DELIVERABLE

D26.7 Framework for European integrated risk assessment

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Summary

This deliverable outlines the risk framework that will be used for the European Seismic Risk Model 2020 (ESRM20) that will be released at the end of the SERA project in April 2020. Significant developments in regional risk modelling in Europe have been made during the first 24 months of the project through collaborations between the SERA JRA4 team and the Global Earthquake Model (GEM), as part of the development of GEM's Global Seismic Risk Map (v2018.1) that was released in December 2018. This deliverable thus begins with a summary of the outcomes of that effort, as it can be considered to be a v0.1 of the European seismic risk model. A detailed explanation of how the seismic risk calculations will be undertaken is provided, followed by a summary of each of the components of the ESRM20. Following the submission of this deliverable, the SERA JRA4 partners will continue to develop the various components and will put them together to produce a v0.2 European Seismic Risk Model that will be shared via the European Seismic Risk Service (https://eu-risk.eucentre.it) in preparation for the stakeholder workshop that is planned to take place in Istanbul in September 2019. Feedback on the risk model will be sought during the workshop and, together with the outcomes of the testing and verification task of JRA4 (Task 26.6) that will take place during the final year of the project, will be used to revise the models.

1 Introduction

The JRA4 work package (Risk Modelling Framework for Europe) of the SERA project has the following main objectives:

- develop a framework for modelling seismic risk at local (e.g. city), national and continental scales;
- combine the research efforts and data collected from recent European projects which have covered various aspects of seismic risk, i.e. SHARE (seismic hazard), NERA (residential building exposure) and SYNER-G (building and infrastructure fragility);
- fill in research gaps, including the development of non-residential and infrastructure exposure databases and the use of experimental test results (from the SERA testing infrastructures) to develop and calibrate fragility functions for structural components and buildings;
- include socioeconomic vulnerability and resilience within the risk framework to create a holistic description of seismic risk across all countries in Europe;
- share the developed models and results through various online platforms.

At month 24 significant progress on all of the above objectives have been achieved and the aim of this deliverable is to summarise all of these developments and explain how they fit within the proposed framework for modelling seismic risk at local, national and continental scale, with a focus on the latter scale.

The following section provides a brief summary of some of the main initiatives that have developed seismic risk models for (or covering) Europe. The main innovation of the current effort with respect to previous initiatives relates to the extension of seismic risk to 46 countries within Europe, the use of a fully probabilistic methodology and the involvement of the scientific community in the development of the models. The seismic risk framework proposed herein is then presented followed by sections that summarise the advances that the work within the SERA project will bring to each component of the framework (i.e. seismic hazard, exposure, physical vulnerability and social vulnerability, resilience and recovery).

2 European Seismic Risk Modelling Initiatives

Corbane et al. (2017) provide an overview of the current situation of risk modelling in Europe, noting that "the ranking of the typologies of risks affecting the EU can hardly be made because the available scenarios and risk assessment in general are often qualitative or semi-qualitative." In their paper they therefore present a feasibility study for a quantitative European seismic risk assessment conditional on 475-year return period ground motions using open datasets available across the EU. They make use of the ELER Level 1 software (BU-KOERI 2010), and the following input models:

- Seismic hazard map in terms of PGA with 475-year return period developed in the SHARE project (Woessner et al. 2013),
- A number of different ground motion to intensity conversion equations (GMICE),
- The European gridded building database for 27 EU countries developed in the NERIES project (and expanded to include Croatia),
- The macroseismic method vulnerability models developed by Giovinazzi and Lagomarsino (2004).

The results of the study by Corbane et al. (2017) were compared with the output of the probabilistic seismic risk assessment produced as part of the Global Assessment Report (GAR, 2015), one of the most notable efforts at the global scale that provides uniform average annual losses for a number of perils including earthquakes. As shown in Figure 1, the expected losses conditional on the 475 year return period ground motions that were computed by Corbane et al. (2017) give a higher ranking to Italy, Slovakia, Romania and Slovenia, whereas the GAR (2015) place the highest losses (in this case in terms of the 475 year return period losses) in Italy, Germany, Greece, and Great Britain. There are many potential reasons for the difference, including the different hazard models and the value of the exposure estimated across Europe, as well as the fact that the two risk metrics being compared are not exactly the same.

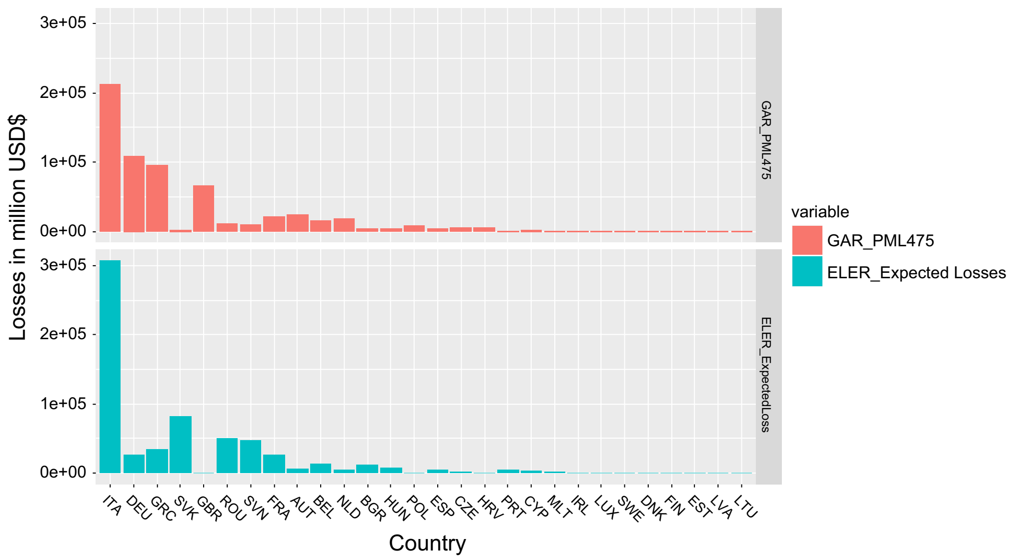


Figure 1. National level losses with 475-year return period estimated by the GAR (2015) (top panel) and losses conditional on 475-year return period PGA estimated by Corbane et al. (2017) (bottom panel).

Since the beginning of the SERA project the JRA4 team, and in particular the partner EUCE, has been collaborating with the GEM Foundation as part of their efforts to produce a Global Seismic Risk Map (GEM, 2018). In December 2018 the aforementioned map was publicly released and published at https://maps.openquake.org/map/global-seismic-risk-map/#3/32.00/-2.00 as described in Silva et al.

(2019). This collaboration has benefited both parties and has led to the development of the seismic risk framework for Europe described in this deliverable. The European results of the Global Seismic Risk Map (v2018.1) (Figure 2) can be viewed as v0.1 of the European Seismic Risk Model as they are based on the v0.1 European Exposure Model (see Deliverable D26.3, Crowley et al. (2019a; 2019b), and Section 3.2), developed under the framework of SERA. However, the vulnerability model made use of a global set of vulnerability functions (Martins and Silva, 2018), the hazard model that was used was ESHM13 (Woessner et al., 2013) and site amplification was modelled using topographic slope to approximate Vs30 (Wald and Allen, 2007). Table 1 presents the top 10 countries in Europe according to the estimated *AAL* from the Global Seismic Risk Map v2018.1 and the GAR (2015) as well as the top 10 countries (out of the 27 considered) from the Corbane et al. (2017) model (as taken from Figure 1).

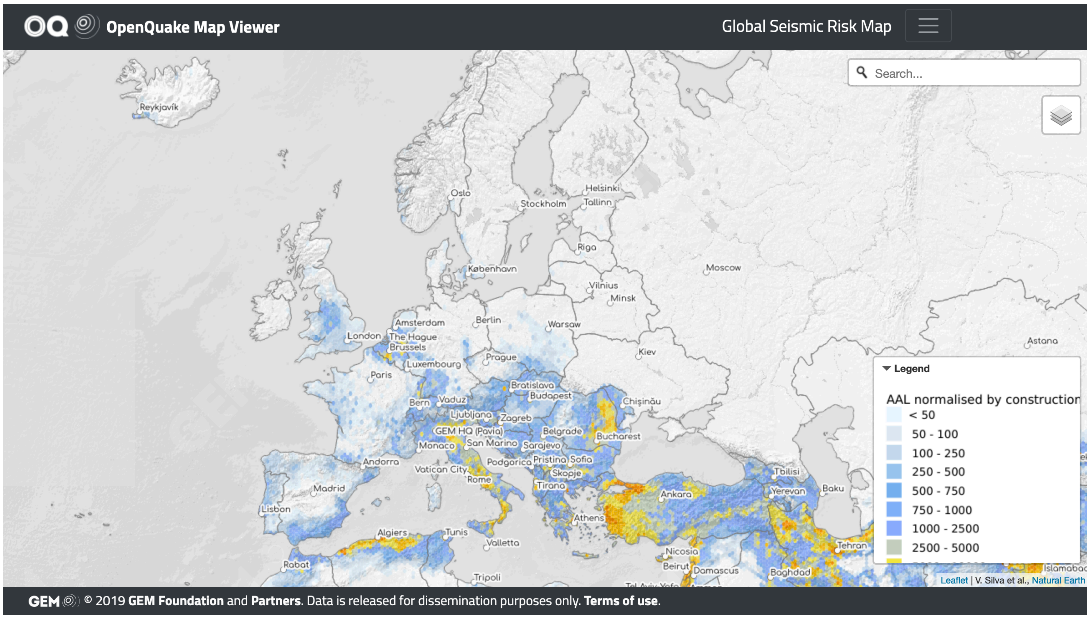


Figure 2. Global Seismic Risk Map (2018.1) showing results for Europe in terms of AAL normalised by construction cost

Table 1. Ranking of countries based estimated *AAL* from GEM 2018.v1 and GAR (2015) and losses given 475-year return period hazard from Corbane et al. (2017)

Based on estimated *AAL*		**Based on losses given 475-year return period hazard**
GEM 2018.v1	GAR (2015)	Corbane et al. (2017)
Turkey	Italy	Italy
Italy	Greece	Slovakia
Greece	Germany	Romania
Romania	Turkey	Slovenia
France	United Kingdom	Greece
Germany	Switzerland	Germany
Cyprus	France	France
Bulgaria	Romania	Belgium
Belgium	Netherlands	Bulgaria
Croatia	Belgium	Hungary

This comparison shows that the GEM model agrees with the other two models for 7 of the 10 countries (though the 7 countries are different in each case). It should be noted that the Corbane et al. (2017) does not cover all countries in Europe, which could be one reason for the difference in countries (for example, Turkey was not included). The authors believe that it is somewhat surprising to find the United Kingdom in 5th position in the GAR (2015) model, and such results could be checked by comparing them with the top 10 countries in Europe in terms of observed average annual losses. Such comparisons will be carried out in the future using the loss databases such as the NatCatService (MunichRe, 2019) and the Centre for Research on the Epidemiology of Disasters (EMDAT, 2019).

The European component of the Global Seismic Risk Map (v2018.1) will be updated using the European Seismic Risk Model 2020 (ESRM) being developed in the SERA project. The latter will differ from the GEM model for Europe as it will make use of an updated European hazard model, an innovative site amplification model, a modified exposure model, and a newly proposed European vulnerability model as presented in the next chapter.

3 European Seismic Risk Framework

A probabilistic seismic risk assessment (PSRA) involves the estimation of the probability of damage and losses resulting from potential future earthquakes. This damage and loss might occur to buildings, infrastructure, people or even the environment. Within the European risk framework that is being developed within the SERA project, the focus is being placed on estimating physical damage and loss for residential, commercial and industrial buildings (and their occupants), by combining seismic hazard (i.e. the probability of different levels of surface ground shaking) with physical vulnerability and exposure models:

PHYSICAL SEISMIC RISK = SEISMIC HAZARD * EXPOSURE * PHYSICAL VULNERABILITY (1)

The calculations for the European probabilistic seismic hazard and risk assessments are being undertaken with the OpenQuake-engine (Pagani et al., 2014; Silva et al., 2014). In the European seismic risk framework, all physical risk calculations are undertaken with the event-based probabilistic risk assessment calculator of the OpenQuake-engine (Figure 3) which requires an exposure model, a physical vulnerability model and a set of ground motion fields, which represent the spatial distribution of the ground shaking at the surface. The latter are produced through the hazard library of the OpenQuake-engine (hazardlib). One of the inputs to the hazardlib is a seismogenic source model (which models the spatial and temporal occurrence of earthquake activity) that is used to create an earthquake rupture forecast (i.e. list of all of the possible ruptures that can occur in the region of interest), which is then employed to generate stochastic event sets (SES). Due to the random nature of the process, a large number of SES is required in order to reach statistical convergence in both the seismic hazard and risk assessments (Silva, 2017). The epistemic uncertainty in the seismogenic source model can be propagated through the use of logic trees (Pagani et al., 2014). For each event in the SES, a ground-motion field (i.e. a spatial representation of the surface ground shaking) will be generated, considering the ground-motion prediction equations (GMPEs, described through a ground motion logic tree) associated with the respective tectonic region as well as the local site conditions. The intra- and inter-event aleatory variability from the GMPEs are propagated using a Monte Carlo approach, and the spatial correlation in the ground motion residuals from the same intensity measure (e.g. a given spectral ordinate) can be considered using the correlation model from Jayaram and Baker (2010).

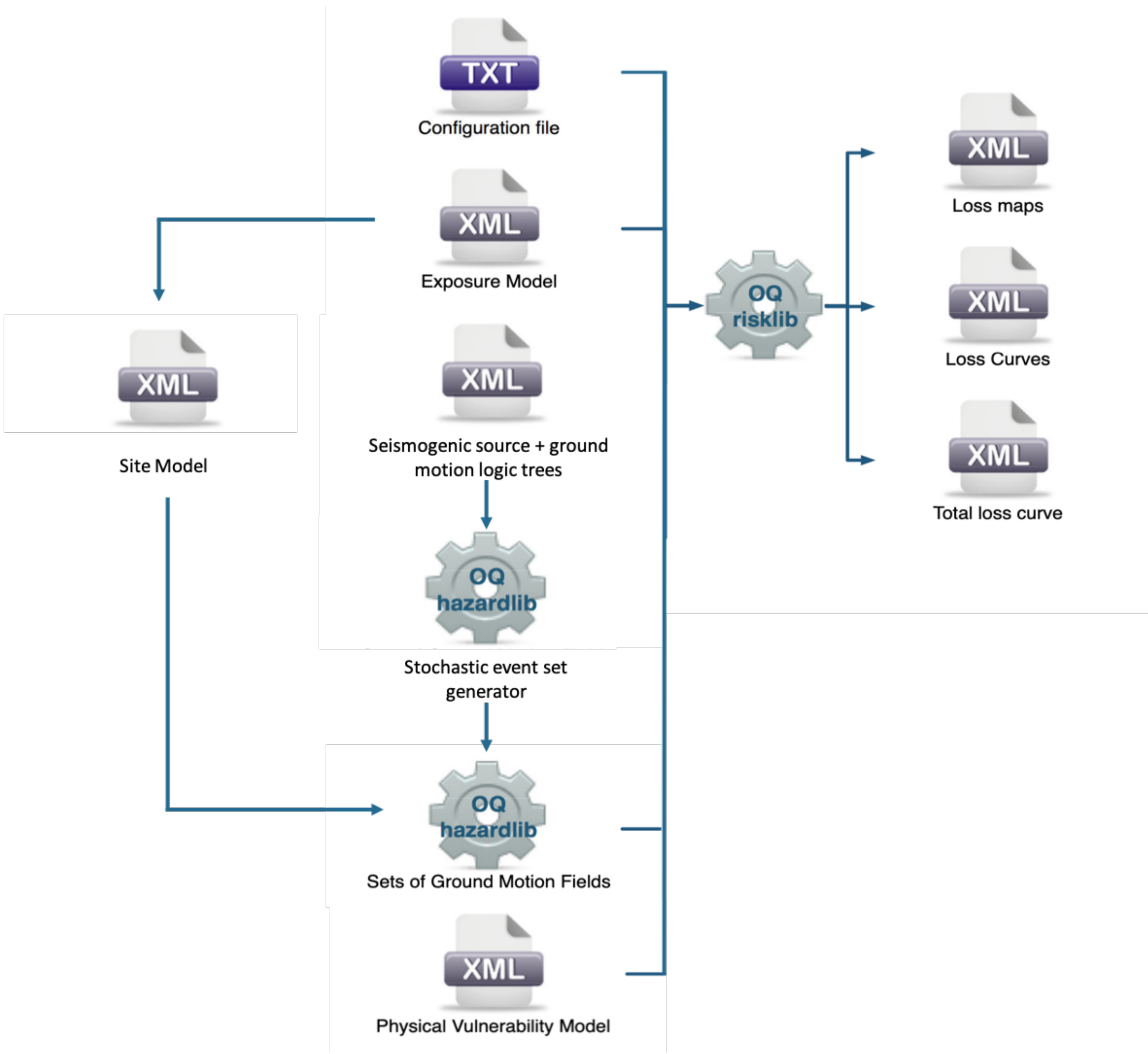


Figure 3. European Seismic Risk Framework described using the OpenQuake-engine Probabilistic Event-based Risk Calculator input/output structure

The surface ground shaking at a given coordinate will be combined with the physical vulnerability functions (see Section 3.3.1) for the building classes identified at that location, and multiplied by their replacement costs / number of occupants (as defined in the exposure model, described further in Section 3.2) to compute the expected loss for each event in the SES. This will lead to the derivation of event loss tables, comprising the losses per building class and location for each event in the SES. These tables can be used for the calculation of several risk metrics, including exceedance probability curves and average annualized losses. The former metric expresses the rate of exceeding (λ) a given loss *l*, as described by Equation (1):

$$\lambda(L > l) = \frac{1}{n}\sum_{i=1}^{j} I(L_i > l) \tag{1}$$

where $I(L_i > l)$ stands for the number of loss values above *l*, *j* is the total number of losses, L_i stands for the loss caused by event *i*, and *n* represents the length of the SES. Likewise, the average annual loss (*AAL*) can be computed using the following equation:

$$AAL = \frac{1}{n}\sum_{i=1}^{j} L_i \tag{2}$$

These metrics will be calculated for each branch of the logic tree, leading to a probabilistic distribution of risk, from which the mean *AAL* (in terms of human loss, economic loss or number of collapsed buildings) can be calculated. For a holistic view of the seismic risk, the physical risk indicators will be combined with social vulnerability, resilience and recovery indices (see Section 3.3.2) to produce impact maps.

All of the inputs presented in Figure 3 are required regardless of the scale of the calculation (i.e. local, national or continental). The main differences when running calculations from one scale to another will generally be found in the exposure model, which is more likely to be at a higher resolution for local level risk assessments, and the site model, with more detailed information likely to be available for local level assessments, which would allow different approaches to be used to amplify the ground motions (as described in Section 3.1). Custom inputs for the seismogenic source model, ground motion model and physical vulnerability model can be provided by the user for a local level assessment, whereas the SERA project will develop and release a set of models to be used for seismic risk assessment at the continental scale. Hence, the rest of this deliverable will focus mainly on the assessment of seismic risk for the whole of Europe and the choices that are being made to implement the proposed framework at a continental scale.

3.1 European Seismic Hazard Model

European seismic hazard for reference bedrock is being developed within SERA JRA3 work package. The current European seismic hazard model (2013 Euro-Mediterranean Seismic Hazard Model – Woessner et al., 2013) is available for download from the EFEHR platform (EFEHR, n.d.). Users of the EFEHR platform can access pre-computed hazard products such as the spatial distribution of the spectral acceleration on reference bedrock for a number of periods of vibration (from 0.01 to 4 seconds) for a number of return periods (73, 102, 475, 975, 2475, 4975 years). These products will also be available from April 2020 for the update to the European seismic hazard model (i.e. ESHM20).

However, as presented in Figure 3, the European seismic risk framework requires the input of the seismogenic and ground motion model logic trees, and so in addition to the aforementioned hazard products, users interested in applying the risk framework will also be able to download the European seismogenic source and ground motion logic tree NRML files from the EFEHR platform. Interested readers are referred to the deliverables of SERA work package 25 (JRA3) for an update on the latest developments in the European seismic hazard model, and in particular Deliverables D25.3 and D25.4.

Given that a seismic risk assessment requires an estimate of the ground shaking at the surface, one of the tasks of JRA4 has been to consider how the aforementioned seismogenic and ground motion logic tree models can be used together with local site conditions to produce probabilistic estimates of surface ground shaking. This should be possible at various scales of resolution, from local (city) scale assessment through to the European scale, as outlined in Deliverable D26.4 (Crowley et al., 2019c). At the European scale, the following options are currently available for implementing site amplification within a probabilistic seismic risk assessment with the OpenQuake-engine:

- V_{S30} from the Wald & Allen (2007) approach can be implemented using an *inferred* V_{S30} amplification model;
- V_{S30} from the Wald & Allen (2007) dataset can be used in conjunction with the geological units and implemented using the geologically-calibrated *inferred* V_{S30} amplification model
- The 30 arc-second slope data can be used in conjunction with the geological units, to be implemented using the geologically-calibrated *slope* amplification model (Weatherill et al., 2019).

The final model to be adopted in the European Seismic Risk Model (ESRM20) will partly depend on the ground motion logic tree that is finally selected, but it currently appears most likely that the third option reported above will be used. It is noted that the additional variability in the estimated ground motions that arises from the use of proxy datasets (i.e. topography and geological units) is explicitly accounted for in the aleatory variability of the amplification model. In order to implement this proposed approach at a European scale, the necessary Europe-wide proxy datasets (Figure 4) will be made available through the EFEHR portal and the OpenQuake-engine will include a European ground-motion model that makes use of the aforementioned geologically-calibrated slope amplification model.

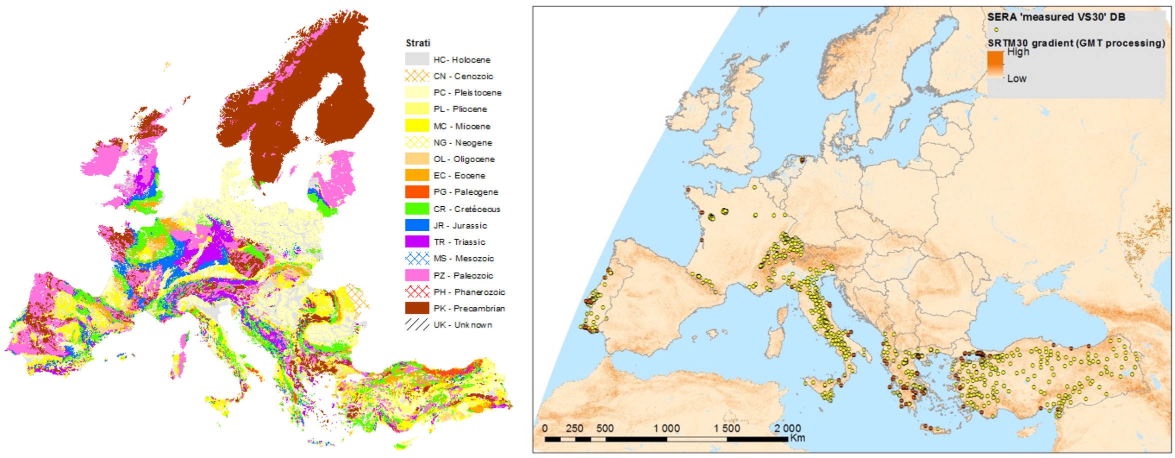


Figure 4. Proxy datasets of simplified stratigraphic map (left) and gradient from the SRTM30 30 arc-second land topography data set, superimposed with measured V_{S30} data (right)

One issue that needs consideration with this continental site amplification approach is the resolution of the proxy data and how this links with the resolution of the exposure data. Ideally, the two datasets should be provided at the same resolution and so the site model XML that is input to the OpenQuake-engine will have the same coordinates as the exposure model XML. The resolution of the exposure data is described further in Section 3.2 and, as will be explained, the European exposure data used for the calculations will be at a coarser resolution than the 30 arc-second proxy data. In order to ensure that the two input models have the same resolution, the amplification factor and associated sigma of the geologically-calibrated slope amplification model will be calculated using the 30 arc-second grid, and then these will be aggregated to the grid resolution used in the exposure model (see flowchart in Figure 5). The ground-motion fields that are subsequently calculated and input to the OQ risklib together with the exposure model and physical vulnerability models (see Figure 3) will therefore be at the same resolution as the exposure model.

For local scale seismic risk analyses where local data provide a good constraint of the site conditions, e.g. microzonation derived site profiles, V_{S30} measurements etc., an amplification model dependent on *observed/measured* V_{S30} should be adopted. Again, such model will be made available within the OpenQuake-engine, as described in Deliverable D26.4.

Alternatively, the nonlinear amplification factors proposed by Pitilakis et al. (2018) and described in Deliverable D26.4 can be used at a local scale (when both data on V_{S30} measurements and the fundamental period of soil deposit, T_0 are available), though it should be noted that this approach is more geared towards code applications and does not fully propagate the uncertainties in the site amplification. That approach is therefore of currently most use for assessing the relative impact of modifications to code-based site amplification modelling in terms of seismic risk metrics.

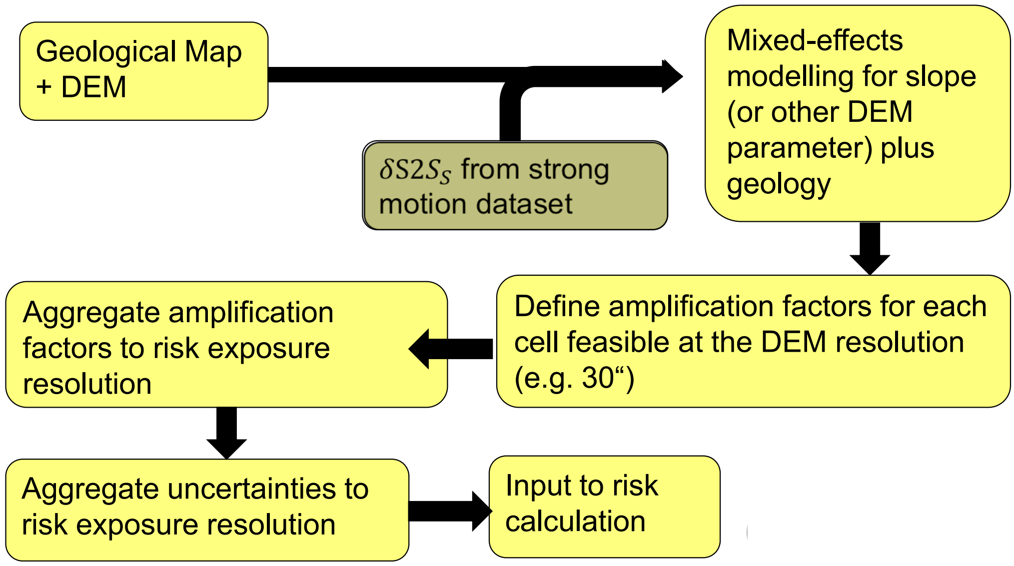


Figure 5. Flowchart showing how the amplification factors will be calculated on the same grid as the exposure model, regardless of the resolution of the proxy data

3.2 European Exposure Model

The European Exposure Model (i.e. the spatial distribution of the residential, commercial and industrial building count, population, and replacement cost - characterized in terms of building classes) being developed in the SERA project is summarised in three deliverables: D26.1, D26.2 and D26.3 (Crowley et al., 2017; 2018; 2019a). The latter deliverable (D26.3) provides an overview of the exposure model that covers residential, industrial and commercial buildings, at the current stage of the project (month 24). The buildings in Europe are being described using an updated version of the GEM Building Taxonomy (Brzev et al., 2013, as updated by Silva et al., 2018) that allows buildings to be classified according to a number of structural attributes. The following main attributes have been selected for the consistent definition of building classes across Europe in the v0.2 exposure model (currently under development):

- Main construction material (reinforced concrete, unreinforced masonry, reinforced/confined masonry, adobe, steel, timber).
- Lateral load resisting system, LLRS (infilled frame, moment frame, wall, dual frame-wall system, flat slab/plate or waffle slab, post and beam).
- Number of storeys.
- Seismic design code level (CDN: pre-code, CDL: low code, CDM: moderate code, CDH: high code).
- Lateral load coefficient used in the seismic design.

The exposure data at a European scale presents several challenges due to the disparity in the size of the administrative divisions at which the building data is available between different countries. To minimize this issue, the exposure model will be spatially disaggregated across Europe on an evenly spaced grid with 30 arc-second using auxiliary datasets, and then aggregated on a hexagonal grid with a spatial resolution of 0.30x0.34 decimal degrees (approximately 1000 km^2 at the Ecuador) (Figure 6).

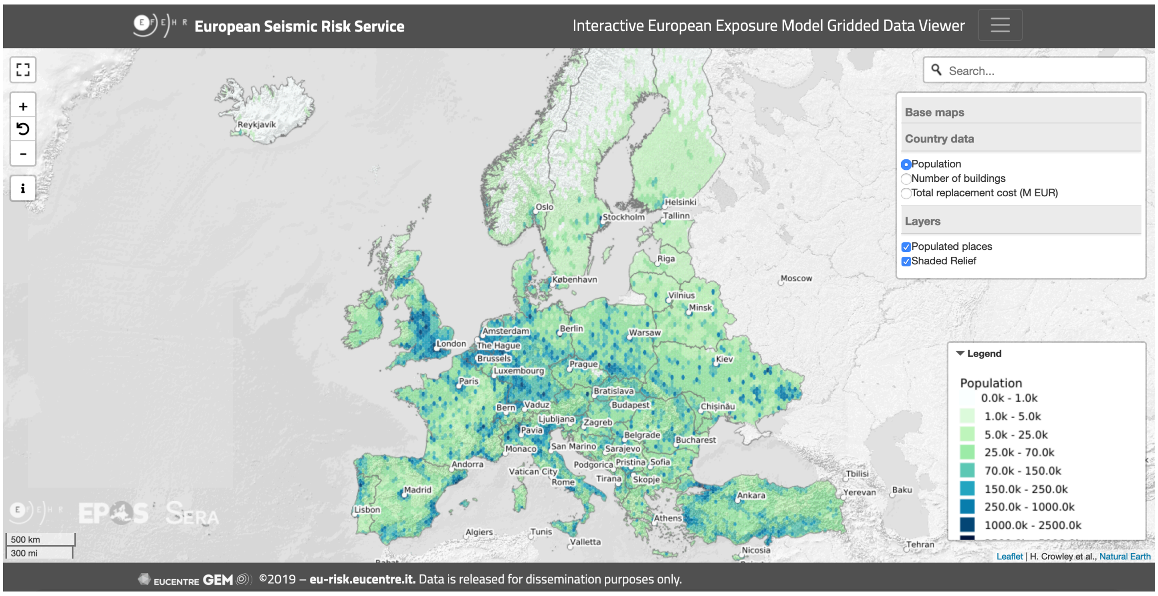


Figure 6. European exposure model gridded data in terms of population (https://maps.eu-risk.eucentre.it/map/european-exposure-gridded-data)

The auxiliary datasets that are currently used to disaggregate the exposure data are the population density provided by WorldPop (Lloyd *et al.,* 2017) and the night-time lights (Elvidge *et al.,* 2012), but additional European-specific datasets will be explored in the future. Experience gained by GEM during the development of their global seismic risk map has shown that resolutions smaller than 0.30x0.34 decimal degrees complicate the identification of rural areas or small urban centres, while coarser resolutions will merge nearby cities or adjacent small countries (Silva et al., 2019).

3.3 European Vulnerability Model

3.3.1 Physical Vulnerability

The methodology being proposed in the SERA project for developing fragility and consequence models for European buildings is outlined in Deliverable D26.5 and shown in Figure 7 (Romão et al., 2019).

The basic workflow of the framework starts with the definition of the Building Class Information Model (BCIM). The BCIM includes the information that is necessary to compute the total variability of the fragility function associated to a building class. Inside the BCIM, the building class is characterized by its simple collapsed taxonomy (used in the exposure model), and includes information about the attributes that are not explicitly included in the simple taxonomy, as well as statistical information about the architectural properties and design assumptions. Furthermore, the BCIM also includes information available from the SERA.REVIEW database, a database of existing/literature information (capacity curves, fragility functions and vulnerability models) that has been produced and which follows the data-structure defined within GEM's Global Vulnerability Database. (i.e. data, metadata and model information).

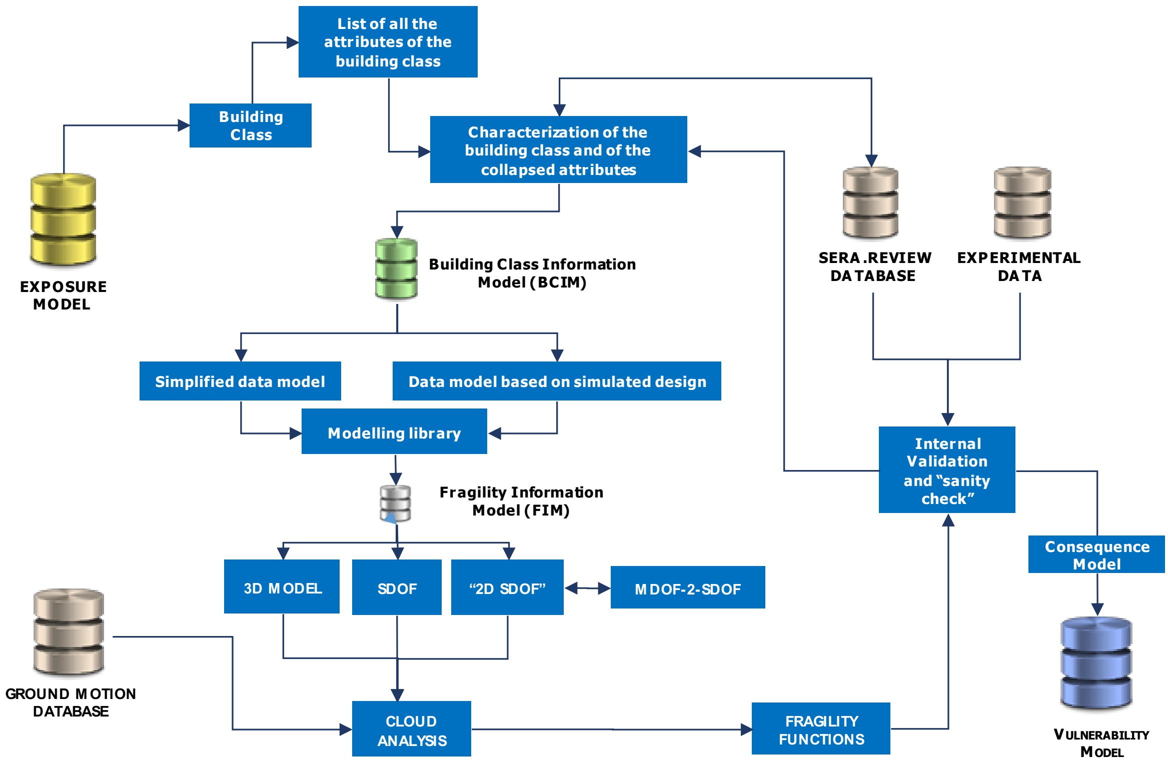


Figure 7. General workflow of the SERA framework for seismic vulnerability analysis

The propagation of the uncertainties and variability sources included in the BCIM to the fragility function is then performed by developing a set of realizations of the BCIM data that represent several possible building realizations of a given building class. Each realization is then analysed in the modelling module, where either a simplified (Type 1) or a complex (Type 2) model based on a simulated design approach are created. The information of these models is stored into the fragility information model (FIM). The FIM also includes a set of realizations of the BCIM data, each of which is defined by a numerical model and a set of seismic capacity variables derived from nonlinear static analysis. Hence, two types of FIM can be generated by the framework, depending on the type of data stored in the BCIM:

Type 1: The FIM is based on a simplified data model, and is based on the main principles used by Villar-Vega et al. (2017) and Martins and Silva (2018; 2019) to develop existing continental fragility functions. The BCIM information required for applying this method are approximations for the probabilistic capacity curve parameters and correlations (in the ADRS format) for the building class.

Type 2: The FIM is based on a simulated design approach, thus targeting mainly engineered buildings (i.e. excluding the masonry building classes). By using statistical distributions for the architectural building parameters and defining the main design assumptions, a set of buildings can be designed for a given design code level (also connected to the age of the buildings considered for each building class). This design is also performed accounting for the seismicity of the site, which can be represented by a lateral load coefficient (β). After designing the buildings, a set of nonlinear models of the buildings are developed and nonlinear static analyses are performed. Hence, the data included in the FIM involves a set of nonlinear 3D models, their corresponding modal properties and statistical distributions of pushover curve parameters.

Each realization of the FIM data model is then analysed using a record-to-record uncertainty propagation method (nonlinear dynamic cloud analysis), either using a SDOF, a 2D SDOF or a full 3D MDOF, depending on the complexity of the building class and the existing degree of confidence in the more simplified modelling approaches. The records used for the nonlinear dynamic analysis include all recordings with PGA greater than 0.05g in the European Strong Motion (ESM: Luzi et al., 2016a; 2016b). From the nonlinear dynamic cloud analysis, a best fit curve between the intensity measure level and the nonlinear displacement response is derived in the logarithmic space, after which fragility functions are readily produced using displacement thresholds assigned to each damage state. The SERA methodology proposes the use of AvgSa (i.e. geometric mean of spectral acceleration values over a range of periods) as the optimum intensity measure type as it has been shown to be a sufficient intensity measure (e.g. Eads et al., 2015, Kohrangi et al., 2017) and it also allows for a direct comparison between fragility functions which is useful for validation purposes (see below). However, for compatibility with the ground motion models that will be implemented within logic tree of the European Seismic Hazard Model (ESHM20), additional intensity measures of PGA, SA(0.3s), SA(0.6s) and SA(1.0s) are also considered for the regression.

Consequence models, or damage-to-loss models, are used to transform the fragility functions (which describe the probability of reaching or exceeding a set of damage states, conditional on a level of ground motion), to vulnerability functions (that provide the distribution of loss ratios conditional on a level of ground motion). The losses that will be considered in the European Seismic Risk Model will be direct economic loss due to structural and non-structural damage (and thus the loss ratios will represent the ratio of cost of repair to cost of replacement of the buildings) and fatalities (and thus the loss ratios will represent the ratio of the number of fatalities to the number of occupants of the buildings). Details of the consequence models are provided in Deliverable D26.5.

One fragility and vulnerability models are computed, they are checked according to a set of benchmark case studies to assess their conformity (‘sanity checks” based on the comparison of fragility curves of different building classes) and their predictability capacity (comparing their results with real data from post-earthquake surveys), as described further in Deliverable D26.5. If a model provides adequate conformity and predictability levels, it is adopted as a good representation for the vulnerability of the building class under analysis. Otherwise, an iterative procedure starts that can involve increasing the complexity of the FIM data model and of the techniques used to include record-to-record variability, or improving the consequence models. In case these measures are insufficient, modifications have to be made to consequence model or to the BCIM model.

3.3.2 Social Vulnerability, Resilience and Recovery

The framework for integrated risk is based on the methodology proposed by the Global Earthquake Model, whereby indicators of socio-economic vulnerability, resilience and recovery (such as homelessness, poverty, corruption) are combined to produce three composite indices: 1) impact on human lives, 2) economic resilience and 3) recovery index (Figure 8).

As described in Deliverable D26.6, databases of socioeconomic vulnerability and resilience indicators (see Table 2) at national and sub-national/city levels are thus needed for the framework, and are being collected. However, following the feedback obtained from the Scientific Advisory Board in their mid-term view, further discussion on the indicators that are most representative for SVRR modelling in Europe is needed, and thus changes to the indicators in the table below are expected. A meeting will take place on 19th June 2019 with experts in the field in order to discuss the most appropriate indicators to use within Europe.

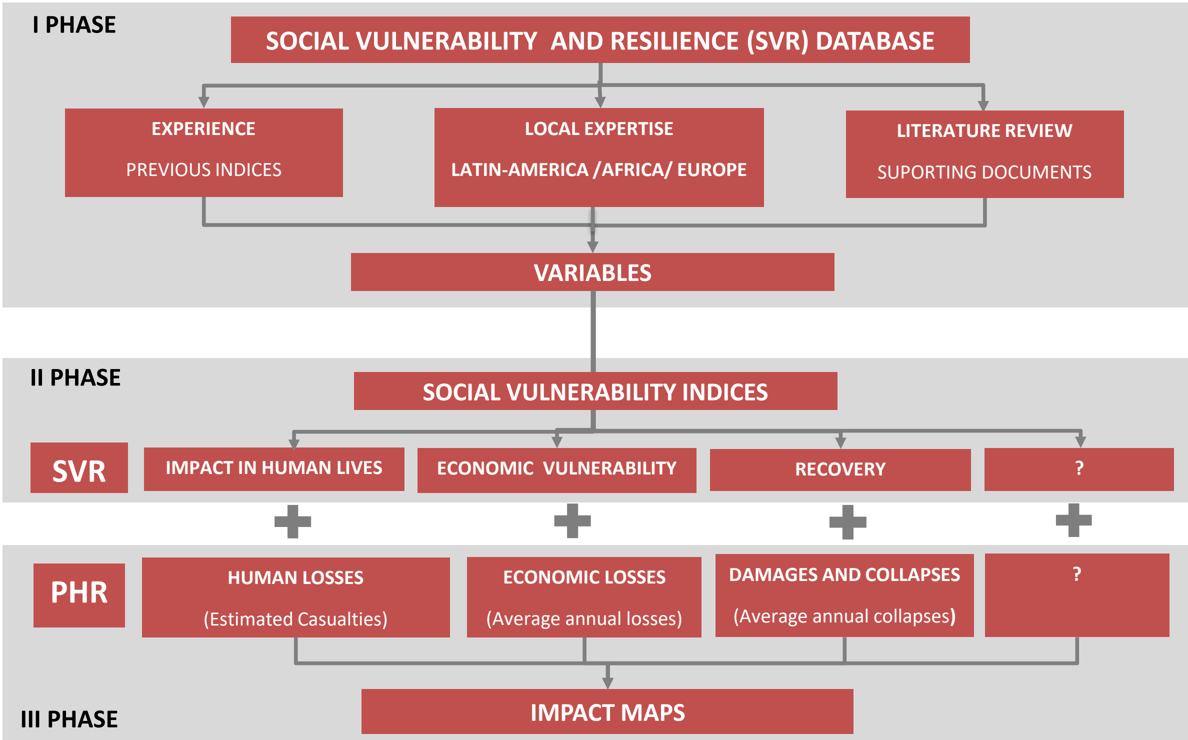


Figure 8: Structure of GEM's SVR indices and impact maps. The question marks in the boxes on the bottom right signify that other combinations of physical risk and social vulnerability might be identified in the future.

Table 2. Indicators of socioeconomic vulnerability and resilience

Impact On Human Lives (Fatalities-Injuries-Homeless)	Economic Resilience (Direct Losses)	Recovery
Average Household Size F I	People Working In Manufacturing Industry, Hotel/Restaurant, Commercial Industry	Female Population
Population Density F I	Unemployment Rate	Indigenous Population
Population With Disabilities F I	Population In Poverty	Population With Disabilities
Age Dependence F I (0-14, 65+)	Population With No Formal Education / Illiteracy Rate	Women Head Of Households
Household Paying Rent Monthly H	No Access To Electrical Energy	Illiteracy Rate
Overcrowded Households / Squatters H		No Access To Electrical Energy
Collective Households H		No Access To Potable Water
Unsatisfied Basic Needs I		No Sanitary Services
Population With No Formal Education I		
Illiteracy Rate I		
No Access To Potable Water I		
No Sanitary Services I		
Households With No Radio / Tv I		
Access To Mobile Phone I		
No Access To Healthcare F		
Number Of Hospital Beds F		
No Access To Internet I		

Key: F = Fatalities, I = Injuries, H = Homeless

3.4 Seismic Risk Outputs

For the purposes of communicating the results of the European risk model, only mean values (across all of the logic tree branches) will be presented. However, the impact of different sources of epistemic uncertainty (from the hazard, exposure and vulnerability components) will be investigated and maps with qualitative indices showing the variation of model input uncertainty across Europe will be presented in the final publications that will accompany the European Seismic Risk Model.

As presented previously in Figure 3, the outputs of the framework include loss maps, loss curves and total (aggregated) loss curves. The interactive risk maps that will be released on the European Seismic Risk Service (https://eu-risk.eucentre.it/seismic-risk) will be expressed in terms of average annual loss (AAL), but other results such as exceedance probability curves and aggregated losses for specific return periods will be presented in country profiles, based on those proposed by GEM on the Global Risk Model Explorer (https://maps.openquake.org/map/global-seismic-risk-map). In addition, the following indicators of the Sendai Framework for Disaster Risk Reduction will also be produced by April 2020 and will be included in the country profiles (see Figure 9 for an example mock-up):

A1: Number of deaths attributed to earthquakes, per 100,000 population;
B3: Number of people whose damaged dwellings were attributed to earthquakes;
B4: Number of people whose destroyed dwellings were attributed to earthquakes;
C3: Direct economic loss to all other damaged or destroyed productive assets attributed to disasters;
C4: Direct economic loss in the housing sector attributed to disasters.

Future research beyond the SERA project will be needed to allow additional indicators related to missing persons, injuries, impact on livelihoods, and damage to infrastructure and cultural heritage to be estimated within the presented probabilistic framework.

As presented previously in Figure 8, integrated risk will be presented by combining physical risk metrics with socio-economic vulnerability, resilience and recovery composite indices through impact maps. These interactive integrated risk maps will also be released on the European Seismic Risk Service (https://eu-risk.eucentre.it/seismic-risk). An example impact map is shown in Figure 10. In order produce these maps, the exposure and SVRR data needs to be mapped to the same administrative unit scale, using the higher of the two datasets.

ITALY

Social Indicators

Population (Million):	60.551
Population Growth Rate (%/Year):	-0.126
GDP (Billion USD):	1,934.798
GDP per Capita (USD):	31,953
Gross Savings (Billion USD):	387.049
Life Expectancy (Years):	82.54
GINI Index:	31.9
Human Development Index:	0.887

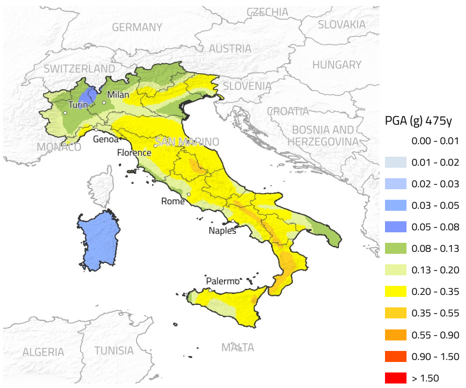
Risk Indicators

Occupancy	Asset Replacement Cost (Billion USD)	Average Annual Loss (Million USD)	Average Annual Loss Ratio (‰)
Residential	2,453.8	1,670.9	0.68
Commercial	443.5	306.8	0.69
Industrial	703.0	127.7	0.18

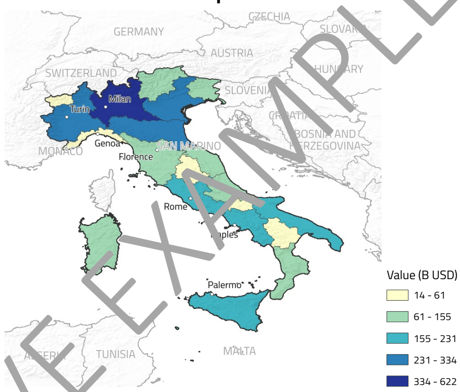
Sendai Framework for Disaster Risk Reduction Indicators

A1:
B3:
B4:
C3:
C4:

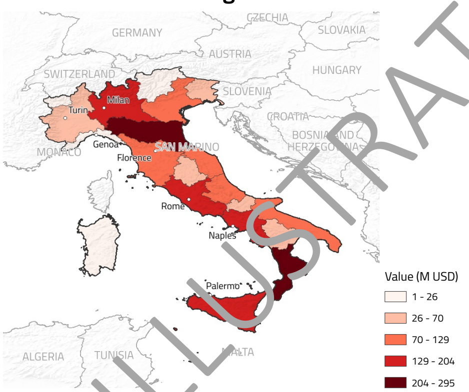
Seismic Hazard



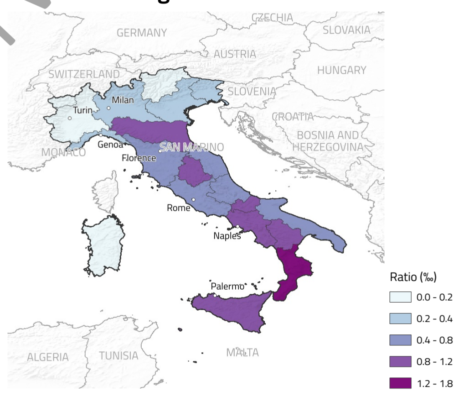
Exposure



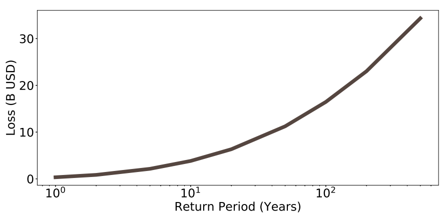
Average Annual Losses



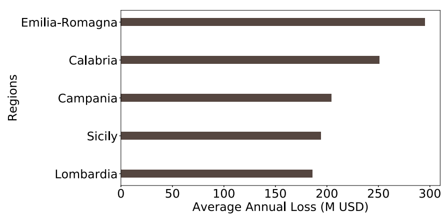
Average Annual Loss Ratios



Loss Exceedance Curve



Regions of Highest Earthquake Risk



https://downloads.openquake.org/countryprofiles/ Version 1.2 Generated: 2019-03-01

Figure 9. Mock-up of the European Seismic Risk Model Country Profile based on the profiles developed by GEM

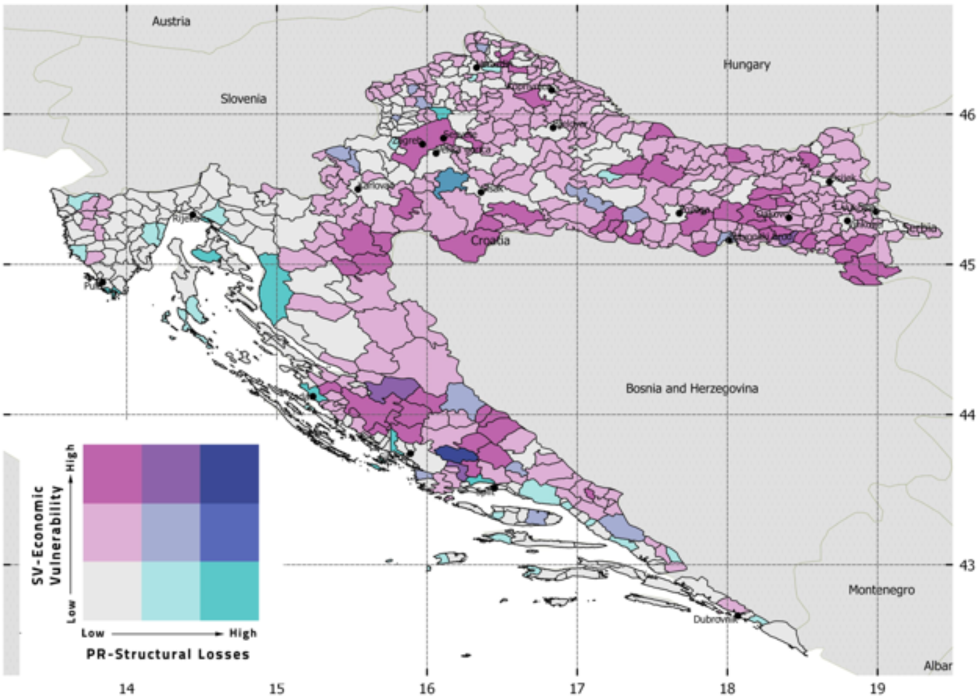


Figure 10. Example impact map of the integrated risk across Croatia

4 Conclusions

The aim of this deliverable has been to report the current status of the different model components of the European seismic risk framework, and present how they will be combined for the purposes of a fully probabilistic seismic risk assessment. The main focus has been on specifying the details necessary for Europe-wide risk calculations, such as the resolution of the exposure and site amplification models, whilst also ensuring that the same framework can be used at national and local scales. Following the submission of this deliverable, the SERA JRA4 partners will continue to develop the various components and will put them together to produce a v0.2 European Seismic Risk Model that will be shared via the European Seismic Risk Service (https://eu-risk.eucentre.it) in preparation for the stakeholder workshop that is planned to take place in Istanbul in September 2019. Feedback on the risk model will be sought during the workshop and, together with the outcomes of the testing and verification task of JRA4 (Task 26.6) that will take place during the final year of the project, will be used to revise the models.

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