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Municipal expected annual loss as an indicator to develop seismic risk maps in Italy

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ABSTRACT This work presents a risk-targeted indicator called Municipal Expected Annual Loss (MEAL) for a quantitative estimation of the seismic risk at territorial level. With MEAL, it is possible to calculate the impact of earthquakes in terms of direct losses, taking account of a wide set of earthquake scenarios on the built environment at municipal level. MEAL is, therefore, able to summarize scenario loss values of each municipality, and define in such a way a risk-targeted metric that can clearly be understood also by different stakeholders dealing with seismic risk management, mitigation, and transfer. The use of MEAL to map seismic risk for the Italian residential building stock is herein presented as a case-study, leading to the development of several maps able to depict seismic risk at different territorial scale levels.

Key words: earthquake scenarios, MEAL, Italy, seismic risk map.

1. Introduction

The financial impact of earthquakes in Italy is a relevant issue, and due to the increasing exposed value, is no longer sustainable, given the fact that actually reconstruction processes are still burdening on public financial funds. In order to try to reverse the course, in 2017, the Italian government approved a tax relief program called “Sismabonus” aimed at assisting householders interested in seismically retrofitting their properties (DM 65, 2017). Citizens can, therefore, take advantage of a tax relief if undertaking a seismic retrofit intervention aimed at reducing the vulnerability of their homes.

In the past, many authors have proposed different seismic risk maps for Italy: a first research on this was conducted by Lucantoni *et al*. (2001), who characterised hazard and damage probability matrices in terms of MCS intensity scale, subsequently revised by Zuccaro (2004) and updated with 2001 census data by Bramerini and Di Pasquale (2008). More recently, Crowley *et al*. (2009) computed seismic risk maps using two analytical methods previously developed by the authors to compute fragility curves and state-of-the-art methods for the estimation of hazard curves, highlighting how the seismic risk spatial distribution resulted significantly different with respect to previous maps developed by other authors. Rota *et al*. (2011) investigated seismic risk for different Italian building types, deriving typological maps in terms of annual probability of loss of the relative value of buildings. Maps were derived by convolving hazard curves with empirical-based fragilities over the entire national territory, thus leaving exposure out of consideration and, therefore, assessing a so-called "typological seismic risk", that can be used as a metric for defining insurance strategies at the building level. Asprone *et al.* (2013) computed seismic risk maps for 5 building types convolving hazard and fragilities with the aim of generating a seismic insurance model for Italy.

The development of a seismic risk map is, therefore, a key-starting point to define a rational seismic mitigation program for a country, since it allows the government to understand needs and priorities, and, thus, rationally develop a risk management plan.

This contribution illustrates in detail the main steps made by the authors in order to calculate seismic risk maps, with emphasis on the residential building stock of Italy, via the use of a novel risk-targeted indicator named Municipal Expected Annual Loss (MEAL). With MEAL, it is possible to quantify potential economic loss to be sustained yearly to repair seismic damage to the residential building stock of each municipality. In addition, the knowledge of MEAL is a starting point for further post-processing issues, aimed at representing seismic risk at the territorial scale considering different administrative levels (i.e. Province- and Regional-level, accordingly with the cogent administrative subdivision of Italy). Lastly, on those bases, a qualitative rating is introduced in order to ensure a clearer picture of seismic risk in Italy via the use of a Seismic Risk Class (SRC) rating scheme.

The workflow can be summarised as follows: first, the characterisation of the seismicity of the Italian territory and the definition of the seismic fragility of building types based on a reliable taxonomy able to match the main structural characteristics of the Italian residential building stock. Hence, the quantification of the exposed value, consisting of characterising the number and type of residential buildings in each Italian municipality. Lastly, the computation of MEAL in each municipality, the development of different seismic risk maps for the analysed asset and discussion of the results. The following gives a detailed description of the main steps of the work.

2. Seismic hazard characterisation

Most of the Italian territory is significantly prone to seismic hazard, with a large number of events recorded in the past, homogeneously along the national borders. To characterise seismic hazard of the Italian territory, a consistent set of earthquake scenarios has been identified as a hazard model, instead of a point-like characterisation usually based on the use of probabilistic seismic hazard analysis curves. The seismogenic source zone model ZS9 (Meletti *et al.*, 2008) has been adopted, using Gutenberg-Richter (G-R) recurrence laws for each seismogenic zone (SZ). Fig. 1 illustrates the main parameters (i.e. maximum magnitude value $M_{max,i}$, mean annual rate of events with magnitude above the minimum magnitude value $\nu_{Mmin,i}$, and slope coefficient b and total seismicity rate a of the G-R law) for each of the 36 SZs, as reported in Barani *et al.* (2009). A 5-km mesh grid of epicentres has been sampled, with a total number of grid points equal to 7237.

Six moment magnitude (M_i) values have been considered for each *i-th* SZ within its $M_{min,i}$-$M_{max,i}$ range. As regards the ground motion prediction equation (GMPE) model, the formulation proposed by Bindi *et al.* (2011) has been used jointly with the 30-m depth shear wave velocity ($V_{s,30}$) soil map (Allen and Wald, 2007) illustrated in Fig. 2 and provided by the United States Geological Survey (USGS). Earthquake scenarios have, thus, been run in each *i-th*

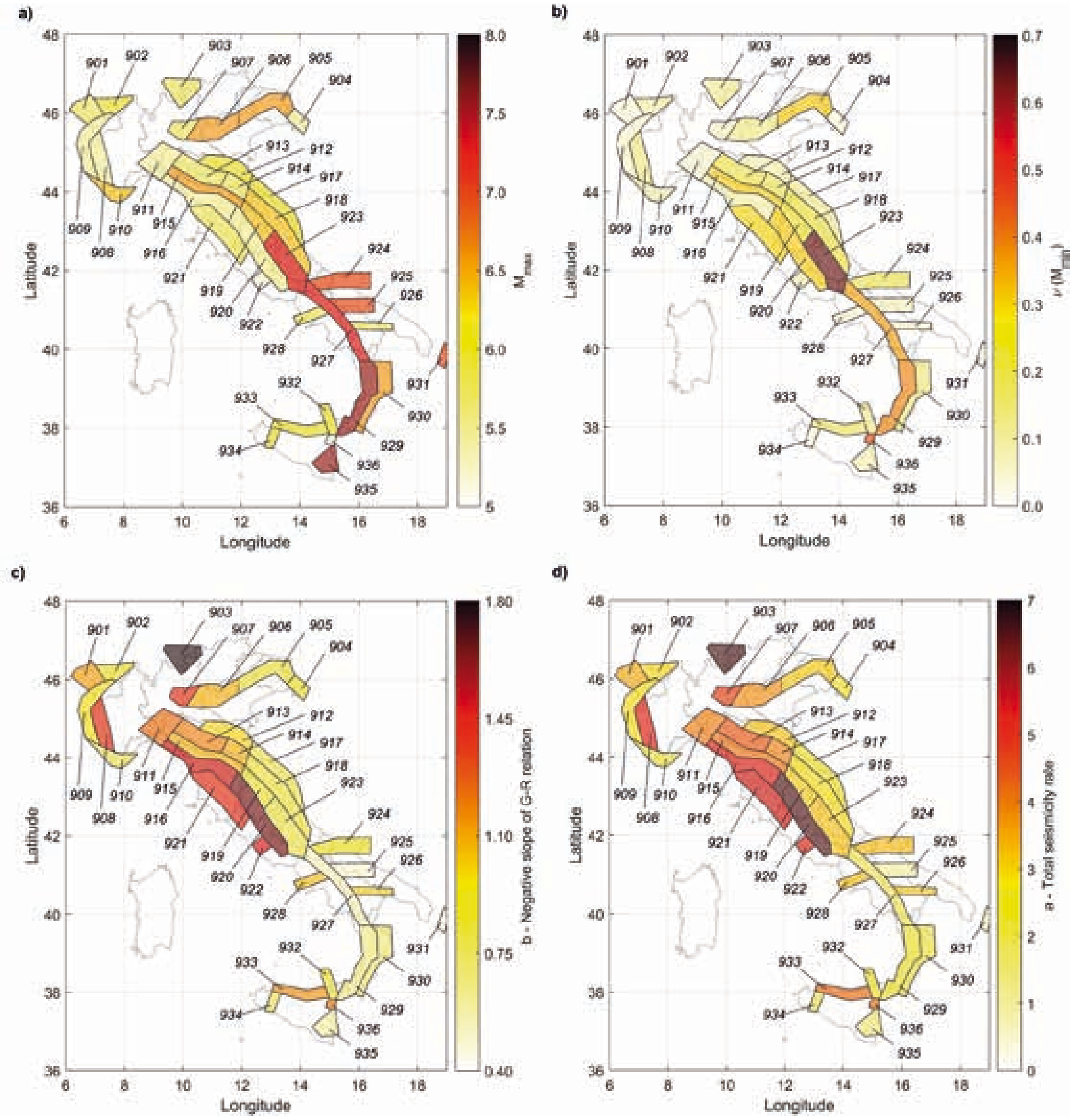

Fig. 1 - Seismogenic source model: M_{max} (a) and ν_{Mmin} (b) values, G-R *b* (c) and *a* (d) coefficients for each SZ.

SZ consistently with its prevailing faulting mechanism [Fig. 3, Barani *et al*. (2009)], leading to the simulation of a total set of 43,422 earthquake scenarios, with the computation of peak ground acceleration (*PGA*) values at each of the 8084 municipality centroids of the exposure model, for a total of 351,023,448 *PGA* estimates.

3. Seismic fragility taxonomy

The seismic vulnerability of the analysed building stock has been characterised by setting a building taxonomy consisting of eight taxonomy classes (TCs). For each *y-th* TC, a suitable set of fragility curves related to four mutually exclusive and collectively exhaustive damage states

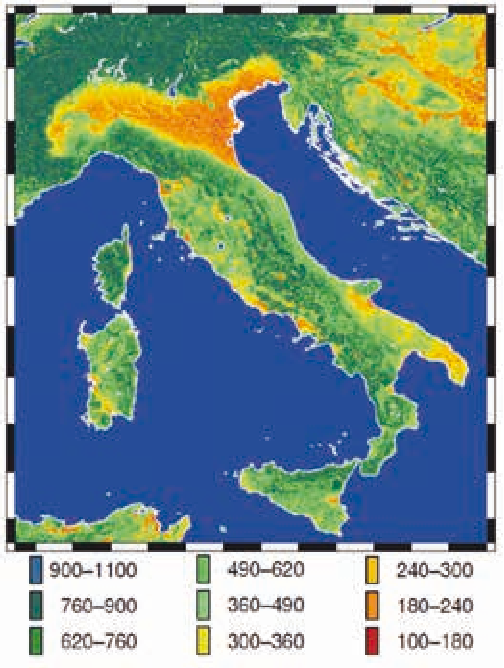

Fig. 2 - Soil characterisation based on $v_{S,30}$ map derived from topographic data (earthquake.usgs.gov/data/vs30/).

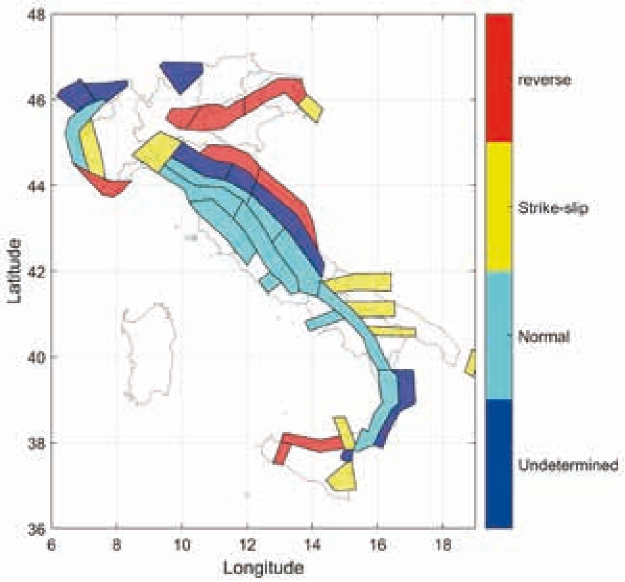

Fig. 3 - Prevailing mechanism of faulting for each SZ.

(i.e. DS_1, DS_2, DS_3, DS_4, respectively related to slight, moderate, extensive damage, and structural collapse) has been fixed, as in Zanini *et al*. (2017). According to Kostov *et al*. (2004), two TCs have been considered for masonry buildings: masonry buildings built before and after 1919, characterising them with a set of empirical fragilities. This choice has been motivated by the substantial lack of a reliable library of fragilities able to capture the influence of main geometrical parameters and masonry quality on the seismic vulnerability of Italian masonry building types. Regarding reinforced concrete (RC) structures, the distinction between gravity-load and seismic-load designed structures has been done by comparing the age of construction with the temporal evolution of Italian seismic codes, to know whether or not each municipality was classified as a seismic risk-prone area by using the ECS-IT software (ECS-IT, 2015). Hence, for each municipality, structures built before that year, have been considered gravity-load designed, whereas those built after that year as seismic-load designed. Moreover, since the census data is classified per decade (i.e. in 1971, 1981, and 2001), a linear variation with time was assumed in order to bridge the gap between the milestone years marking the code evolution and the census ten-year classification. A further subdivision has also been performed both for RC-gravity and RC-seismic buildings, considering the number of stories and, thus, defining two additional subclasses (1-2 story, 3 or more stories). In addition, two TCs have been considered representative of "other" mixed structural types, again subdivided in gravity-load and seismic-load designed, with the same approach adopted for RC classes. Census data provide no information on structural features for these types: it can be argued that it refers to other typical structural types, i.e. wood structures, steel structures and combined RC-masonry structures. However, combined RC-masonry structures could constitute a large majority of this partition, so for that reason, these two TC categories have been approximated to be composed totally of combined RC-masonry structures (as in Asprone *et al*., 2013).

For each *y-th* TC, a suitable set of fragility functions with *PGA* as reference intensity measure has been assumed between those proposed in literature (i.e. Kostov *et al*., 2004; Ahmad *et al*., 2011). Table 1 lists the main parameters of the adopted sets of lognormal fragility curves, whereas Fig. 4 illustrates them.

4. Exposure model

The exposure model considered in the analysis is the national residential building stock, modelled with a granularity at the municipality-level, and based on the 15th census database of

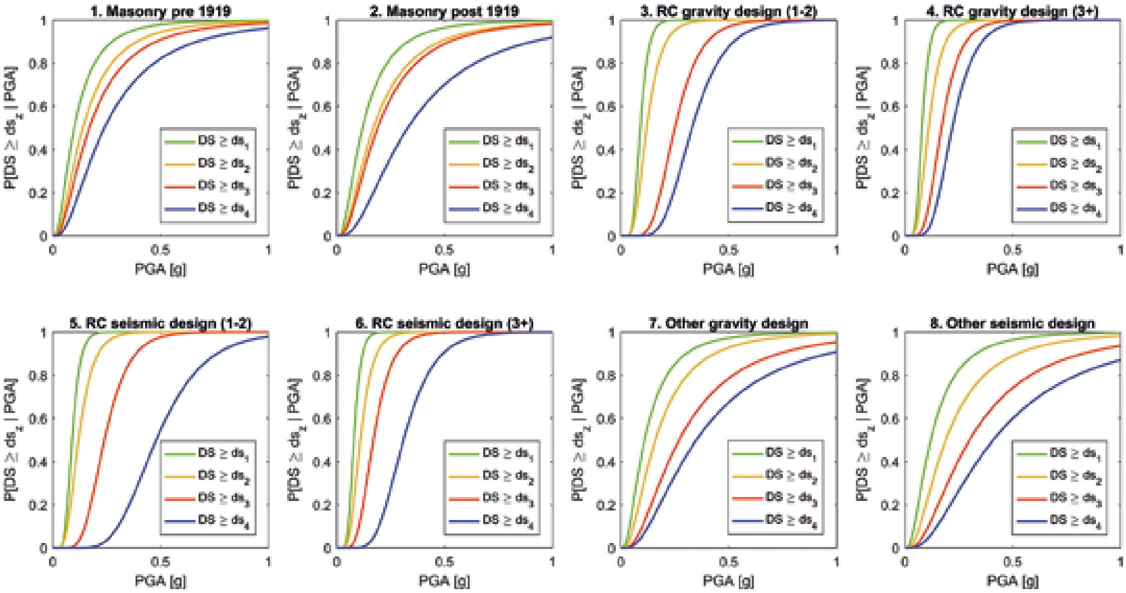

Fig. 4 - Seismic fragility curves adopted for the assumed building taxonomy.

the National Institute of Statistics (Istituto Nazionale di Statistica, 2011). Sardinia region was excluded from the final maps due to the negligible seismic hazard level of its municipalities. Census data provide the number of buildings per category in each of the 8084 municipalities, whereas TC disaggregation normalised by unit area is available per province and not per municipality. Hence, in order to obtain the disaggregated data per square metres per municipality, it has been assumed that the average square metres per building for each of the category identified by the disaggregation is constant for all the municipalities within each province. Hence, multiplying the

Table 1 - Main parameters of fragility curves for each *TC* and *DS*.

TC ID	Description	Damage State *DS*	$\mu_{DS_{z,y}}$ [g]	$\sigma_{DS_{z,y}}$
TC #1	Masonry-pre1919	*DS*1 – Slight	0.10	0.79
		*DS*2 – Moderate	0.14	0.80
		*DS*3 – Extensive	0.17	0.81
		*DS*4 - Collapse	0.24	0.80
TC #2	Masonry-post1919	*DS*1 – Slight	0.12	0.79
		*DS*2 – Moderate	0.17	0.81
		*DS*3 – Extensive	0.19	0.79
		*DS*4 - Collapse	0.33	0.79
TC #3	*RC*-Gravity l 1-2	*DS*1 – Slight	0.09	0.33
		*DS*2 – Moderate	0.12	0.44
		*DS*3 – Extensive	0.25	0.37
		*DS*4 - Collapse	0.33	0.36
TC #4	*RC*-Gravity l ≥3	*DS*1 – Slight	0.08	0.32
		*DS*2 – Moderate	0.11	0.43
		*DS*3 – Extensive	0.17	0.40
		*DS*4 - Collapse	0.22	0.38
TC #5	*RC*-Seismic l 1-2	*DS*1 – Slight	0.09	0.33
		*DS*2 – Moderate	0.12	0.44
		*DS*3 – Extensive	0.24	0.37
		*DS*4 - Collapse	0.48	0.36
TC #6	*RC*-Seismic l ≥3	*DS*1 – Slight	0.08	0.32
		*DS*2 – Moderate	0.11	0.41
		*DS*3 – Extensive	0.17	0.39
		*DS*4 - Collapse	0.31	0.36
TC #7	Other-Gravity	*DS*1 – Slight	0.11	0.79
		*DS*2 – Moderate	0.16	0.78
		*DS*3 – Extensive	0.27	0.78
		*DS*4 - Collapse	0.35	0.79
TC #8	Other-Seismic	*DS*1 – Slight	0.12	0.79
		*DS*2 – Moderate	0.19	0.79
		*DS*3 – Extensive	0.30	0.79
		*DS*4 - Collapse	0.41	0.79

number of buildings belonging to each subcategory in each municipality by the assumed average square metres per building, has allowed deriving the building disaggregation reported in terms of total the square metres for each *y-th* TC and *x-th* municipality. Fig. 5 shows the main data of the exposure model in terms of TC disaggregation diagram (Fig. 5a), total built area (Fig. 5b) and exposed value (Fig. 5c) in each municipality, by assuming a unitary replacement cost (URC) equal to 1200 €/m^2.

A set of repair cost ratios $RCR_{z,y}$, one for each *z-th* DS, have been assumed homogeneous for each *y-th* TC and equal to 0.15, 0.40, 0.65, 1.00, for DS$_1$, DS$_2$, DS$_3$, and DS$_4$, respectively. Such estimates have been fixed on the basis of some statistical post-processing of rough data collected during the reconstruction process following the 2009 L'Aquila earthquake, as reported in Dolce and Manfredi (2015), of which a detailed description can be found in Di Ludovico *et al.* (2017a, 2017b).

Municipality direct losses $L_{x,j,i}$ have been subsequently computed for each *x-th* municipality centroid due to each *j-th* simulated earthquake scenario belonging to a generic *i-th* SZ as follows:

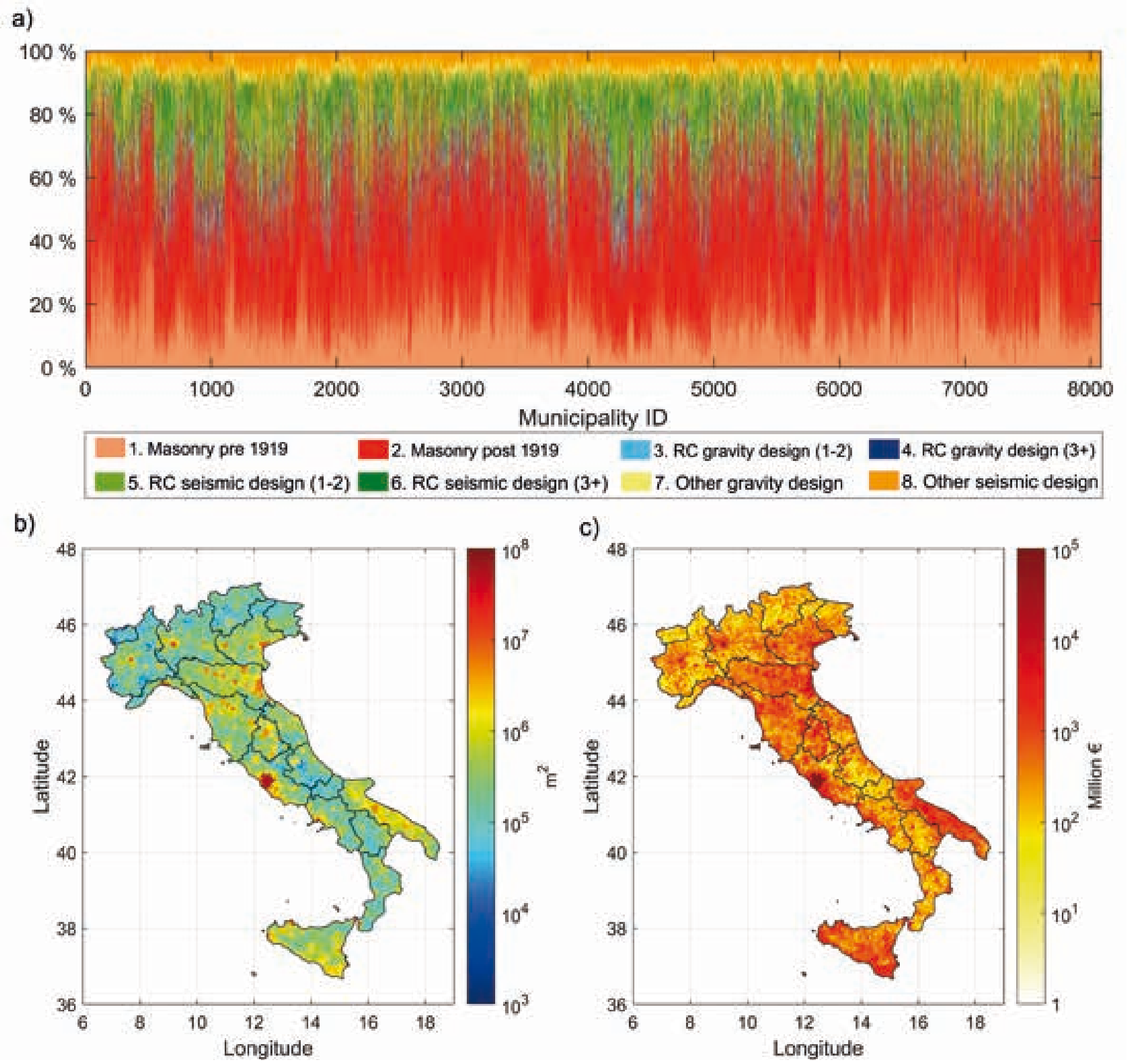

Fig. 5 - Exposure model: taxonomy disaggregation (a), total built area (b), and exposed value (c) in each municipality.

$$L_{x,j,i} = \sum_{y=1}^{8} \left[\sum_{z=0}^{4} \left(P\left[DS_{z,y} \geq ds_{z,y} \,|\, PGA_x\right] - P\left[DS_{z+1,y} \geq ds_{z+1,y} \,|\, PGA_x\right] \right) \bullet RCR_{z,y} \right] \bullet A_{y,x} \bullet URC \tag{1}$$

where $A_{y,x}$ is the built area for each *y-th* TC of each *x-th* municipality, and:

$$P\left[DS_{z,y} \geq ds_{z,y} \,|\, PGA_x\right] = \Phi\left[\frac{1}{\sigma_{DS_{z,y}}} \ln\left(\frac{PGA_x}{\mu_{DS_{z,y}}}\right)\right] \tag{2}$$

is representative of the damage state exceedance probability computed via fragilities as a function of the PGA_x computed at the municipality centroid for each earthquake scenario, with the following constraints when $z = 0$ and $z = 4$:

$$RCR_{0,y} = 0 \tag{3}$$

$$P\left[DS_{0,y} \geq ds_{0,y} \,|\, PGA_x\right] = 1 \tag{4}$$

$$P\left[DS_{5,y} \geq ds_{5,y} \,|\, PGA_x\right] = 0\,. \tag{5}$$

By grouping municipality loss values $L_{x,j,i}$ in each of the six magnitude classes herein considered for each SZ, probability density functions of the municipality loss given a magnitude value $f(L|M_i)$ have been derived. Hence, $f(L|M)$ have been further condensed considering relevant loss statistics *ls* (i.e. mean, 25th, 50th or 75th loss values): in the following, for sake of brevity, only results related to mean loss values $L_{x,mean,i}$ have been reported.

5. Meal calculation workflow

Based on simulation outcomes, the MEAL has been computed for each Italian municipality, with reference to mean loss values. First, recurrence relationships have been derived for each *i-th* SZ, adopting the classic G-R recurrence law:

$$log\nu_i = a - b \bullet M_i \tag{6}$$

where ν_i is the mean annual rate of exceeding a certain moment magnitude value M_i in a generic *i-th* SZ, and *a* and *b* are model constants, standing for the total seismicity rate of the SZ and the slope coefficient of the G-R law, i.e. those illustrated in Fig. 1. For each of the six magnitude values M_i spanning over the range of admissible magnitudes for each SZ, ν_i value is calculated with Eq. 6 and then coupled in a 2D chart with municipality loss values $L_{x,mean,i}$ related to mean values as relevant loss statistics *ls*, coming from earthquake scenarios simulation, as illustrated in Fig. 6a.

Two additional points have been introduced in order to complete resulting municipality loss exceedance curves, consistently with the following assumptions:

- each *i-th* SZ is characterised by a minimum magnitude value $M_{min,i}$, that usually is set with the aim of removing small events that are characterised by negligible impacts in terms of

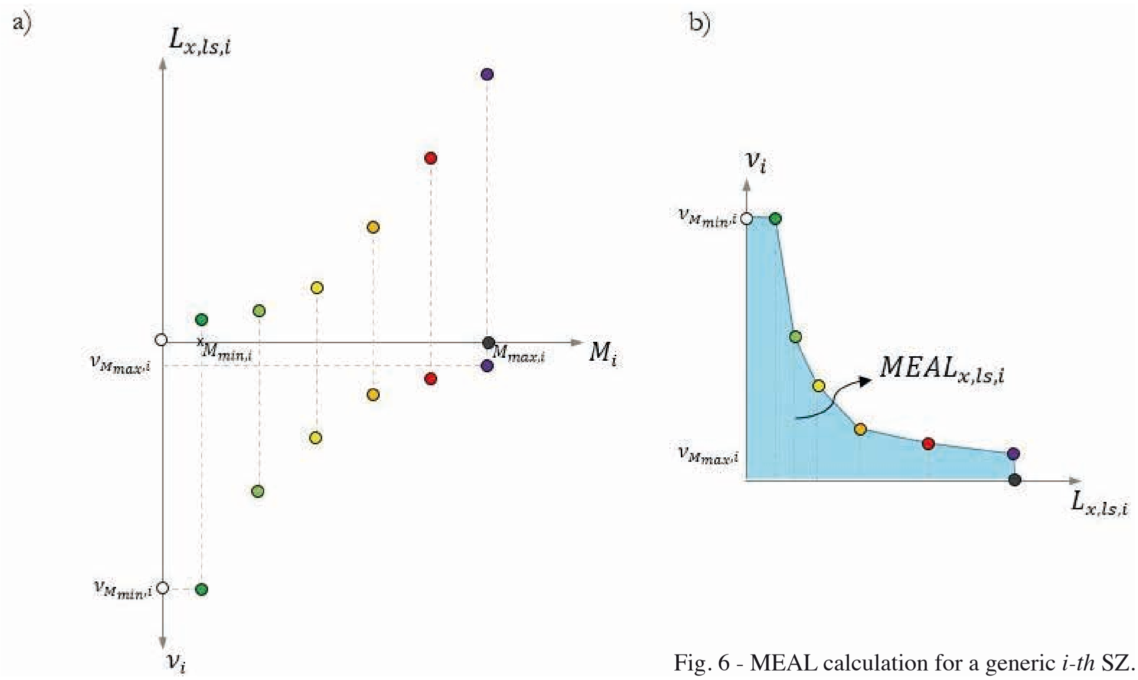

Fig. 6 - MEAL calculation for a generic *i-th* SZ.

seismic damage and associated losses. For this reason, earthquakes with magnitudes lower than $M_{min,i}$ are associated to zero loss levels;

- each *i-th* SZ is also characterised by a maximum magnitude value $M_{max,i}$, fixed on the basis of its seismological characteristics, so this issue is accounted by truncating the loss exceedance curve in correspondence of the loss level induced by $M_{max,i}$.

Finally, the $MEAL_{x,mean,i}$ of each *x-th* municipality associated to a generic *i-th* SZ is computed with the following expression, as shown in Fig. 6b:

$$MEAL_{x,mean,i} = \int_{0}^{\nu_{M_{min,i}}} L_{x,mean,i}(M_i) \left| d\nu_{M_i} \right| . \tag{7}$$

When more SZs are present, $MEAL_{x,mean}$ is derived by summing up the contributions provided by all the SZs.

6. Results

Once $MEAL_{x,mean}$ values were derived for each municipality (in the following simply named *MEAL*), they have been used to build an absolute seismic risk map in terms of *MEAL*, i.e. the financial amount yearly required to face potential direct losses induced by the occurrence of seismic events to the analysed building stock. Fig. 7a depicts the resulting seismic risk map: it can be observed how this seismic risk map is significantly influenced by the spatial distribution of the exposure.

The same map can therefore be expressed in relative terms using the following unitary metric, the *UMEAL*, (i.e. the *MEAL* for 1 m^2 built area in each municipality, in €/m^2), as shown in Fig.

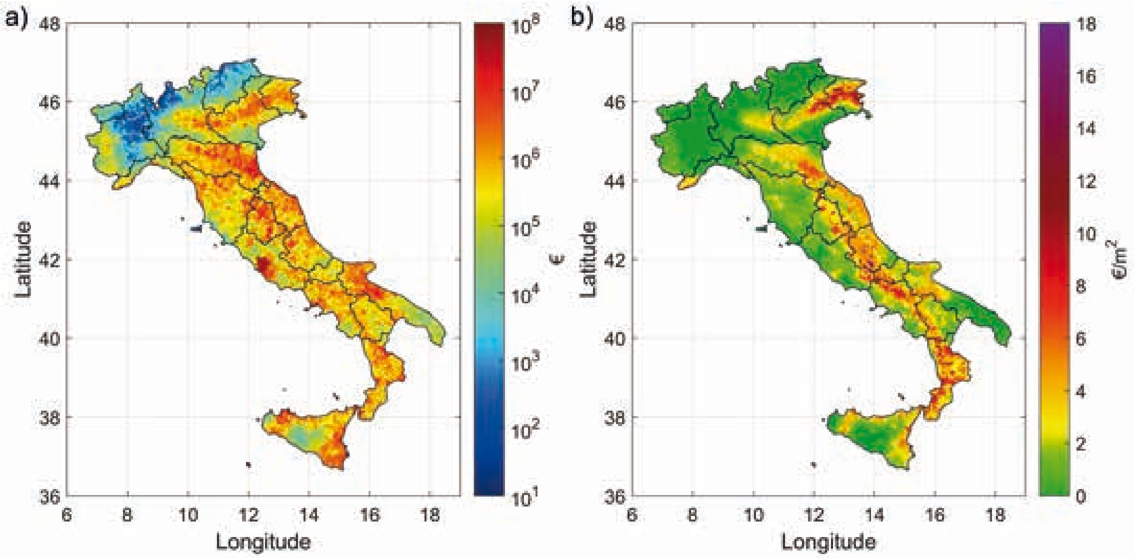

Fig. 7 - The seismic risk map of Italy in terms of *MEAL* (a) and *UMEAL* (b).

7b. The *UMEAL* map allows to better detail the effective spatial distribution of seismic risk, since it represents risk in relative terms, and can be used as a basic metric when dealing with defining insurance coverage schemes.

Further post-processing activities have been carried out starting from *MEAL* estimates.

Figs. 8 to 11 depict the disaggregation of seismic risk with respect to the adopted seismogenic source model, highlighting the percent contribution to the *MEAL* in all the Italian municipalities provided by each of the 36 SZs. Such kind of evidence is useful to understand which SZs mostly contribute to the risk for the residential stock belonging to each Italian municipality.

Fig. 12 illustrates the disaggregation of *MEAL* with respect to each of the eight TCs, further subdivided by the respective built areas (so with a *UMEAL* metric), in order to provide unitary targeted risk estimates for each building type: the results show how higher risk values may be attributed to masonry structures, and RC and other gravity-designed types, and this information can be used for instance to calibrate tax relief schemes able to ensure differentiated benefits to property owners in relation to the structural features of their residential buildings.

Previous risk maps detail seismic risk of Italy quantifying in economic terms its impact: such risk maps are, therefore, relevant for stakeholders (e.g. government, research institutes, insurance industry, banks), but at the same time might be incorrectly interpreted by a non-technical audience. For this reason, a further indicator has been introduced, namely Municipality Seismic Risk Class (*MSRC*, in % of replacement cost), from the ratio between *UMEAL* estimates and the *URC* value. A qualitative seismic risk rating consisting in five *MSRCs* (i.e. very low seismic risk (LL), low seismic risk (L), medium seismic risk (M), high seismic risk (H), very high seismic risk (HH)) is thus introduced by subdividing the *MSRC* range from 0 to the national peak value (i.e. 1.25%) qualitative in five equally spaced intervals. In this way, it is possible to communicate the seismic risk rating in a more user-friendly way (i.e. LL, L, M, H, HH) during information campaigns and dissemination events with seismic prevention purposes. Fig. 13 shows the seismic risk map in terms of *MSRC* classes, with intervals listed in Table 2.

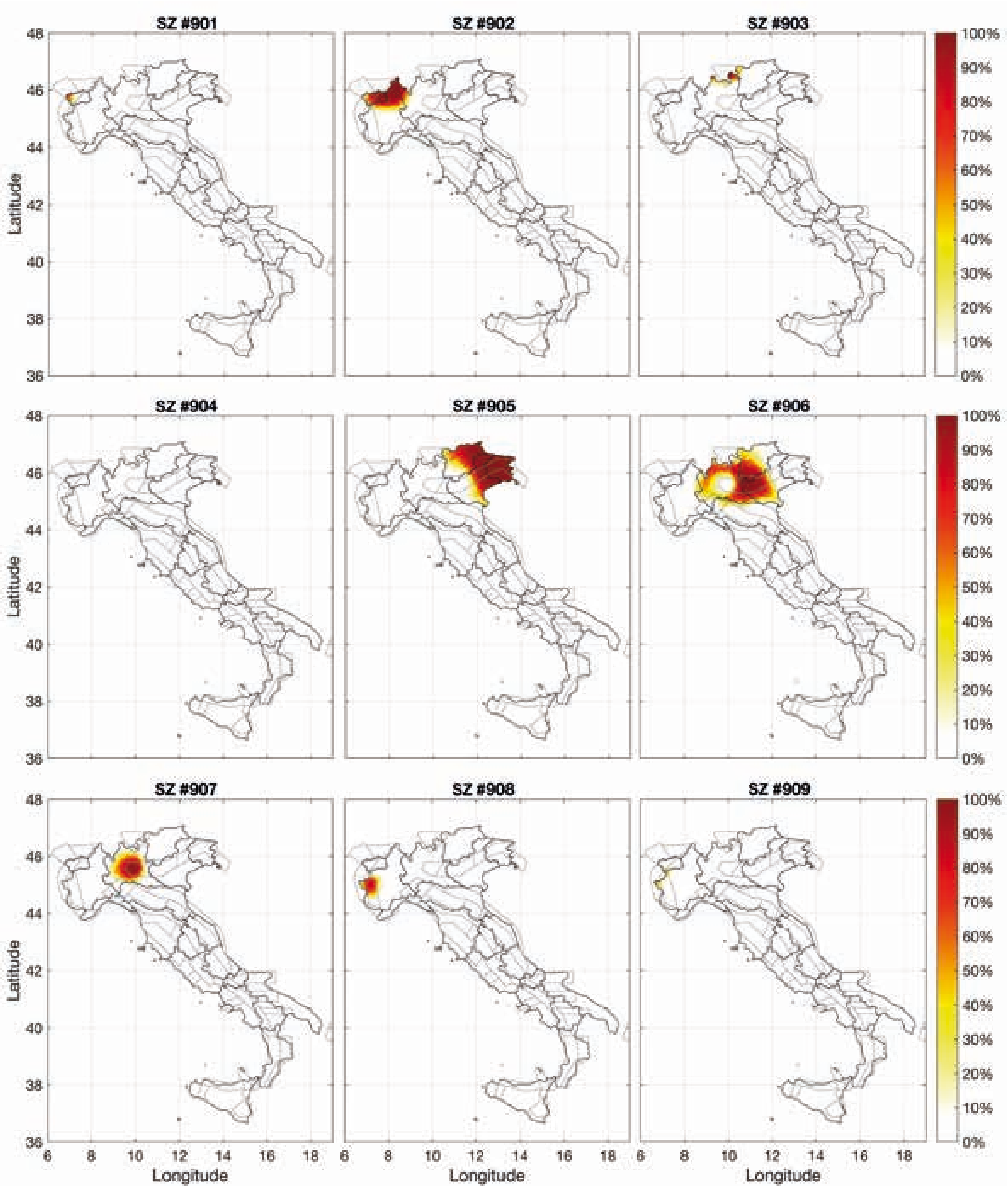

Fig. 8 - *MEAL* disaggregation for SZ #901, #902, #903, #904, #905, #906, #907, #908, #909.

Table 2 - *MSRC* and *PSRC* range values for the adopted seismic risk ratings.

Seismic Risk Rating	Very low	Low	Medium	High	Very high
MSRC [%]	0.00 - 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.00	1.00 - 1.25
PSRC [%]	0.00 – 0.10	0.10 – 0.20	0.20 – 0.30	0.30 – 0.40	0.40 – 0.50
RSRC [%]	0.00 – 0.09	0.09 – 0.18	0.18 – 0.27	0.27 – 0.36	0.36 – 0.45

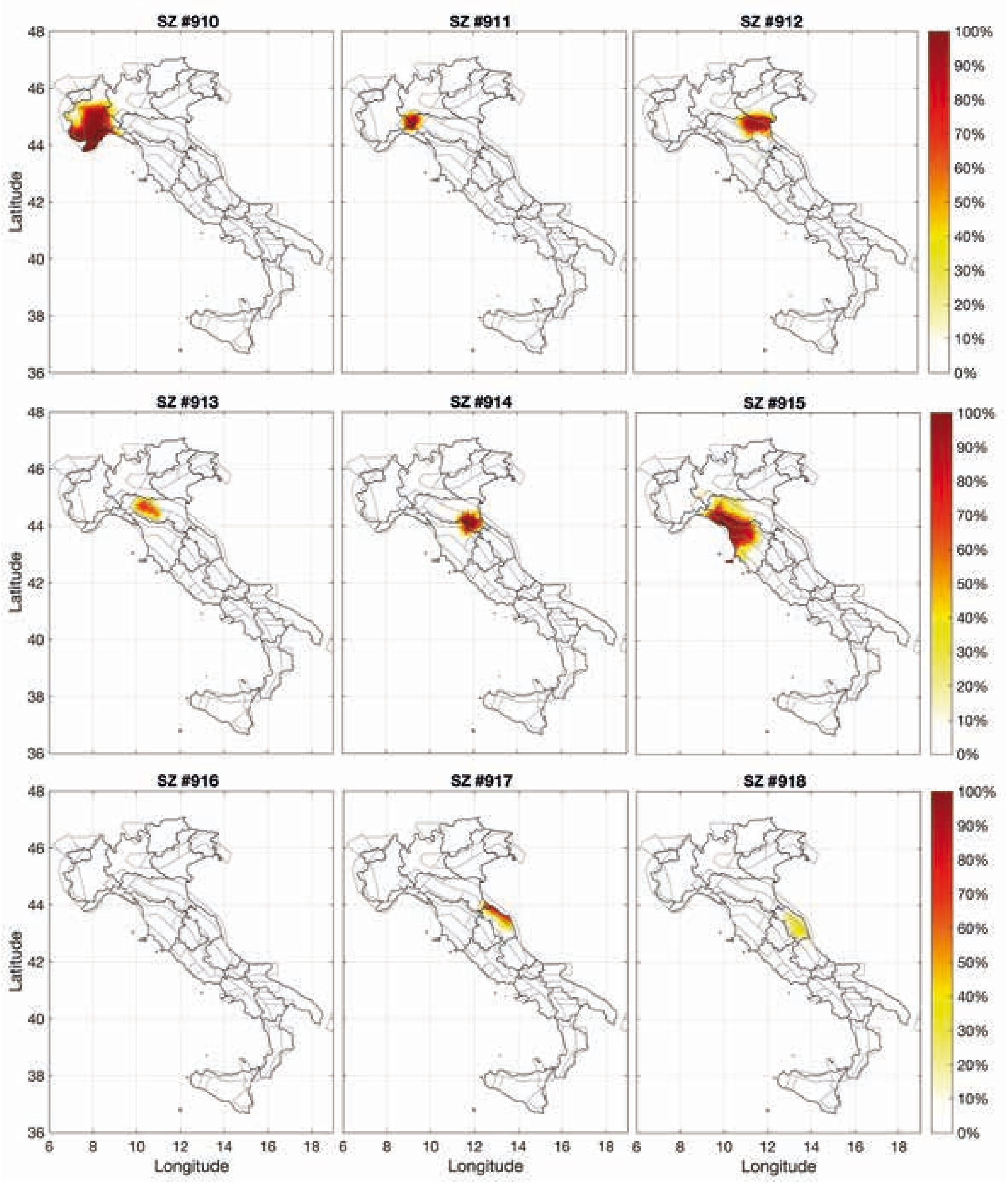

Fig. 9 - *MEAL* disaggregation for SZ #910, #911, #912, #913, #914, #915, #916, #917, #918.

Following the administrative subdivision of Italy, some further risk maps have been produced starting from the *MEAL* values, using other risk indicators at lower spatial discretisation, i.e. the Province Expected Annual Loss (*PEAL*), the Regional Expected Annual Loss (*REAL*), the related unitary indicators *UPEAL* and *UREAL* computed by subdividing *PEAL*/*REAL* by the respective province- and regional- built areas (both in €/m^2), and lastly the companion seismic risk rating

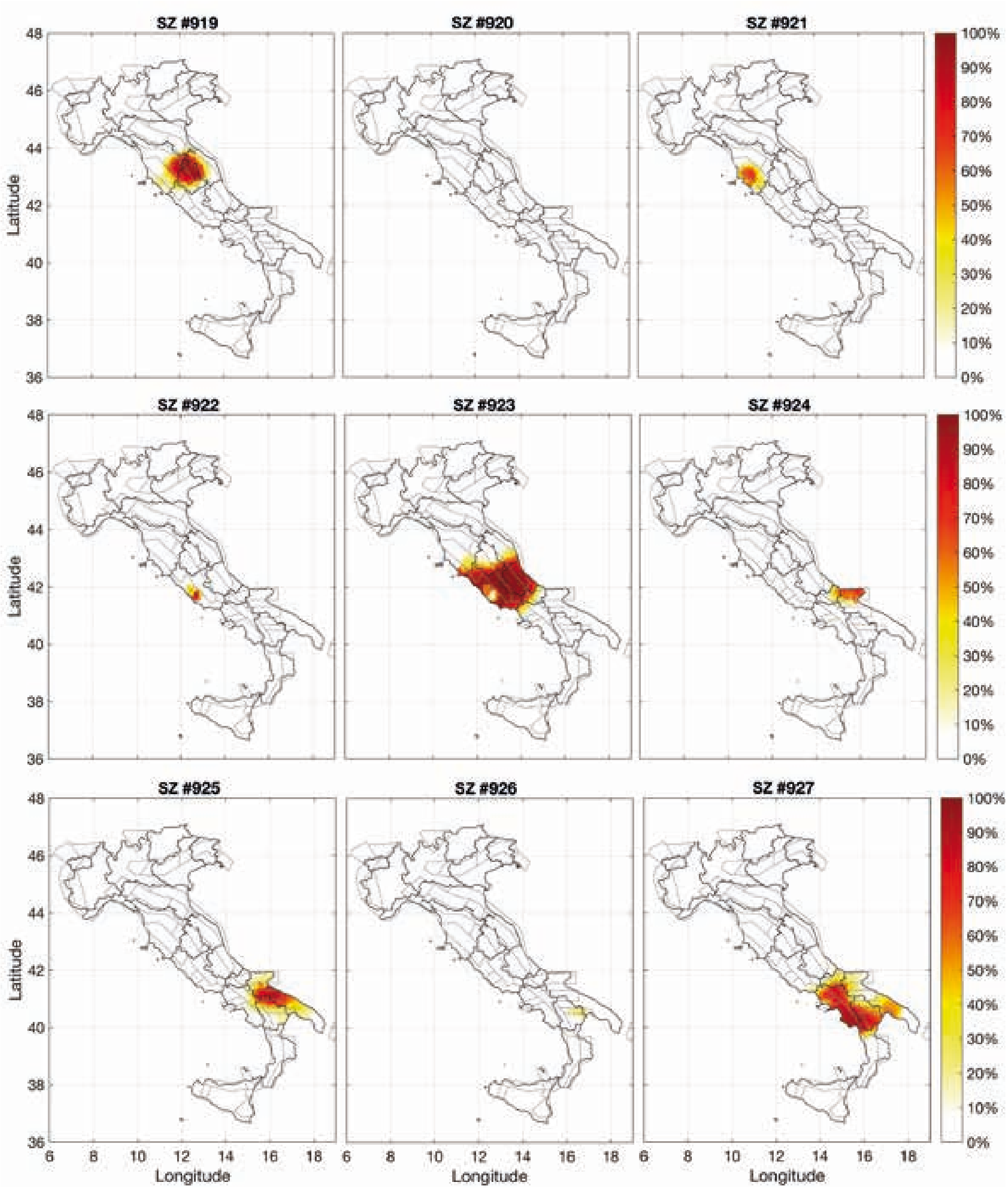

Fig. 10 - *MEAL* disaggregation for SZ #919, #920, #921, #922, #923, #924, #925, #926, #927.

indicators, i.e. the Province Seismic Risk Class (*PSRC*) and the Regional Seismic Risk Class (*RSRC*) (both in % of replacement cost, obtained as ratios between *UPEAL*/*UREAL* and *URC*).

Fig. 14 shows the seismic risk maps in terms of *PEAL* (in €, Fig. 14a) and *UPEAL* (in €/m^2, Fig. 14b): it can be observed how the lower granularity leads to an averaging effect over all the unitary risk estimates computed on the municipalities belonging to a same province. The *PEAL*

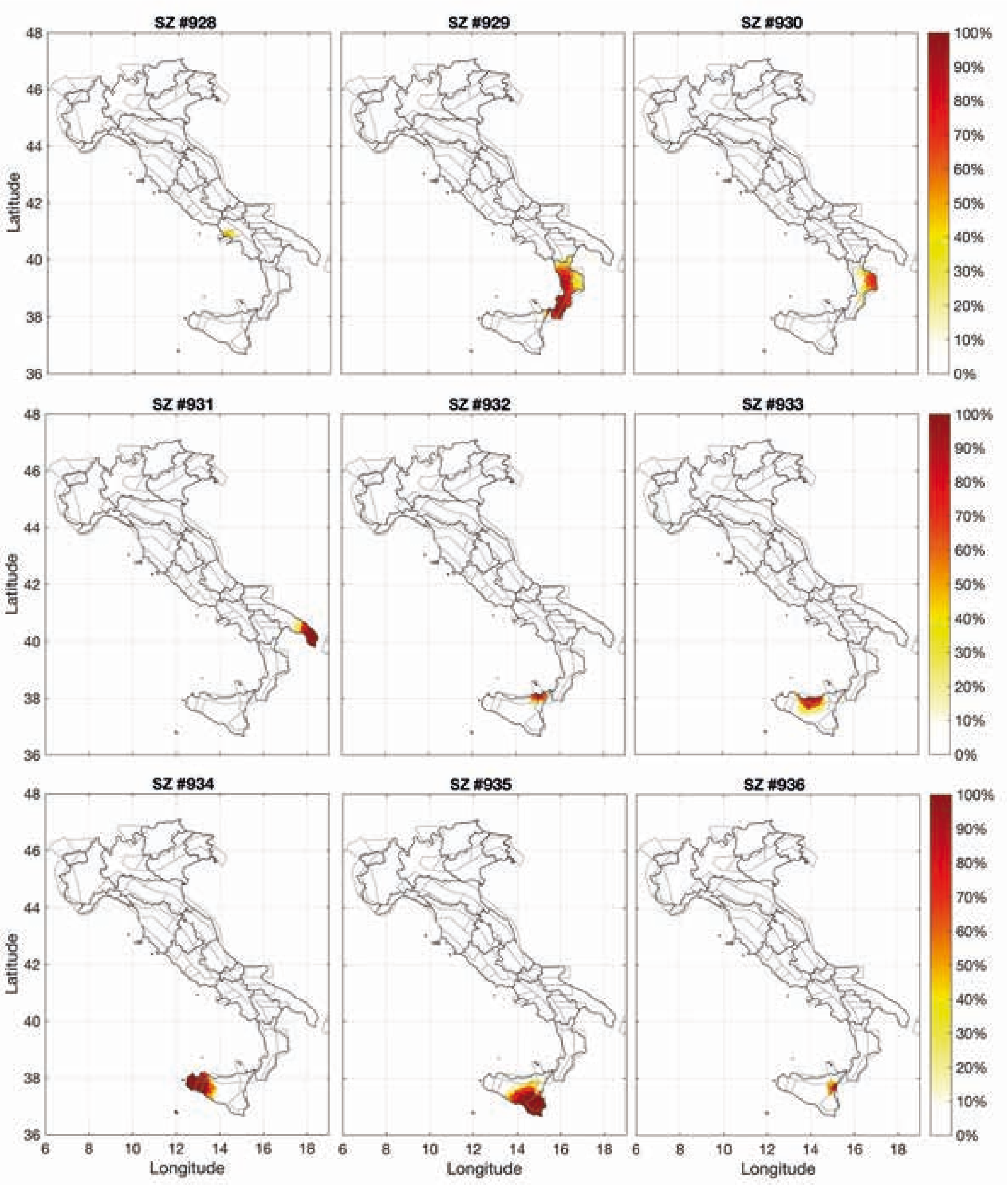

Fig. 11 - *MEAL* disaggregation for SZ #928, #929, #930, #931, #932, #933, #934, #935, #936.

seismic risk map provides information related to the yearly amount to be saved in each province to face seismic damage induced by earthquake occurrences and ranges between 0.001 and 300 million €. The *UPEAL* map accounts instead for the extent of built area in each province, and provides a unitary seismic risk metric, with peaks around 6.08 €/m^2.

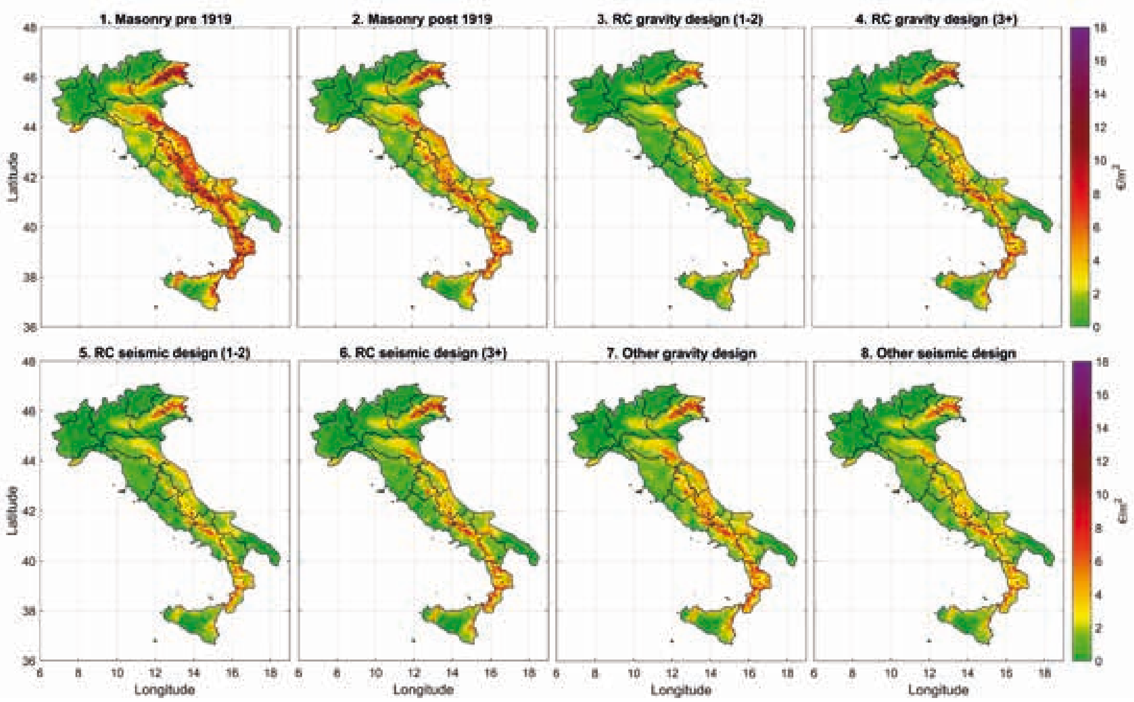

Fig. 12 - *MEAL* disaggregation for each of the eight TCs (in terms of *UMEAL*).

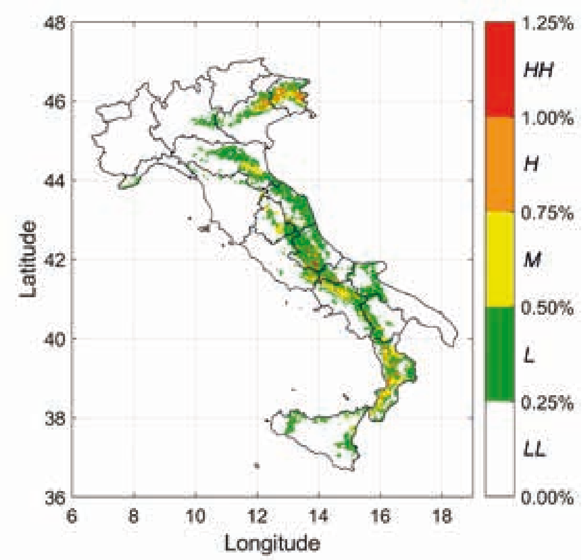

Fig. 13 - The seismic risk map of Italy in terms of *MSRC*.

Fig. 15 shows the seismic risk map in terms of *PSRC*, characterised by a peak value of about 0.5%, and *PSRC* intervals listed in Table 2. A very high *PSRC* rating (HH) is attributed to Udine, Pordenone, Treviso, Forlì-Cesena, L'Aquila, Isernia, Benevento, Catanzaro, Vibo Valentia and Reggio Calabria provinces, whereas a high *PSRC* rating (H) characterizes Gorizia, Savona, Pesaro-Urbino, Ancona, Macerata, Fermo, Ascoli Piceno, Teramo, Pescara, Avellino, Cosenza, Crotone and Messina provinces.

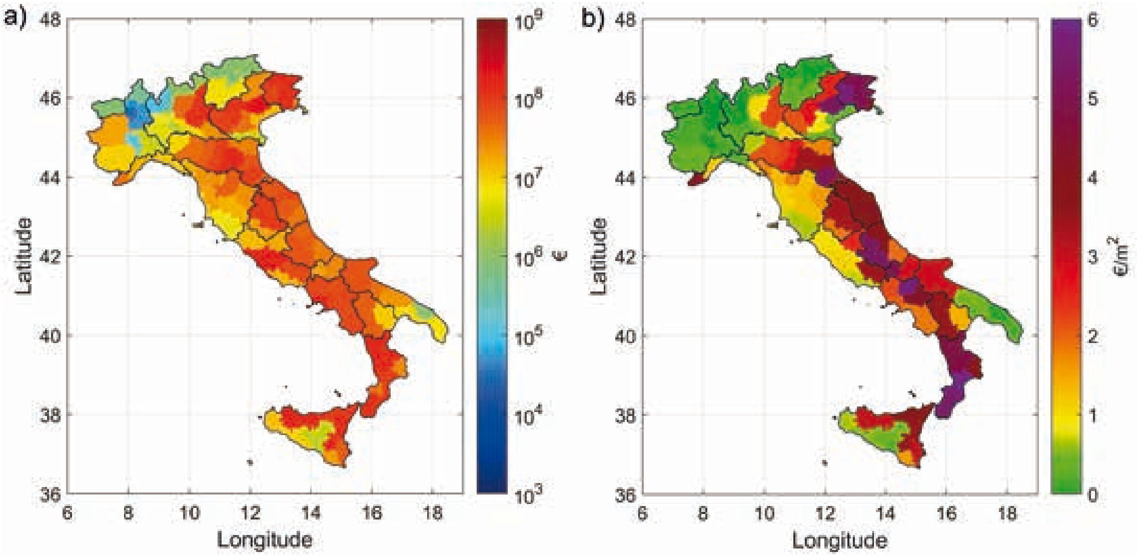

Fig. 14 - The seismic risk map of Italy in terms of *PEAL* (a) and *UPEAL* (b).

Appendix 1 lists *PEAL*, *UPEAL*, and *PSRC* values for each of the 102 Italian provinces. Fig. 16 illustrates the seismic risk maps in terms of *REAL* (in €, Fig. 16a) and *UREAL* (in €/m^2, Fig. 16b): it can be observed how similar values are observed with reference to *UPEAL* unitary risk estimates, thus highlighting how an averaging effect is lower moving from province-to-regional level with respect to municipality-to-province granularity. The *REAL* seismic risk map provides information related to the yearly amount to be saved in each region to face seismic damage induced by earthquake occurrences and ranges between 0.793 and 542 million € for Valle d'Aosta and

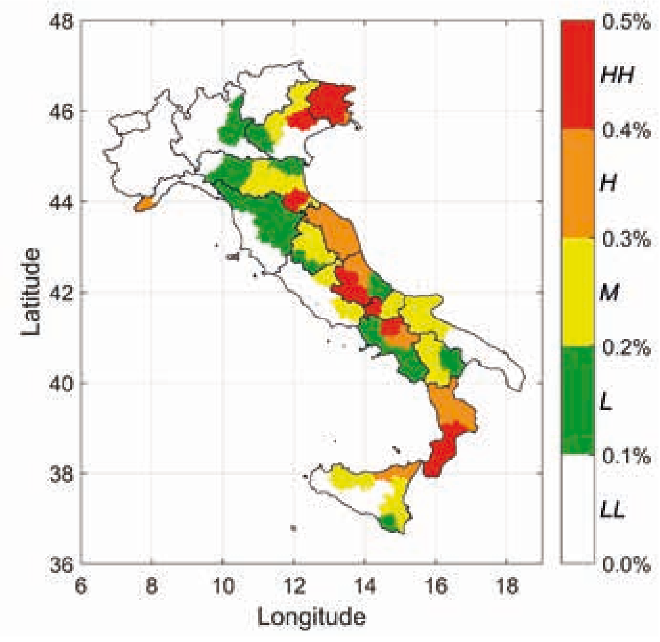

Fig. 15 - The seismic risk map of Italy in terms of *PSRC*.

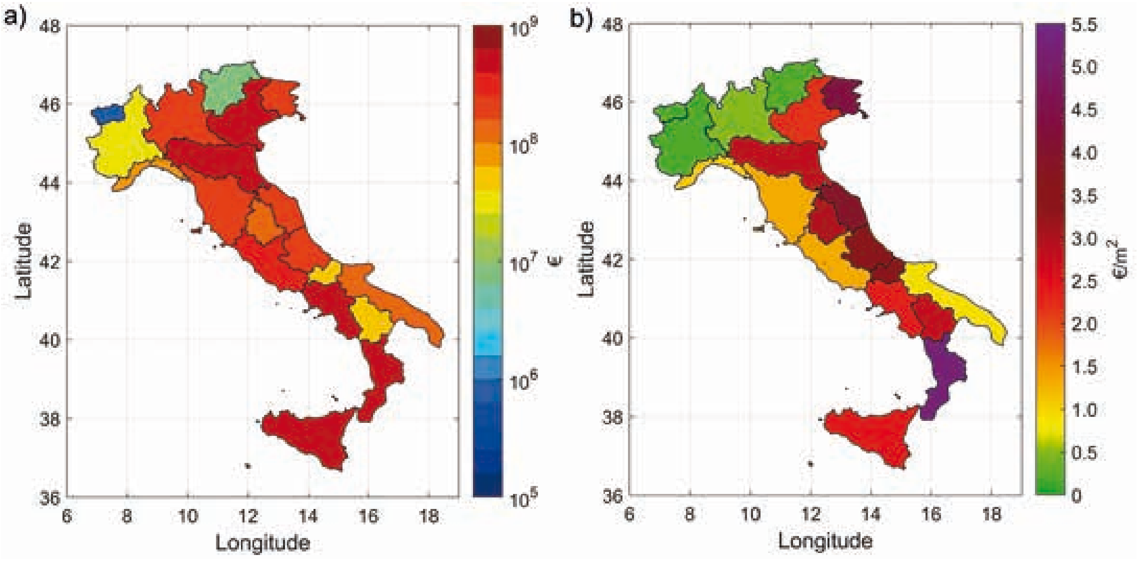

Fig. 16 - The seismic risk map of Italy in terms of *REAL* (a) and *UREAL* (b).

Emilia-Romagna regions, respectively. The *UREAL* map accounts instead for the extent of the built area in each province, and provides a unitary seismic risk metric, and ranges between 0.16 and 5.18 €/m^2.

Lastly, Fig. 17 shows the seismic risk map in terms of *RSRC*, with a peak value of about 0.45% and *RSRC* intervals listed in Table 2. The following results have been obtained: a HH seismic risk rating for Friuli - Venezia Giulia and Calabria, a H seismic risk rating in Marche, Abruzzo and Molise, a M seismic risk rating for Veneto, Emilia-Romagna, Umbria, Campania, Basilicata and

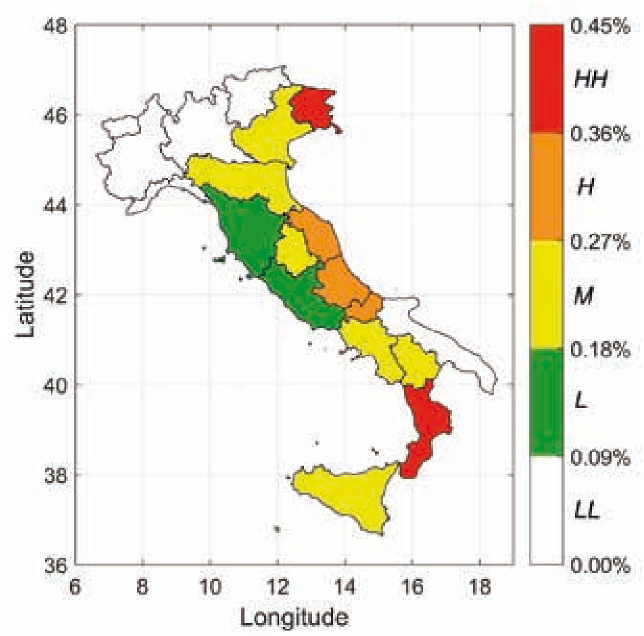

Fig. 17: The seismic risk map of Italy in terms of *RSRC*.

Sicilia, a L seismic risk rating in Toscana and Lazio, whereas a LL seismic risk rating for Valle d'Aosta, Piemonte, Lombardia, Trentino-Alto Adige, Liguria and Puglia.

Appendix 2 lists *REAL*, *UREAL,* and *RSRC* values for each of the 19 Italian regions.

7. Conclusions

The development of seismic risk maps in countries prone to earthquakes is a key task for public authorities worldwide. The work here addressed this specific topic, deriving different types of seismic risk maps for the Italian residential building stock. Such seismic risk maps are computed using as input data different hazard, vulnerability and exposure models able to properly capture seismicity, represent fragility of the analysed building with respect to ground shaking and its spatial distribution and economic value, respectively. Seismic risk maps were developed starting from the computation of the *MEAL*, a seismic risk targeted indicator at the territorial scale, representative of the financial amount required annually to face potential direct losses induced by the occurrence of seismic events to the analysed building stock, and then deriving *UMEAL* and *MSRC* values. Two lower granularity level were also considered (i.e. province- and regional-level maps), introducing *PEAL*, *UPEAL*, *PSRC*, and *REAL*, *UREAL*, *RSRC* in analogy to the municipality level indicators. Resulting maps depict national seismic risk spatial distribution, thus providing reliable information to government agencies, which can promote specific mitigation intervention at the territorial scale to reduce the impact of future earthquakes in the areas mostly exposed to seismic risk. Results obtained, even if closely related to the modelling assumptions made, are promising. The seismic risk maps developed with the methodology proposed in this study could in fact be directly useful for the Italian government to underpin prevention activities, e.g. outlining specific tax relief schemes in order to promote and support the implementing of seismic retrofit interventions in most risky areas. Future developments will be oriented towards investigating the impact on final risk estimates of the different modelling choices (e.g. set of fragilities, repair cost ratios) and to substitute empirical fragilities with more targeted mechanics-based functions.

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Appendix 1: *PEAL*, *UPEAL* and *PSRC* values (province-level granularity)

Region	Province	*PEAL* [€]	*UPEAL* [€/m^2]	*PSRC* [%]
Abruzzo	Chieti	30575175	1.89	L
Abruzzo	L'Aquila	62354017	5.25	HH
Abruzzo	Pescara	48135863	3.77	H
Abruzzo	Teramo	45625583	3.65	H
Basilicata	Matera	10265302	1.40	L
Basilicata	Potenza	49162305	3.53	M
Calabria	Catanzaro	86193014	6.08	HH
Calabria	Cosenza	140882045	4.78	H
Calabria	Crotone	24988347	3.85	H
Calabria	Reggio Calabria	114469082	5.40	HH
Calabria	Vibo Valentia	34775961	5.64	HH
Campania	Avellino	73089099	4.26	H
Campania	Benevento	68419780	5.78	HH
Campania	Caserta	68915501	2.14	L
Campania	Napoli	184897680	1.98	L
Campania	Salerno	71463242	1.83	L
Emilia Romagna	Bologna	143268743	3.40	M
Emilia Romagna	Ferrara	28809440	1.72	L

Region	Province	*PEAL* [€]	*UPEAL* [€/m^2]	*PSRC* [%]
Emilia Romagna	Forlì-Cesena	84673268	5.22	HH
Emilia Romagna	Modena	79372480	2.67	M
Emilia Romagna	Parma	41529465	2.12	L
Emilia Romagna	Piacenza	8641087	0.67	LL
Emilia Romagna	Ravenna	62866743	3.51	M
Emilia Romagna	Reggio Emilia	49580700	2.24	L
Emilia Romagna	Rimini	43702573	3.48	M
Friuli V.G.	Gorizia	26217929	4.26	H
Friuli V.G.	Pordenone	81472537	5.79	HH
Friuli V.G.	Trieste	4147947	0.44	LL
Friuli V.G.	Udine	128705776	5.00	HH
Lazio	Frosinone	70951549	3.46	M
Lazio	Latina	14171189	0.70	LL
Lazio	Rieti	16409244	2.55	M
Lazio	Roma	165296711	1.07	LL
Lazio	Viterbo	12577235	0.97	LL
Liguria	Genova	10854674	0.30	LL
Liguria	Imperia	35132284	4.21	H
Liguria	La Spezia	9913161	1.10	LL
Liguria	Savona	13568925	1.15	LL
Lombardia	Bergamo	43240026	1.00	LL
Lombardia	Brescia	111369967	2.21	L
Lombardia	Como	103155	0.00	LL
Lombardia	Cremona	8587391	0.54	LL
Lombardia	Lecco	446618	0.03	LL
Lombardia	Lodi	1877502	0.21	LL
Lombardia	Mantova	22552772	1.16	LL
Lombardia	Milano	5841702	0.05	LL
Lombardia	Monza-Brianza	1223876	0.04	LL
Lombardia	Pavia	4830825	0.20	LL
Lombardia	Sondrio	1206463	0.17	LL
Lombardia	Varese	101917	0.00	LL
Marche	Ancona	73787519	3.83	H
Marche	Ascoli Piceno	34290037	3.97	H
Marche	Fermo	30665711	4.23	H
Marche	Macerata	52569891	4.01	H
Marche	Pesaro-Urbino	57290915	3.82	H
Molise	Campobasso	27359366	2.90	M
Molise	Isernia	18883260	4.99	HH
Piemonte	Alessandria	3433080	0.17	LL
Piemonte	Asti	142743	0.01	LL
Piemonte	Biella	29868	0.00	LL

Region	Province	*PEAL* [€]	*UPEAL* [€/m^2]	*PSRC* [%]
Piemonte	Cuneo	9619089	0.38	LL
Piemonte	Novara	51470	0.00	LL
Piemonte	Torino	17544330	0.19	LL
Piemonte	Verbano-Cusio-Ossola	500546	0.07	LL
Piemonte	Vercelli	49544	0.01	LL
Puglia	Bari	22112104	0.49	LL
Puglia	Barletta-Andria-Trani	38375456	2.98	M
Puglia	Brindisi	841735	0.05	LL
Puglia	Foggia	63052906	2.92	M
Puglia	Lecce	7396709	0.21	LL
Puglia	Taranto	8397491	0.36	LL
Sicilia	Agrigento	9189358	0.53	LL
Sicilia	Caltanissetta	2760574	0.27	LL
Sicilia	Catania	141660032	3.53	M
Sicilia	Enna	2947727	0.45	LL
Sicilia	Messina	95140477	3.85	H
Sicilia	Palermo	144578698	3.05	M
Sicilia	Ragusa	19157161	1.56	L
Sicilia	Siracusa	48274227	3.09	M
Sicilia	Trapani	11877105	0.66	LL
Toscana	Arezzo	22903624	1.59	L
Toscana	Firenze	49752811	1.27	L
Toscana	Grosseto	5774550	0.65	LL
Toscana	Livorno	9294711	0.73	LL
Toscana	Lucca	22382229	1.30	L
Toscana	Massa Carrara	14018698	1.73	L
Toscana	Pisa	18797247	1.09	LL
Toscana	Pistoia	22400886	1.80	L
Toscana	Prato	19320903	2.01	L
Toscana	Siena	14002985	1.25	L
Trentino A.A.	Bolzano	915095	0.05	LL
Trentino A.A.	Trento	7454732	0.36	LL
Umbria	Perugia	93997579	3.40	M
Umbria	Terni	17700454	1.81	L
Valle d’Aosta	Aosta	793435	0.16	LL
Veneto	Belluno	23871142	2.57	M
Veneto	Padova	37999567	0.89	LL
Veneto	Rovigo	3061413	0.27	LL
Veneto	Treviso	207647244	5.23	HH
Veneto	Venezia	13310956	0.37	LL
Veneto	Verona	82207907	2.08	L
Veneto	Vicenza	104385952	2.70	M

Appendix 2: *REAL*, *UREAL* and *RSRC* values (regional-level granularity)

Region	REAL [€]	UREAL [€/m²]	RSRC [%]
Abruzzo	186690638	3,50	H
Basilicata	59427607	2,79	M
Calabria	401308450	5,18	HH
Campania	466785302	2,41	M
Emilia Romagna	542444499	2,86	M
Friuli V.G.	240544190	4,35	HH
Lazio	279405928	1,30	L
Liguria	69469043	1,06	LL
Lombardia	201382214	0,51	LL
Marche	248604073	3,93	H
Molise	46242626	3,50	H
Piemonte	31370669	0,17	LL
Puglia	140176401	0,91	LL
Sicilia	475585358	2,47	M
Toscana	198648645	1,31	L
Trentino A.A.	8369827	0,21	LL
Umbria	111698034	2,98	M
Valle d'Aosta	793435	0,16	LL
Veneto	472484182	2,17	M

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