.5. Activity rates were calculated using the largest maximum magnitude as input parameter.

Algorithmic estimate of activity rates: A penalised maximum likelihood procedure was used to compute activity rates using a Bayesian procedure for the b-value estimation.

The maximum likelihood procedure was skipped for SSZs with less than two earthquakes within the completeness bands. The procedure followed for such zones was as follows:
- the b value was taken to be the prior, with no uncertainty;
- for every completeness time window, an activity rate was calculated based on the number of events in the window divided by the length of the window; in case no events remains after completeness, it was set to N(M=4.0/106km)=0.05.
- Depending on the number of input data, either 25 pairs of activity rate parameters or only 1 pair was output.

Implementation of feedback from scientific advisory board

WP3 received ample feedback from the SAB following all three Annual meetings (Rome, 15-16 June 2010; Oslo, 15-17 June 2011; Istanbul, 19 - 20 November 2012).

After the first annual meeting the SAB pointed out that '...some of the SHARE activities are not well connected yet. This is especially true for building the database on active faults and seismogenic sources on the one hand, and establishing the seismic source zones on the other hand. These activities should be better brought together to fully exploit the potential of existing data for contributing to optimal seismic zoning. Up to the meeting a strategy was missing on how and how far the active fault and seismogenic source data base should be integrated in the seismic zoning activities...'. This point was well taken but was the inevitable effect of Tasks 3.1, 3.2 and 3.4 operating in parallel rather than sequentially. This problem was dealt with by running additional workshops specifically targeted to redesigning some of the seismic zones based on the knowledge gained by other Tasks, and particulary 3.1 and 3.2.

The SAB added that '...Guidelines and quality standards for harmonization should be elaborated by SHARE, in particular with respect to the integration of the active fault data base in the zoning activities...'. These concepts have been thoroughly elaborated in Task 3.2 (see description above), to the point that the SHARE guidelines on the harmonization of active faults and seismogenic source data have been partially incorporated into the relevant GEM global component.

Following the second annual meeting the SAB pointed out that the Mmx map showed '...astonishingly uniform Mmax values in zones of very different seismicity', and asked for '...A thorough review...'. The map was revised in 2012 following these recommendations.

The SAB pointed out again that '...An obvious difficulty of SHARE is that many partial projects with numerous interconnections go on in parallel whereas ideally, they would have been dealt with in a sequential manner ... it is strongly recommended to always favour the quality of the results and not the respect of deadlines. One year after the end of the project, nobody will ask anymore whether the project had respected its final deadlines – only the quality of the project results will then be of interest...'. These recommendations were taken very seriously. As already pointed out in the previous section on Deviations from Annex I, the deadlines for the some of the deliverables were slightly relaxed, workshops were organized and updates were provided to absorb into each databases the indications arising from the other databases as they became available.

Finally, the SAB pointed out that '...significant differences in SHEEC were presented between historical and statistical completeness. If the reasons for that are not clear, it would be interesting to discuss potential reasons/hypotheses for that in the report...'. This aspect was addressed by Task 3.1 scientists with an additonal report (downloadable from http://www.emidius.eu/SHARE/task3_1/SHEEC/docs/SHEEC_completeness_v3.pdf).

WP4 – Ground motion modeling

Main scientific and technological results

A new extended strong-motion database

A new extended strong-motion database has been built. All the characteristics of the initial strong-motion database, and on the extended one, with a description of the unification procedure are given in Yenier et al. (2010).

A consensus rock motion model for the European-Mediterranean region

From the very large number of existing ground-motion predictions equations (GMPEs), a pre-selection of those which are most relevant in the context of SHARE following exclusion criteria as proposed in Bommer et al. (2010). From the pre-selection a number of models have been identified for each category: 6 models for stable continental regions; 19 models for active crustal regions; 8 models for subduction zones; 1 model for deep earthquake focus area; 1 model for volcanic regions. The models have been adjusted to a common rock site definition. It has been agreed that the rock site will be defined by vS30=800 m/s. For the stable continental equation however, which are based on data from very hard rock site, e.g. vS30 greater than 2000 m/s, an adjustment has been needed in term of vS30 as well as an adjustment for the high frequency decay and hard rock to generic rock amplifications have been described (Van Houtte et al., Bull. Seismo. Soc. Am., 2011).

It was planned originally to perform a full host-to-target adjustment for regions of low to moderate seismicity which would have allowed the adjustment of GMPEs to regional properties of source, propagation and site determined from the analysis of weak motion data. However, since the scaling effects from weak to strong motion are not resolved (Drouet et al., 2011) this option has been cancelled. Rather, since the SHARE database is very large, a testing procedure has been combined with standard expert analysis to compare the performance of each model against the SHARE database. This methodology, the logic tree structure and logic tree weights are described in Delavaud et al. (2012). This new consensus ground-motion model for Europe takes into account 4 different tectonic types for GMPE's use (Active regions, SCR-'shields', SRC-'Foreland', subduction). This regionalisation scheme has been defined w with WP3.

The tools developed in the EC projects NERIES and SAFER, to generate shaking scenarios for individual events have been imported and their compatibility with the SHARE ground-motion models has been ensured.

New Site amplification factors

SHARE has achieved progress along two directions:
(1) keeping the EC8 site classification criteriaunchanged and proposing the corresponding 'optimal' spectral shapes and/or amplification factors,
(2) exploring new tracks for new site classification, and proposing site amplification factors accordingly.

The mean (+- 1SD) of the SHARE recordings has been compared with the EC8 normalized spectra (Pitilakis et al., 2012). The following results have been obtained : (a) EC8 proposed spectra values for subsoil B in periods Tgreater than1.5sec are higher from mean recorded values in contrast with recorded data for subsoil C, where the EC8 values are lower from the average recorded values (b). For soil classes C1, C2 proposed values are in good comparison with recorded data. The proposed elastic acceleration spectra have been improved (Pitilakis et al., 2013, in revision).

A new site amplification model for shallow crustal regions that considers both linear and nonlinear 23 soil effects has been proposed (Sandikkaya et al, 2013, in press). To comply with this objective, a database with the most recent VS30 information from pan-European region ihas been compiled. This feature of the model encourages its use for the future ground-motion prediction equations that will be devised particularly for Europe.

The response spectral amplification obtained by Pitilakis et al. (2013) and Sandikkaya et al. (2013) have been independently verified by Poggi et al. (2012, Report SED/SHARE/R/001/20121114) using a site-dependent methodology. The comparison showed good agreement.

Europe-wide proxies to site conditions

Slope and associated Vs30 values have been collected for Europe. Including the SHARE strong-motion database, a set of measured Vs30 estimates at thousands of locations in Europe have been obtained.

For each of these locations the topographic slopes using various digital elevation models were computed using GIS. The correlations between Vs30 and topographic slope were examined and compared to those presented by Wald & Allen (2007). The results (Lemoine et al., 2012) show that the method does a better job than blind chance for all site classes in active regions but only for class B (rock) and to a lesser extent class C (stiff soil) sites located in stable areas, although the conclusions for stable areas are based on limited data. According to these SHARE results, site classifications based on the VS30-slope correlations proposed by Wald and Allen (2007) are only useful for regional or national (and not local or site-specific) first-order studies in active parts of Europe and only in the absence of other more detailed information, excluding sites inside small basins or those with special geological conditions that may affect results (e.g. flat-lying volcanic plateaux, carbonate rocks, continental glaciated terrain or a coastal location if slope is not calculated using bathymetric data

Toward the new generation of ground-motion models

The discussions with WP2 (engineering needs) and WP5 (use of GMPE's for hazard computations) gave the opportunity to develop new methods of innovative tests which wil help to derive the next ground-motion models for Europe.

- A new model for the prediction of V/H ratios for peak ground acceleration and spectral accelerations from 0.02 to 3.0 s have been developed from the database of strong-motion accelerograms from Europe and the Middle East (Bommer et al., 2011).
- Ground-motion prediction equations (GMPEs) for spectral accelerations have traditionally focused on the range of response periods most closely associated with the dynamic characteristics of buildings. Providing predictions only in this period range (from 0.1 to 2 or 3 s) has also accommodated the assumed limitations on the usable period range resulting from the processing of accelerograms. There are, however, engineering applications for which estimates of spectral ordinates are required at shorter response periods. Additional regressions have been performed to extend a recent pan-European GMPE to higher response frequencies. This model and others that also include coefficients for spectral ordinates at several high response frequencies are used to explore options for interpolating coefficients for equations that do not provide good coverage in this range (Bommer et al., 2012).
- Most modern ground-motion prediction equations (GMPE) use definitions of the source-to-site distance that reflect the dimensions of the fault rupture for larger earthquakes rather than using point-source measures relative to the epicenter or hypocenter. However, seismic source configurations defined for probabilistic seismic hazard analysis (PSHA) almost invariably include areas of distributed point-source seismicity in addition to linear fault sources, particularly in regions of lower earthquake activity. Herein, two GMPEs have been derived from the same dataset to demonstrate the errors that can result from combining point-source simulations and extended-source distance metrics (Bommer and Akkar, 2012). Following these results GMPE's developers are now considering deriving pairs of equations, one using an extended-source distance metric, the other a point-source.
- We have investigated the artificial neural network method for the derivation of physically sound, easy-to-handle, predictive ground-motion models. Avoiding the specification of any a priori functional form, artificial neural networks (ANNs) provide fully data-driven predictive

models and allow the testing of the relative importance of the effects of independent variables on seismic ground motion (Derras et al., Bull. Seismo. Soc. Am.).
- Alternative ground-motion parameters (and associated predictive equations) such as strong motion duration, Arias Intensity, central frequency and frequency bandwidth have been derived
Deviations from Annex I, Corrective actions and their impact on other tasks, resources and planning

The work performed during the project has shown that a few points were missing in the proposal task list.
- The feedbacks from the engineering community shows that such of the dissemination of the SHARE strong motion database trough a web portal is important. Such a portal development and the data-providers authorisation procedure were beyond the scope of SHARE and such actions have been organized within the NERA Seventh Framework Programme (FP7) project and the SIGMA project (French Electricity Company research project)
- The selection or development of GMPE's adapted to the Vrancea area, volcanic areas and the oceanic crust have been difficult because of the lack of data for such specific environment. The PSHA results obtained in the last project year have shown that the ground-motion models initially chosen for the Vrancea area needed to be revised. A corrective action had to be organized with a strong collaboration with the IT team and WP5 experts.
- Several tasks have taken more time than expected (e.g. vs30/slope work, amplification factors developments) and several actions, not planed initially, had to be organized because of engineering needs or IT needs from WP2, WP3 or WP4 (V/H ratios models, high frequencies interpolation, GMPE's use regionalisation). Because of these additional tasks, the work performed to derive alternative ground-motion parameters (and associated predictive equations) such as strong motion duration, Arias Intensity, central frequency and frequency bandwidth have been performed quite late in the project and is not yet published in peer-review papers.
- We had underestimated the hazard computations problems generated by the choices of ground-motion models using rupture distance metrics. The SHARE experience on this point has motivated the development of a new GMPE's generation which will use combined point-source and extended source distance metrics definitions.

WP5 – Seismic hazard assessment

Main scientific and technological results

Task 5.1. Quality control procedures and input-output specifications
The hazard modeling team took a key role in asserting the quality of the model components. The tasks that were addressed have been outlined in D5.6 that summarizes multiple quality assurance procedures at the various levels of a PSHA: data assessment, selection of modeling procedures, evaluation of the modeling results. The focus here was set on the evaluation of the source model, while the evaluation of the hazard results has been targeted within Task 5.6.

In order to ensure homogeneity in the approach as much as possible, strong interaction between WP3 and WP5 was required as decisions made in the procedures for the data assessment have direct influence on the derivation of parameters. As an example, the derivation of activity rate parameters strongly depends on the definition of the completeness periods, so strong interaction here was required to align the modeling approach. This lead to a strong feedback process between data providers and modelers and to a strong quality control of the implemented procedures.

Within this task, SHARE also benefitted from the collaboration with the GEM Testing and Evaluation facility. The SHARE source model rate forecasts were retrospectively tested against independent data using the testing suite as implemented by the Collaboratory for the Study of Earthquake Predictability (CSEP). We employed the data consistency tests for a data period of 5 years that lead to indications about the model predictive skills; however, it is to be noted that the short testing period can only provide a snapshot since the models are targeted to a long-term forecast.

Task 5.2. Logic tree design

The principal design of the SHARE logic-tree is outlined in deliverable D5.2 that encompasses the logic-tree for the SHARE source model with details given in D3.6. The logic-tree considers the epistemic uncertainty for the various approaches to parameterize the stationarity of seismicity. Within the model building process, all options have been evaluated, yet with different levels of detail.

The Area Source (AS) model has been reviewed in greatest detail, mostly because (a) it is the most widely used source representation, (b) it is the legacy of past projects in the region, (c) almost all national hazard models were built upon these source representation, and hence the expert are very familiar with modeling and characterizing this type of source. The AS-model has undergone several revisions within the feedback process yet in general follows the procedures outlined in the deliverables D3.1, D3.6 and D3.7. A major difference arose in the definition of activity rate as we did not entirely rely on the algorithmically determined values and considered for many sources an expert judgement (details to be described in section Task 5.5).

The fault source and background model (FSBG) introduces knowledge about fault slip rates and geometry to estimate activity rates of each source. It combines with the knowledge of seismic activity with assumptions about the frequency-magnitude distribution. The approach differs in particular in the distribution of events within the background zone, as the largest events starting above some threshold magnitude can only occur on faults. Activity rate estimations were based on the approach proposed by Anderson and Luco (1983) and implemented in Bungum (2007).

The kernel-smoothed approaches, often called smoothed seismicity approaches, introduce a less subjective means to estimate future seismicity rates. Within the project, two models where suggested, one based on the Woo (1996) approach and another one based on the Hiemer et al. (2013) approach. The latter combines smoothing seismicity rates and smoothing the contribution of moment from faults to the overall seismicity taking advantage of the fully parameterized composite seismogenic sources. We consider only the latter in the SHARE model as the usage of only seismicity has not found enough support within the community.

Defining weights for the various branches of the logic-tree is the final step. Since the final computations were performed following the final SHARE meeting in Istanbul (November 19, 2012), the modelling team distributed the results of single branches and ask specific questions to evaluate the trust / believe in the various branches from the beneficiaries. The final proposition is to give the largest weight to the AS-model and then weight the FSBG-model and the kernel-smoothed model that uses seismicity and fault slip information (SEIFA). Note that with this distribution of weights, estimates based on geologic information, enters for the first time on this scale prominently a seismic hazard model.

Respecting the various feedback rounds within the project and with the expertise of a detailed knowledge about the data and methods used for the creation of the single branches, SHARE implemented its weighting-scheme that reflects the base data used to build each one. The AS-model is given the largest weight for the various exceedance probability levels and the weight increases with decreasing exceedance probability levels. We increase the weight of the FSBG-model for decreasing exceedance probability levels due to the importance of the geologic information for the estimation of activity rates. The contribution of the SEIFA model decreases with decreasing exceedance probability levels because SEIFA itself considers the contribution of seismicity stronger than the fault information. For exceedance probabilities larger than 10% in 50y, believe that the SEIFA-model and the AS-model should be equally weighted. We define the combination 0.5 AS-model, 0.2 FSBG-model, and 0.3 SEIFA-model as the average weighting scheme used to generate hazard curves.

Task 5.3. Computation of synthetic earthquake catalogues

Task and deliverable were removed from the DoW. The OpenQuake engine has however the capability to generate synthetic earthquake catalogs as this is one of the requested outputs from some of the GEM stakeholders.

Task 5.4. Computation of seismic hazard

The seismic hazard calculations were performed on the computational infrastructure (see WP6, Task 6.3). The preliminary computations were performed with OpenQuake v0.8.1 using a Java-based core. A major drawback of those preliminary computations were the use of a point-rupture representation in the case of area and point sources. Sensitivity analysis performed for each computational model showed that there can be significant differences on the final hazard estimates when excluding the extended rupture options for the area/point sources. The experts recommended the use of the extended ruptures, as a more appropriate representation of the earthquake source characterization. Therefore, the final calculations were performed with the latest version of the hazard library of the OpenQuake package to explore the full model that was suggested for the SHARE region. The use of the latest version allows using extended and complex sources for the FSBG-model (see Deliverable D5.1 for their definition). In addition, with the latest engine, subduction interface regions can be handled as complex sources, while the inslab seismicity in the subduction zones is still handled as volumes at different depth levels.

Due to the complexity, the size and the large scale of the SHARE-model, the computation time for the final model is in total about 15 days on 224 CPUs without pre- and post-processing; this is roughly 40 times less computational time compared to what was estimated for the original engine on the same cluster.

Pre-processing includes all steps to generate the input files for the OpenQuake engine from the files that include the parameterization of each source model. The base files for each source model are either plain ascii-files (for the smoothed seismicity models) or standard shapefiles (see http://en.wikipedia.org/wiki/Shapefile online), a popular geospatial vector data format for geographic information systems software. The parameters of the files are explained in the deliverable D6.6.

In comparison to the availability of results from other hazard models, the SHARE results are outstanding and are close to the requested list of parameters of the engineering community (Deliverable D2.1). At the time of the final report, hazard estimates for the return period 101y-5000y are computed, for PGA and spectral ordinates between 0.1s-4s. For all grid points of the SHARE model located on-land (126044), hazard curves and uniform hazard spectra are available.

Disaggregation is at this time available for selected sites for which either scenario calculations were proposed at the beginning of the project (WP2) or for which we obtained requests from other projects such as EC-FP7 project PERPETUATE. The cities selected spread across the entire Euro-Mediterranean region representing various tectonic settings, e.g. Basel, Bergen, Lisbon, Thessaloniki, L'Aquilla, Istanbul and so on. Disaggregation is provided in terms of magnitude, distance and epsilon.

Originally proposed was the computation of seismic hazard also for the entire off-shore region. The total number of grid points at a 0.1x0.1 degree discretization would then reach about 400,000. The modeling team refrained from performing the entire computation due to time constraints and the larger importance of the on-shore results. However, the roadmap formulated within the final meeting contains the request to perform calculations for off-shore areas of the continental shelf above which oil and gas platforms and pipelines are located.

Task 5.5. Validation of seismic hazard results

Throughout the project, long philosophical and technical discussion on how to evaluate the seismic hazard results obtained with the new model. In particular, discussions about the correct terming arose, leading to a consensus that 'validation' of hazard results in its strict sense is not correct. SHARE therefore focused on a stringent evaluation of the hazard results.

Evaluation of hazard results were performed following each new computation of hazard presented for the model review meetings (see Task 5.6). It is to be noted that due to the introduction of new model types and the usage of a new computational infrastructure, differences to previous models are expected and desired.

The major evaluation procedures, with specifications given in deliverable D5.6, included:
1. Sanity checks of the hazard values against existing products
a. On the regional scale, this was performed against the pvrevious map of SESAME and GSAHP,
b. On the national scale, this was done against the national hazard maps by the modeling team and the consortium members. As an example, results in Switzerland could be compared to the Swiss National Seismic Hazard map (Wiemer et al., 2009);

2. Comparative computation of seismic hazard using the area source model with two different hazard engines: the computations were run at GFZ with their implementation of the FRISK-software and at ETHZ with the OpenQuake engine. The results, computed using point sources, deviate only slightly in a range of up to 5% difference;
3. Evaluation of site-intensity histories at various places;
4. Evaluation of ground-shaking parameters against observed distributions at sample locations;
5. Evaluation of the main contributors to the seismic hazard by means of disaggregation at about 30 sites throughout the study region.
6. CSEP testing procedures were used to assess the data consistency of the earthquake rate forecasts with current seismicity. The SHARE catalog includes events until the end of 2006. For testing, we downloaded the Harvard CMT and the NEIC catalog for the period 2007-2012 and run the CSEP-test data consistency suite for the 5 year period.

Task 5.6. Community feedback on seismic hazard results

Organizing community feedback in a well-defined procedure was a major task throughout the SHARE project. For the SHARE-project, it was not possible to organize this as a formal expert elicitation procedure as suggested by the Senior Seismic Hazard Analysis Committee (SSHAC) in their documents NUREG/CR-6327 and NUREG-2117. However, these recommendations were used as a guideline for some of the processes within SHARE. Within the possibilities, WP5 was involved in all meetings of WP3 and WP4 to help organize and understand the roles and participation of the various researchers in the project. WP4 organized much of the procedure and documented the procedure in Delavaud et al. (2012) for the selection of the logic-tree for the ground motion prediction equations. WP3 and WP5 worked closely together to define the source model logic-tree, yet there were not several teams that worked on building a multiple-source models, these were rather suggested and iterated on within the two WPs. Details of these source models were then presented to the entire consortium and additional external experts for feedback.
To achieve an adequate feedback, WP5 organized two 2.5 days dedicated review workshops (March 12-14 and September 3/4 2012, see deliverable D5.4) and organized together with WP1 the final meeting in Istanbul that one entire day was dedicated to an additional review of the hazard model. To each of these meeting, we invited external experts from the seismic hazard and earthquake engineering community to consider the perspective from outside the project.

All topics of the hazard model were discussed within these meetings: particular focus was on 1) the estimation of activity rates parameters and the models used for this, 2) the concept of using large superzones as the basis to estimate parameters such as data completeness, maximum magnitude and tectonic regionalization, 3) the integration of data uncertainty within the models, 4) the usage of algorithm driven approaches vs. an expert opinion model, 4) the computational implementation of the models. The first review meeting was prior to the final delivery of all datasets, thus included discussions on data issues within the model building process. During the second workshop, preliminary hazard results could be evaluated. During the final meeting in Istanbul, revised hazard calculations were presented and together with the revised models. Due to the granted extension for the project, the final hazard calculations were run in spring 2013. For the final hazard results, we organized a feedback round via email for finally deciding on the full composition of the SHARE hazard model. Within the phase of final reporting, WP2 organized an additional one-day meeting to obtain a feedback of their products based on the latest results. The meeting involved earthquake engineering experts that had followed the SHARE process.

WP6 – Computation infrastructure

Main scientific and technological results

Task 6.1 Databases (SED-ETHZ)

The computational infrastructure at SED-ETHZ is committed to host all data relevant for building and computing the seismic hazard of the SHARE region. SED-ETHZ host all the derived parameters that are necessary to reproduce the SHARE hazard model, details of the databases are outlined in deliverable D6.6 and will be available on the SHARE website and portal for download (see http://www.SHARE-eu.org online).

These databases do not include the raw data; this is stored at partner institutions. Two examples of the raw data are:
1. The European Archive of Historical Earthquake Data (AHEAD, http://www.emidius.eu/ahead) which serve as the base data for the SHARE European Earthquake Catalogue for the period before 1900 (see http://www.emidius.eu/SHEEC online)
2. The SHARE database of active faults and seismogenic sources (see http://diss.rm.ingv.it/SHARE/ online).

The databases that are used for the computation of seismic hazard in Europe are:
1) The European Earthquake Catalog,
2) Superzones of maximum magnitude,
3) Superzones of completeness periods,
4) Superzones of tectonic regimes,
5) parameters of the Area Source Model,
6) parameters of the composite seismogenic sources (fault sources),
7) parameters of the background sources (similar to the parameters of the area source model), and
8) parameters of the smoothed seismicity models.

The data of the databases exists in different formats, yet they all are available as ESRI-SHAPEFILES (see http://en.wikipedia.org/wiki/Shapefile and references therein) that can be displayed in Geographic Information Systems (GIS). From this files type, data can be exported to simple ASCII files if needed.

Task 6.2: Web service-oriented architecture (BRGM, SED-ETHZ)

The base of being able to serve all results of the SHARE project lies in the definition of an appropriate database and the web-services to access this data from the local computational infrastructure as well as remotely from any computer worldwide. The hazard data is stored in a PostgreSQL database instance (see http://www.postgresql.org online) developed on the basis of the GEM1 project; for details see deliverables D6.3 and D6.7.

Data discovery services and data delivery services are implemented as RESTful web services, providing information in XML format using extended NRML 0.3 for data (see http://github.com/gem/nrml online), an ad-hoc XML dialect for discovery information. These services are available publicly and can used by 3rd party data users for interactive or software-based data discovery and retrieval. Mapping components are implemented using OGC web services, mainly web map services (WMS, see http://www.opengeospatial.org/standards/wms online).

All components are implemented in order to host and provide data of multiple seismic hazard models. They provide the possibilities to access and display aggregated data from logic tree models or from individual logic-tree branches. While this was useful during the model building process to compare results of different hazard model sub-tree branches, and may be useful in future in the framework of EFEHR (see http://www.efehr.org online) to show multiple hazard models, the final, publicly available result of SHARE will not display single logic-tree branches model.

Major achievements are the implementation of the web-services based on a standardized data formats and the usage of open-source components so that the features can be used openly. The architecture allows to interchange the information and display them in associated portals, allows to receive external data via external web-services and is there extendable for future requirements.

Task 6.3: SHA computational engine (SED-ETHZ, BRGM)

SHARE has throughout the project kept close connections to the developments within the Global Earthquake Model (GEM) project. Until the very end of the project in November 2012, the hazard computations were performed with an OpenQuake v0.8.1 using a Java-based core. The OpenQuake v0.8.1 engine uses only point-/ and line sources to calculate hazard and is not able to digest all information provided within the source model; in addition, the performance of the engine when using line-sources as extended sources proofed to be not efficient enough for the scale of the project. For this reasons, the preliminary models were calculated with point-sources only.

Given that at the same time a new version of the hazard library of the OpenQuake package was implemented, SHARE switched to use the new version to explore the capacity of the full model for the hazard calculations. This library, named oq-hazardLib, was developed to improve the overall PSHA calculation and enhanced the performance of the OpenQuake platform. The source code and documentation is available at http://github.com/gem/oq-hazardlib. It provides an improved way of modelling the seismogenic sources (as points, areas and faults), most important to mention the capability of modeling extended ruptures in the case when area and point sources are considered. Thus, the hazard results are calculated with extended sources, which is a more accurate description of the earthquake source physics.

The newly developed software library was designed and implemented following the 'Test Driven Development' philosophy, which reduces the risk of introducing errors and allows to iteratively verifying the package components. Scientifically, the software was validated following the PEER (Thomas et al. [2010]) procedures on testing the seismic hazard codes. The validation procedure is the same as the one described in the D6.8.

The OpenQuake engine used for the seismic hazard computation within SHARE Project it will be freeze and the source code as well the installation

documentation will be available at
http://launchpad.net/~openquake/+archive/SHARE.

The SHA engine is to be understood as a dynamic entity and the features available are a function of the hazard modellers wishes. Compared to the model outlined and its numerical implementation will need to be explored always and is necessary to explain features of the results.

Task 6.4: SHARE portal (SED-ETHZ, BRGM, INGV, UPAV)
The SHARE portal serves as the entrance to access the results of the seismic hazard assessment and the relevant input databases. The portal design and technical implementation is documented in detail within the deliverables D6.2, D6.3, D6.5 and D6.7. The main features of the portals are the capabilities to serve results 1) in the form of hazard maps and 2) for single sites in form of various graphs (hazard curve, uniform hazard spectra, disaggregation).

Establishing the portal is a major step to provide the seismological and engineering communities with the latest reference hazard results for the Euro-Mediterranean region. It is also a major resource of information for decision makers, media and the general public. We highlight that this is the first time on the Euro-Mediterranean wide level to have an openly accessible resource like this – while similar features on national levels existed before.

The portal serves multiple seismic hazard maps in terms of the exceeding probability of an intensity measure in a given time period, such as Exceeding a peak ground acceleration with 10% in 50years.

For all single sites, the portal serves

1. Hazard curves showing the exceedance probability as a function of the size of the intensity measure,
2. Uniform hazard spectra.

For selected sites, in particular cities of particular interest for which also risk and loss scenarios are computed within WP2, detailed disaggregation results are available.

The portal technology is in line with the technologies used at the EMSC (see http://www.emsc-csem.org/ online), ORFEUS (see http://www.orfeus-eu.org online) and the Earthquake Data Portal (see http://www.seismicportal.eu/jetspeed/portal/ online). The SHARE portal sets the base for future developments of the portal within the EU-FP7 project NERA (see http://www.nera-eu.org online) and develops into the portal of the European Facility for Earthquake Hazard and Risk (EFEHR, http://www.efehr.org), that will serve additional data on top of the seismic hazard results.

WP7 – Dissemination

Task 7.1. Collaboration in dissemination e-platform development

SHARE continuously casted announcements, news and information on its activities via its homepage http://www.SHARE-eu.org. Information on conference participation and presentations were announced together with the syllabus of meetings and workshops. The website provides relevant documents for download as long as they are categorized as publicly available and also features all peer-review articles.

The website is implemented using a Content Management System, thus is flexible for updates for some period after the project is finished. The systems remains with the flexibility to announce news via newsletters, one envisioned containing the widespread dissemination of results.

The SHARE homepage links to the SHARE portal that serves the results of the project. The portal was designed in a common effort of WP6/WP7 to appear with a common look and feel.

Task 7.2. Scientific external dissemination

Scientific dissemination was strongly promoted throughout the project. Participants published during the course of the project more than 20 papers in peer-reviewed journals, with several other manuscripts being in review at the time writing the final report. Documentation of the entire hazard model remains to be finalized in the months following the end of the project. This documentation will result in several peer-reviewed publications.

WP7 and WP1 coordinated scientific dissemination within the project and supported the organization of targeted sessions at scientific meetings. SHARE members organized various sessions at the European Seismological Commission meeting in 2010, Montpellier (ESC2010), a special session at the 14th European Conference of Earthquake Engineering, Ohrid, 2010, and one dedicated session at the European Seismological Commission meeting 2012, Moscow (ESC2012, http://www.esc2012-moscow.org). Specific aspects of the projects and advancements in methodology, data and applications have also presented at the meetings of the European Geophysical Union meetings 2010-2012, at the meeting of the Seismological Society of America (2012), at the meetings of the American Geophysical Union 2010-2012, at the 7th Gulf Seismic Forum, Jeddah, 2012, and at the Fragile Earth conference 2011 (see http://geosociety.org/meetings/2011munich/online).

Task 7.3. Outreach to policymakers and stakeholders

One of SHARE's principal goals is to produce methods and products that can be readily employed in the updating of building codes such as Eurocode 8. In order to ensure that products are effectively used by policymakers, industry, and related groups, we have:
- Invited policymakers and stakeholders to take part in plenary and review meetings.
- Organised targeted meetings with the engineering community aimed at increasing the awareness of these specific end-users to the pertinence and value of achieved outcomes.
- Taken preparations for development of tailored documentation (attractive overview sheets and brochures) aimed at communicating the results of the projects in a way that is consistent with such target audience.

Meetings with the EC8 committee (SHARE's main stakeholder) have been taking place all throughout the project duration, e.g. at the very beginning, during the 2nd year annual SHARE meeting, at the 15th World Conference of Earthquake Engineering, and following the release of preliminary hazard model results. Also, the SHARE E-Newsletter serves to reach out to policymakers and stakeholders.

In order to develop the outreach strategy of SHARE, coordinators of WP2 have been asked to participate in Portal design and development meetings, as well as meetings related to the final hazard map, to see how the needs of engineers and others directly working with Eurocode 8, can be best integrated into these major deliverables.

Task 7.4. Synergies with other related projects and initiatives
The overall goal of this task is to stimulate the growth of a wide technical hazard community in Europe, beyond national or project boundaries.

Global connections

SHARE connects to the global earthquake model (GEM) as a Regional Programme and is one of the first operating ones feeding into GEM. Since the start of SHARE, the GEM E-Newsletter has regularly reported on the latest SHARE developments. SHARE is an integral part of main GEM outreach activities, such as the semi-annual meeting, serving as an effective example for regional coordination and collaboration in Europe. In addition, joint workshops have been organised with the GEM Regional Programmes in the Middle East region (EMME) and Central Asia (EMCA). Representatives of the projects have organized joint conference sessions at various international meetings.

Connections with FP7 projects

There are close ties between SHARE and the NERA project [Network of European Research Infrastructures for Risk Assessment and Mitigation], and many of SHARE's deliverables will be featured through and used in SHARE. In particular, the WP6 cooperated with NERA which supports the European Facility for Earthquake and Risk (EFEHR) to serve in future the SHARE hazard results, derivatives and additional data (see http://www.efehr.org online).

Many of the partners in SHARE are also part of the SYNER-G project (Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain) and the latter has already expressed an intention to use the output of SHARE for their case study applications.

More important connections between SHARE and other European (FP7) projects are with:
- PERPETUATE: Used preliminary SHARE results for their hazard input;
- GEISER: Aims at using a rate forecast for small magnitude events as background in their hazard assessment.
- MATRIX: Aims to integrate the seismic hazard obtained within SHARE within its multi-risk assessment.

SHARE activities informed various activities in these programmes, and vice versa some findings and activities in these programmes contributed to improvements of deliverables in a number of tasks.

SHARE deliverables will furthermore inform the European Programme EPOS, both through NERA and independently.

Task 7.5. Promoting public awareness

It is important to ensure that the general public is not only aware of the level of seismic hazard to which it may be exposed to, but also of the commitment of scientific/professional communities.

In order to promote public awareness on seismic hazard in the region, as well as disseminate and build knowledge, the SHARE website will be used as living core. More in detail, it will be reorganised in order to actively facilitate three overall goals, of which the last one specifically addresses public awareness. The goals are aligned with the various stakeholder groups SHARE tries to serve: from scientists to engineers and from policy makers to the general public.

- SHARE the science to facilitate on-going debate and collaboration
This has 3 major goals: 1) to be transparent as to what research was carried out, what methods were used and why, 2) bring together a legacy that can be used in other (European) projects and 3) facilitate a culture of joint learning and improving.
- SHARE the outcomes to build (back) safer
Through the portal that will be prominently promoted in the website, scientists, engineers and other expert users can access maps and other results in the context that is suitable for their work or further research.
- Provide a context for policy making and understanding of seismic hazard
Online information provides the context for the research results. From the website the 2 types of E-brochures will be downloaded, as well various types of hazard maps that are accompanied by information for the general public and policy makers.

Electronic brochures as defined in the deliverable list will be produced when the final results are available.

Task 7.6. Euro-Mediterranean seismic hazard map

SHARE designs one highly visible product in form of an A0-style poster. This poster will include a hazard map, likely a PGA map of 10% exceedance probability in 50 years, together with a short explanation and the main data sets. This major product is to show for general use the relative hazard in Europe. This product will be printed on the order of about 10,000 replicates to be disseminated European- and worldwide. The map will prominently link all other products that SHARE produces. The map shall clearly outline the limits that the underlying science has to carry by lightly explaining its uncertainties.

SHARE outputs many more products via its portal and these are all of interest in particular for engineering purposes, yet these are too many to be printed. As example, there will be about 50 mean hazard maps as 5 return periods and 10 frequencies are computed in the current model.

Deviations from Annex I

Because of project extension the deliverable of the last newsletter will be with the announcement of the release of the model (D7.1c – E-Newsletter Issue 3).

Because of project extension and a need to integrate all project outcomes and deliverables, the following deliverables are planned for March/April

2013, making use of co-financing of the project. This involves the dissemination of brochures (D7.2a-b) and the A0-style Euro-Mediterranean seismic hazard map (D7.3).

Potential impact:

SHARE has throughout the project involved participants of various competences and experts spanning all fields from earthquake engineering to geology to engineering seismology to information technology to communication experts. Specific disciplinary needs have been taken into account and have generated innovative research and results. Besides the multidisciplinary needs, SHARE has taken an approach to leave aside national borders and boundaries coinciding with cultural differences in perceiving the seismic hazard and potential threat to society. The delivered products form the base to compare seismic hazard throughout Europe on a common scientific methodology and supports the European Community in making decision about future actions on this scale.

The procedural level for the probabilistic seismic hazard assessment as implemented in SHARE will influence and guide the design of future hazard assessment efforts within Europe. SHARE sets a level of PSHA that is, given the expertise throughout Europe, a new standard and will serve as reference and guide in the future. The project released guidelines on quality assurance measures that should be taken during a PSHA and thus adds to the guidelines provided by the Senior Seismic Hazard Analysis Committee (SSHAC). Consequently, we expect a strong influence on project budgets within the private- and public sector because the level of formal elicitation of experts and the involvement of larger groups of experts are likely to involve higher funding levels. At the same time, the projects results are accessible facilitating the application of new modeling techniques, thus it provides the opportunity to accelerate model development and removes the need of costly data collection and compilation procedures.

The SHARE results will have a major impact on society through the recommendations for the CEN/TC250/SC8 Committee. Seismic design of buildings and infrastructures which people use in their daily life across Europe will change buildings designed in future following more appropriate criteria. The impact may range from possible modifications of the National Annexes to Eurocode 8 to new methods for describing seismic actions in future design codes. SHARE delivers the input for the revision of the EC8. Following the close interaction with the members of the CEN/TC250/SC8, the JRC meeting in October 2013 organized by the SC8 will dedicate a full day to the implementation of the SHARE result.

The SHARE results can serve as reference for policy and strategy formulation for future research on required technological actions in the industry sector, in particular when questions arise about the seismic safety of infrastructure or critical infrastructure for the society. SHARE provides the means to assess seismic hazard for critical infrastructures through all its products and applied procedures through delivering hazard estimates for return periods ranging from 10y to 10000y. In the aftermath of the enormous disaster caused by the 2011 Tohoku MW=9.0 earthquake and its accompanying tsunami, SHARE reflects aleatory and epistemic uncertainties appropriately in multiple components through the formal elicitation of experts for the source model and the ground motion prediction logic-trees. The source model, for example employs multiple approaches for estimating the maximum magnitude of earthquakes possible in Europe by including the odds of very high magnitude events throughout the region, in particular important for critical infrastructures like nuclear power plants or dams. The source model also set a new global imprint by adopting a weighting scheme of the independent branches of the source model logic tree: the three models used - the Area Source (AS) Model, the Fault Source and Background (FSBG) Model, and the kernel smoothed seismicity and fault model (SEIFA) – gained various credibility through the use of different data sets as primary input. Therefore, the weighting scheme reflects the predictive skill of the models that use more geologic information to be more important for longer return periods compared to the SEIFA model that considers more the recent seismicity and thus receives more weight for the shorter periods.

SHARE forms the starting point for the proposed EU-FP7 project 'Harmonized approach to stress tests for critical infrastructures against natural hazards (STREST)' in defining harmonized procedural handling that can be applied in other hazard studies within the stress tests. The procedural level of formal expert elicitations and the assessment of low-frequency but high-impact events can function as a key examples to develop guidelines and protocols for stress tests. Moreover, the low-frequency hazard assessment can be used for non-nuclear critical infrastructures in parts of the energy industry sector.

For the geothermal industry sector it is highly important to assess the hazard and associated risk when looking at small-to-moderate magnitude earthquakes that might be caused by e.g. Enhanced Geothermal System projects like the one in Basel, Switzerland, 2006. SHARE can serve for such sites as input to formulate the potential short-term time-independent hazard in prior hazard and risk assessment by extrapolating to the magnitudes of interest. By short-term, time periods of 1y-10years are targeted. The application is not ideal then within an ongoing sequence and should during the course of a developing sequence be replace with a time-space varying hazard model. Within the EC-FP7 project GEISIR, SHARE was requested to provide such hazard estimates on the basis of the final model. The SHARE model, however, can only function as a reference and benchmark comparison for such an assessment and not serve as the full and only reference.

SHARE may similarly serve as a new standard reference model for the insurance and re-insurance sector by providing results in the targeted time span. Within this sector, it is of high economic interest to understand not only the low-probability hazard but also the higher probability hazard at short periods. The provided range of results enables to compose insurance rates that are often revised on a yearly basis in the portfolio assessment with innovative procedures and concepts.

Impact on GEM

As the regional component of the Global Earthquake Model, SHARE contributes to the global initiative as the flagship application. SHARE is the first project to finish its PSHA with OpenQuake, the software mainly developed by GEM but heavily tested within the framework of SHARE. Thus, the legacy of the generated knowledge integrated in the software will impact the global hazard assessment community. Through the collaboration within GEM, the SHARE model gains worldwide visibility and influences the preparation of other hazard models around the world. Many of the scientific ideas portrayed within SHARE have influenced the model building process of the Earthquake Model for the Middle East (EMME). The global impact of SHARE can be instantiated as follows:

- For the Global GMPE program, an international team of 27 experts gathered to select a harmonized suite of GMPEs that can be used at the global, regional and national levels. Five of these experts had been previously strongly involved within SHARE.

- SHARE choices have been discussed with non European GEM experts from US, Canada and New Zealand. The pioneering selection methods developed and tested within SHARE have been used by the GEM Global GMPE project.
- There is obviously a strong need to define a regionalization scheme for the use of ground motion prediction equations. Such a scheme has been suggested in Delavaud et al. (2012) for Europe. This work has motivated the creation of a new GEM working group dedicated to regionalization including the leading experts from SHARE in the GEM working group. This group of experts, which mainly meets remotely, has recently assembled a review of relevant datasets and defined a methodological approach for providing an appropriate set of GMPEs and magnitude scaling relationships for any point on the globe.
- The very same approach followed to construct the AHEAD archive, that forms the main data source for developing the SHARE European Earthquake Catalogue (SHEEC), has been used to design one of GEM's global components devoted to building up Tools for compiling a Global Earthquake History. The project started from existing regional initiatives, anticipated new regional capacities yet to be developed, and considered mainly earthquakes with M=7.0 in the time window 1000 to 1903. It is expected to establish a distributed, online resource, called 'Global Archive of Historical Earthquake Studies', where both reports and macroseismic data points can be uploaded, organized and made available to the public. Its main expected outcome is a set of the best global parametric earthquake catalogues that can be compiled from current resources. Whenever possible, catalogue entries are linked to the background information and complemented by comments and earthquake parameters reassessed from intensity data points and from historical evidence of length of rupture.
- SHARE scientists also participated in several formal and informal meetings with colleagues involved in developing the GEM 'global components' (GEM faulted earth project, GEM working group of tectonic regionalization) and GEM regional programs (EMME and EMCA). These meetings focused on the discussion of both scientific and technical issues related with (1) the collection of tectonic data and their organization in appropriate repositories and with (2) enabling the retrieval and delivery of spatial data from those repositories.
- For what concerns specifically the seismogenic faults, SHARE contributions appear in various GEM reports/deliverables, such as the 'Inventory of existing fault databases and data attributes' (Litchfield et al., 2011, GEM Faulted Earth deliverable D1). Another contribution in this perspective is represented by the review of fault source definitions used in the INGV and USGS databases of seismogenic sources (Haller and Basili, 2011, SRL). Throughout the progress of realization of the database of active faults and seismogenic sources and its implementation in the actual fault-source input files, the compatibility of the adopted parameter scheme of both crustal and subduction fault sources with OpenQuake standards has been validated. The final release of the SHARE database that has been made available for upload into the GEM Faulted Earth repository consists of 1,128 crustal fault sources and three subduction sources.
- The Global Earthquake Model is focusing on seismic hazard and risk assessment, and has not invested significant effort in defining outputs of use for engineers. Much of the team working on engineering requirement

and application in SHARE is heavily involved in GEM, and thus the recommendations from SHARE will be passed to GEM such that outputs of interest to engineers can be provided through GEM's platform.
- The Scientific Advisory Board and external earthquake engineers recommended that the ground motion maps should transparently show the values resulting from the SHARE model although they might differ from previous calculations for good reasons. The output might not be accepted by structural engineers in Europe right from the beginning, but may in a timely perspective. The seismic zonation maps are not been produced to mask the ground motions in any way.
- SHARE has acted as a leading project that uses the implementation of OpenQuake, the GEM software to calculate seismic hazard. The collaboration of the IT-components and the hazard modelers has been fruitful for both sides, as SHARE was able to employ new technologies to for its computational purposes and also SHARE expertise in the model development. The GEM initiative profits from the constant feedback of the user perspective and also of a first large scale project with its own defined targets. This lead for example to the optimization of the OpenQuake code and in particular to bug-fixing that still was not possible to be fixed within the rigorous programming philosophy implemented in GEM.

Impact from new databases

The impact of newly available databases largely coincides with the impact of the entire SHARE project. The new European-scale earthquake catalogue (SHEEC), the European Database of Seismogenic Faults (EDSF), as well as the finite element strain model (Barba & Carafa, in prep.) may potentially outreach much beyond the scopes and the goals of SHARE. In fact, they may live an independent life in probabilistic and deterministic seismic hazard applications and in many scientific applications concerning the geology and the geodynamics of Europe. Some likely immediate applications may be:
- Use of the new harmonized databases in deterministic seismic hazard assessments e.g. in the frame of revisiting the hazard of critical infrastructures;
- Based on the EDSF, develop new earthquake forecasting models and promote a testing region for European wide earthquake forecasting research in the framework of the Collaboratory Study of Earthquake predictability (CSEP);
- Generate hazard models based on the input of the strain rate models provided for the region and not only use this information when moment balancing with the fault and seismicity based models;
- Initiate the usage of earthquake simulators throughout the region to generate physics-based earthquake forecasts;
- Employ the EDSF to generate scenario strong ground motion computations for selected regions but also for large scale applications such as the entire Northern Anatolian Fault zone;
- Employ the EDSF to understand limits and extremes of strong ground motions and evaluate these with respect to the observed ground motion intensity measures;
- Simulate near-field ground motion to bridge the gap of under sampled empirical GMPEs at distances up to 10km from the causative faults with physics based models of fault rupture;

In a broader sense, the EDSF also provides a source of information on the earthquake and tectonic properties of Europe for the general public. Seismologists are often asked on which fault an earthquake occurred and

what this fault is capable of generating in terms of maximum magnitude in the future. The EDSF provides a widely visible tool for rapid earthquake information through Europe and can be readily used by the European data portal such as the European–Mediterranean Seismological Centre (see http://www.emsc.org online) and the Earthquake Data Portal (see http://www.seismicportal.eu online).
SHARE has produced the first consensus rock motion model in the form of a logic tree for the European-Mediterranean region, based on
- a new pan-European compilation of well-calibrated strong- and weak-motion records,
- the incorporation of well-calibrated waveforms from key earthquake databases from other region of the world (to complement the European data coverage in the near-field and high magnitude range),
- the critical evaluation and selection of published models,
- and the definition of a logic tree combining different model realizations and expert opinions.

This approach used by SHARE to derive the model is innovative in itself: SHARE brought together recognized experts in a single group and new testing procedures have been extensively used. SHARE developed a new procedure to qualify a consensus ground-motion logic tree of the hazard. The model has been assembled by seeking extensive expert elicitation and participation, and through community feedback. Such methodology is a basis for longevity and continuous improvement of ground-motion models.

Although SHARE has been based on the expertise of reputed scientists with long-standing experience in PSHA, a new generation of seismologists, geologists, engineering seismologists and earthquake engineers has been involved in the process from all over Europe: C. Beauval, E. Delavaud, B. Derras, S. Drouet, B. Edwards, N. Kuehn, O. Knenidou, A. Lemoine, V. Poggi, A. Sandikayya, M. Segou, E. Riga, H. Tazan, G. Weatherill, J. Wössner, L. Danciu, E. Nemzer, M. Demicioroglu, S. Hiemer. Half of these young scientists are women. Out of this pool of researchers, the next generation of seismic hazard experts will evolve shaping the future of seismic actions in Europe.

4.4.2 Main dissemination activities and exploitation of results

Throughout the project, dissemination has addressed the scientific community, the wider engineering community as well as the general public. For all audiences we have used the homepage to distribute news of the projects, using all technical means such as newsletter to distribute the information.

A significant result is the establishment of a comprehensive, understandable website that is easy to maintain. This website does not just allow users / readers to access the information they need, but also to subscribe for the E-newsletter. The website is (going to be) the living core of dissemination of SHARE results and products, long after the project itself will have finished. The focus so far has been on 'building the knowledge base' in the last phase of this project, the focus will be on 'creating excitement', both for the project and its outcomes, as well as for seismic hazard in general.

Once all deliverables are integrated into the website and the map is distributed, all these results will have contributed to reaching the following goals:
- Keep informed and engaged

- Build the foundations for joint research, policy-making and risk management
- Produce and SHARE tangible products

In the scientific sector, SHARE already highlights its influence and stimulation for scientific progress with more than 20 publications in high-level peer-reviewed scientific journals as listed on the SHARE website, with a similar of high impact publications to be published within a few month from the projects end. In addition to these, SHARE scientists have (co-) organized more than six sessions at scientific meetings, e.g. at the European Seismological Commission meetings 2010 / 2012, the European Conference on Earthquake Engineering 2011, at the 15th World Conference on Earthquake Engineering 2012, at the International Union for Geodesy and Geophysics meeting 2011 in Australia. These have large response and targeted each between a few hundred to a few thousand of scientists, with the symposiums being held in rooms of 50-400 attendees. Within these and at sessions of other scientific meetings (e.g. American Geophysical Union meetings, Seismological Society of America meeting 2012, German Geophysical Society meeting 2011), SHARE scientists presented their work in more than 50 presentations.

Dissemination to the wider community was promoted through the SHARE partners with their involvement in on-going activities of other European Projects such as NERA, SYNER-G, MATRIX, PERPETUATE, and GEISIR, as well as through the cooperation with GEM. SHARE scientists gave presentation on the status and possible products of the project and worked on common issues.

Within the cooperating EU-projects, SHARE products will be further exploited:
- In the NERA-project, the SHARE hazard results will be the basis of risk assessment applications;
- Through the concerted technical design of the SHARE portal and the European earthquake data portal, the European Facility for Earthquake Hazard and Risk (EFEHR) will provide the SHARE hazard results and serve additional products;
- As indicated, EDSF can contribute to rapid remote access to earthquake data shedding light on the question on which fault an earthquake occurred;
- Preparing for operational earthquake forecasting, REAKT aims to move from providing earthquake probabilities to disseminate actual hazard results including time-dependency at short and medium time scales. SHAREs major contribution is to provide the most innovative ground motion prediction equation logic tree for various tectonic regimes targeted.
- The SHARE source models provide rate forecasts for time-independent testing within the planned testing regions of Iceland and Turkey in the framework of CSEP as targeted within REAKT;
- The SYNER-G project starts from the input of seismic hazard assessment and evaluates systemic seismic vulnerability and Risk for Buildings, Lifeline Networks and Infrastructure Safety gain. For the development of methodologies to evaluate the systemic vulnerability, SYNER-G scientists could exploit the selection criteria for ground motion prediction equations to make appropriate selections.

Addressing policymakers and the general public will be done within the month following the release of the main products via specific electronic brochures. We expect the largest public impact by disseminating a poster-form European Seismic Hazard Map on the order of 10,000 copies. This product will then be used to communicate the European seismic hazard at all intellectual levels, from the school level to the public to the media and to policy makers.

List of websites:

http://www.SHARE-eu.org