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Seismic risk maps for the seismic risk management and reduction

Mariano Angelo Zanini[a,*], Lorenzo Hofer[a], Flora Faleschini[a], Carlo Pellegrino[a]

[a]*Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, 35131, Italy*

Abstract

The paper illustrates the seismic risk maps computed by the Authors for the residential building stock of Italy by using a general framework specifically set up for mapping seismic risk for a generic asset of interest. Seismic risk maps are computed taking into account a seismogenic model of the analyzed area, and properly characterizing vulnerability and exposure of an asset of interest. Seismic risks maps are computed for two different conditions, the former represents the so-called *as-built* condition, the latter one is computed assuming for the residential building stock a possible strategic retrofit program. These two maps are then used for investigating the financial sustainability of national seismic risk reduction programs, focusing the attention on the specific case of the national residential building stock of Italy.

Keywords: Seismic risk map, insurance, Italy, risk mitigation, earthquake, engineering, cost-benefit analysis.

1. Introduction

In the last decade, the number of significant losses following natural disasters worldwide, has been rapidly growing (Munich Re 2017). This is mainly due to the growing of urbanization, world population and Gross Domestic Product (GDP). This main three factors, imply a concentration of people, thus increasing the exposure of our society to natural hazards more than in the past (Daniell et al. 2011). In addition, the vulnerability of many structures and infrastructures is still high (Hofer et al. 2018a), since retrofitting and re-building are time and money consuming processes.

* Corresponding author. Tel.: +39 049 8275982
E-mail address: marianoangelo.zanini@dicea.unipd.it

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Furthermore, in many cases the vulnerability is increased by degradation phenomena (Faleschini et al. 2018). Earthquakes represent one of the most destructive natural events that can significantly affect the economy of a region and lead to long-term restoration processes (Hofer et al. 2018b). In particular, in Italy, several significant losses occurred in the last decades: in 2009 a moment magnitude $M_w = 6.1$ stroke the Abruzzo Region, in 2012 a $M_w = 6.0$ and $M_w = 6.1$ earthquake occurred in Emilia Romagna, while within the summer of 2016 and the winter of 2017 several significant seismic events with $M_w = 6.0\text{-}6.5$ occurred in the Central Italy area (Zanini et al. 2016 and Hofer et al. 2016). The rapid succession of these seismic events unavoidably ended up to weight on public financial funds. For this reason, the Italian government has recently approved specific incentives for householders interested in seismically retrofitting their properties (DM 65 Sismabonus). Nowadays seismic risk evaluation is a well-known and established procedure, mostly applied for the risk assessment of punctual structures or spatially distributed portfolio of structures. The use of this procedures is then commonly extended for a quantitative assessment of seismic risk at regional level. In this case, a multidisciplinary approach is needed for fully describing the seismic activity of the region of interest, its vulnerability distributions, and the associated exposure. In particular, the development of seismic risk maps is the key point when dealing with the seismic risk assessment at territorial level, since they provide a quantitative representation of the current risk and are a fundamental tool for computing the benefit associated to the structural retrofit. Their use is thus needed when dealing with the design of possible sustainable risk reduction programs at regional and national scale. This paper adopts as seismic synthetic risk indicator the Expected Annual Loss (EAL) that represents the potential economic loss to be yearly sustained to repair the seismic damage to the residential building asset of each Italian municipality. EAL is computed at three different levels of granularity, i.e. municipal, provincial and regional, accordingly with the cogent administrative subdivision of Italy. This work wants to propose a possible seismic retrofit scenario for the entire Italian residential building stock, and accordingly compute the seismic risk maps for the retrofitted assets. Furthermore, this paper provides an insight on the problem of evaluating the profitability of retrofit interventions at national scale when a significant number of vulnerable structures is involved, and thus scale-effects may happen on the cost-benefit analysis. More details, and the complete procedure description can be found in (Zanini et al. 2019a and Zanini et al. 2019b). Finally, seismic risk maps can be used as starting point for the development of a seismic risk transfer program based on the use of CAT bond (Hofer et al. 2019 and Hofer et al. 2020).

2. Seismic risk maps of Italy

2.1. The as-built condition

Zanini et al. 2019a, showed the construction of the seismic risk map for Italy, computing the Expected Annual Loss for every Italian municipality, province and region. For the hazard representation, Zanini et al. 2019a adopted the seismogenic model of Meletti et al. 2008, jointly with the Gutenberg-Parameter of Barani et al. 2009, the Ground Motions Prediction Equations of Bindi et al. 2011, and the soil map of Allen and Wald 2007. A suitable building taxonomy have been adopted for representing the seismic vulnerability of the Italian residential building stock, which has been subdivided in eight Taxonomy Classes TCs. Masonry buildings have been subdivided in two TCs, masonry buildings built before and after 1919, respectively TC1 and TC2. Reinforced concrete structures have been subdivided in two main classes, depending if gravity-load design, or seismic-load design. Each one of these two classes have been furtherly subdivided in two classes, on the base of the number of storeys (1-2, or 3+), respectively TC3 and TC4 for the gravity-load design, and Tc5 and TC6 for the seismic-load design. Finally, two more TCs (again Other – gravity design TC7, and Other – seismic design TC8) have been adopted for describing structures other than masonry and RC, mainly combined RC-masonry structures. All parameters of the adopted fragilities can be found in Zanini et al. 2019a. About exposure data, they have been retrieved from the 15th census database of the National Institute of Statistics. Fig. 1 shows the seismic risk maps in terms of MEAL, PEAL and REAL, that are representations of the seismic risk in the so-called *as-built* condition.

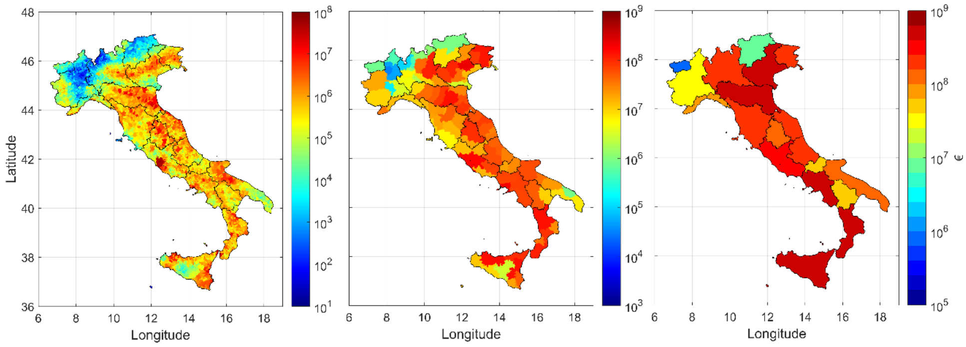

Fig. 1. Expected Annual Loss at municipal, provincial and regional level for the *as-built* condition.

2.2. The retrofitted condition

This work investigates benefits of implementing a full seismic retrofit of the Italian residential building stock. In particular, this paper assumes to improve the structural behavior or masonry buildings (TC1 and TC2), RC gravity load-designed structures (TC3 and TC4), and "Other" gravity load-designed structures (TC7). Retrofitting implies a change of the fragilities for the abovementioned TCs: in particular it has been assumed that in the retrofitted configuration they behave like the respective seismic-designed classes, i.e. TC1, TC2, TC3 change in TC5, TC4 is modified as TC6, and TC7 is characterized as TC8. Under these assumptions, seismic risk maps have been recomputed for the three level of granularity. Fig. 2 shows results in terms of MEAL, PEAL and REAL.

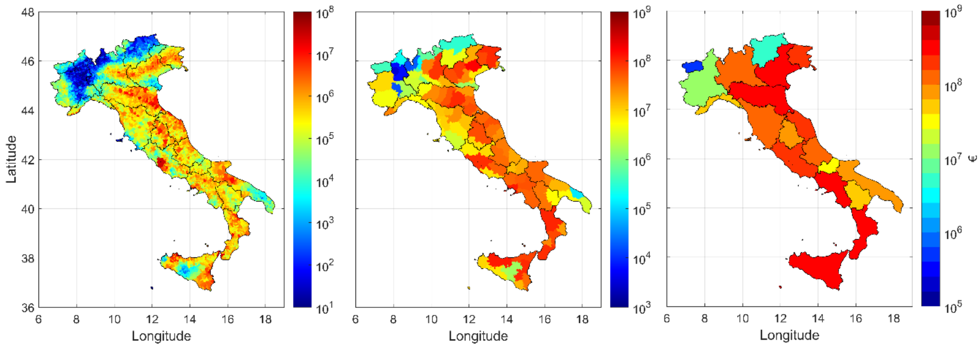

Fig. 2. Expected Annual Loss at municipal, provincial and regional level for the *retrofitted* condition.

3. Cost-benefit analysis

The financial sustainability of the proposed seismic retrofit program can be assessed through a cost-benefit analysis (CBA) (Gardoni et al. 2016, Hofer et al. 2018b). Usually, the profitability of a retrofit intervention is analyzed by computing the break-even time T_{BE}, i.e. the temporal point at which total cost and total revenue are equal. For each x^{th} municipality, t_{BE} can be computed as

$$T_{BE,x} = C_x / B_x \qquad (1)$$

where Cx is the cost to be sustained by the xth municipality for retrofitting TC1, TC2, TC3, TC4 and TC7, and Bx is the benefits in terms of EAL provided by the all the retrofit interventions in the xth municipality. Bx can be computed as the different between the EAL in the as-built condition, and the EAL after the structural improvement interventions in the retrofitted condition, as $B_x = EAL_{x,as\text{-}built} - EAL_{x,retrofit}$. Similarly, the benefit due to seismic retrofit can be computed at provincial and regional level. Fig. 3 shows the three benefit maps, highlighting how higher benefits are expected in the area of higher Annual Expected Losses. Furthermore, Fig. 4 shows the unitary benefit referred to the total built area of buildings belonging to TC1, TC2, TC3, TC4 and TC7.

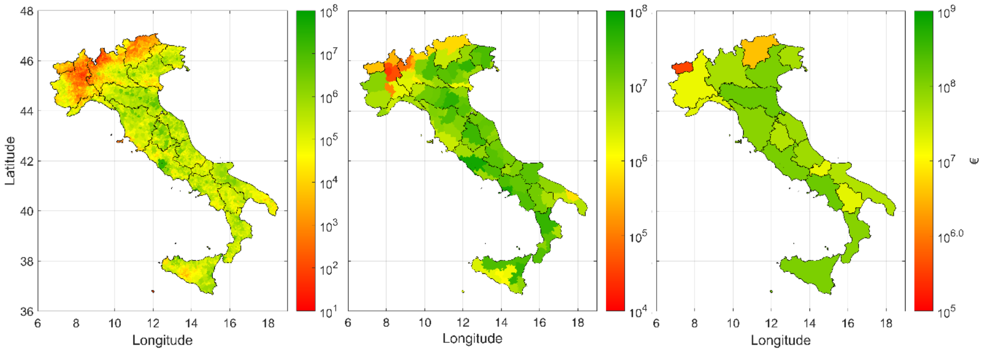

Fig. 3. Benefit map at municipal, provincial and regional level.

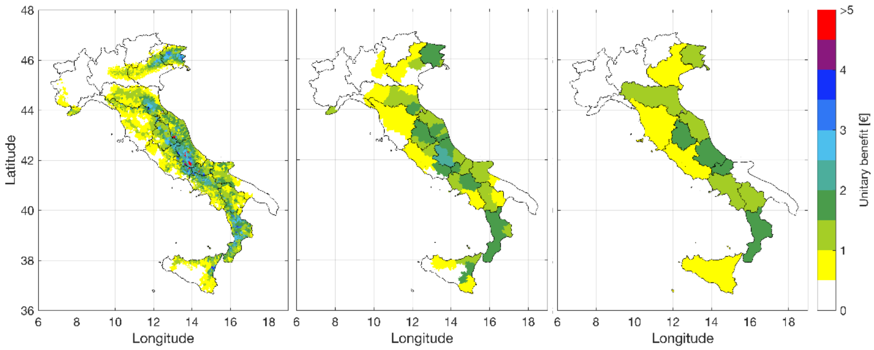

Fig. 4. Unitary benefit map at municipal, provincial and regional level.

Cost at municipal level C_x in Eq. (1) strictly depends on the planned seismic retrofit interventions for $p = 5$ TCs that need a structural improvement, and can be computed as

$$C_x = \sum_{y=1}^{p} A_{y,x} \cdot SRC_y \tag{2}$$

where $A_{y,x}$ is the built area of the y^{th} TC that needs seismic retrofit, and SRC_y is the unitary seismic retrofit cost for the y^{th} TC. The SRC_y values have been assumed equal to 68 €/m^2 for TC1, TC2, TC7 structures (i.e. retrofit schemes consisting in the insertion of tie-roads and reinforced plaster) and 34 €/m^2 to for TC3, TC4 buildings, i.e. interventions based in FRP wrapping (Faleschini et al. 2019 and Toska et al. 2021, or reinforced concrete jacketing of RC frame elements, in accordance to Prota 2016. Fig. 5 shows the retrofit cost to be sustained at municipal, provincial and regional level. Fig. 6 shows the break-even time map, computed at municipal, provincial and regional level according to Eq. (1). Basing on this indicator, the Italian territory is mainly divided into two parts: in the first zone, coinciding with the Appennini area and Northeastern Italy, seismic retrofit is recommended and T_{BE} ranges between few decades till about one hundred years. In the second case, for Northwestern Italy, Puglia and the Tyrrhenian coast, retrofit interventions seem not to be convenient, since the break-even time is hundreds of years. Even in this case, the calculation at provincial and regional level, has an averaging effect, increasing the lower T_{BE} values at municipal level, and reducing the higher T_{BE} values.\

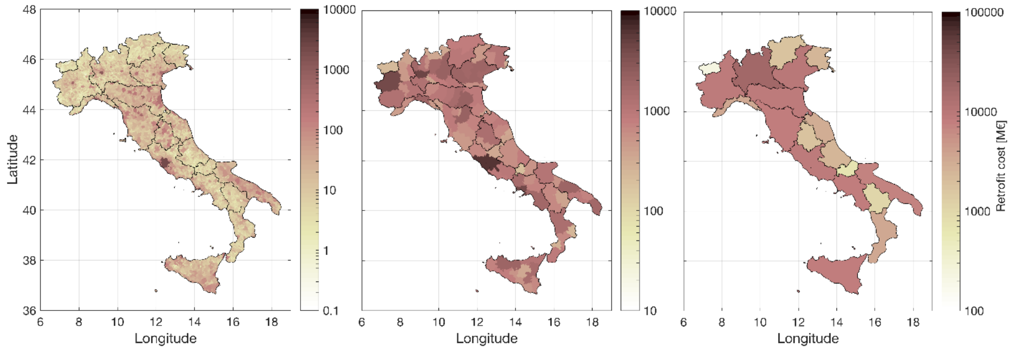

Fig. 5. Retrofit cost map at municipal, provincial and regional level.

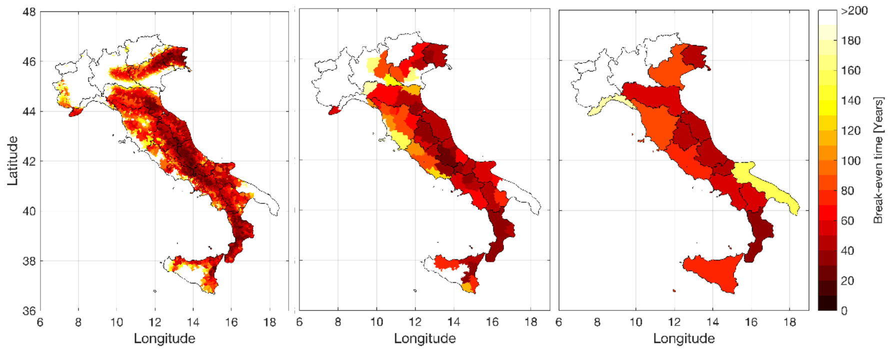

Fig. 6. Break-even time map at municipal, provincial and regional level.

4. Proposal of a of sustainable risk reduction program

In general, for the entire national territory, structural retrofit implies gains in a medium-long term, and, except for some municipalities and provinces where it is highly recommended, seems not to be a convenient strategy for reducing seismic risk. However, the safety of citizens and the national risk reduction, cannot be neglected basing on cost-effectiveness analysis. For this reason, a financially sustainable seismic risk reduction program is herein proposed. The financial sustainability of implementing a nationwide retrofit program, has to be investigated in order to guarantee reasonable break-even times. The idea is that the implementation of the national seismic risk reduction program, should be managed by the Italian Government, or, better, by an *ad hoc* national public agency, which have to support the seismic retrofit at municipal level (or provincial and regional). The cost-effectives of the initial investment, and thus a reasonable financial return time, should be guaranteed by increasing benefits due to the seismic retrofit. This can be obtained by introducing for each x^{th} municipality (or Province and Region) a property tax PT_x, that can be seen as an additional income to be summed to the benefit B_x, thus reducing the break-even time in the following way:

$$T_{BE,x} = C_x / \left(B_x + PT_x \right) \tag{3}$$

In each x^{th} municipality, PT_x can be computed as a fraction PTR_x (property tax rate) of the total municipal cadastral income as $PT_x = PTR_x \cdot CI_x \cdot A_x$, where A_x is the total built area in the x^{th} municipality, and CI_x is the municipal cadastral income in €/m^2: in this application CI has been assumed constant and equal to 484 €/m^2 (OMI 2017). From Eq. (4) it is thus possible to compute the PTR_x, given a specific T_{BE}, and, on the contrary, compute the break-even time corresponding to a specific PTR_x. Fig. 7 shows the map of the break-even time for PTR_x equal to 0.5‰, 1‰, 2‰ and 3‰ and it clearly shows the benefit of introducing this contribution. In particular, with PTR_x = 2‰ almost the entire national territory has a payback period lower than 30 years. Even in this case, considering less refined granularity has an averaging effect on T_{BE}, increasing the lower values, and reducing the higher ones. Finally, Fig. 8 shows the PTR

map for four different T_{BE} values, i.e. 10, 30, 50 and 80 years. It should be remarked how negative values of the property tax rates in Fig. 7 are present in municipalities that reach the financial break-even in a time interval lower with respect to a fixed uniform T_{BE} target value, so they have "no physical meaning" but they provide in such a way an information of how long the financial sustainability has been achieved.

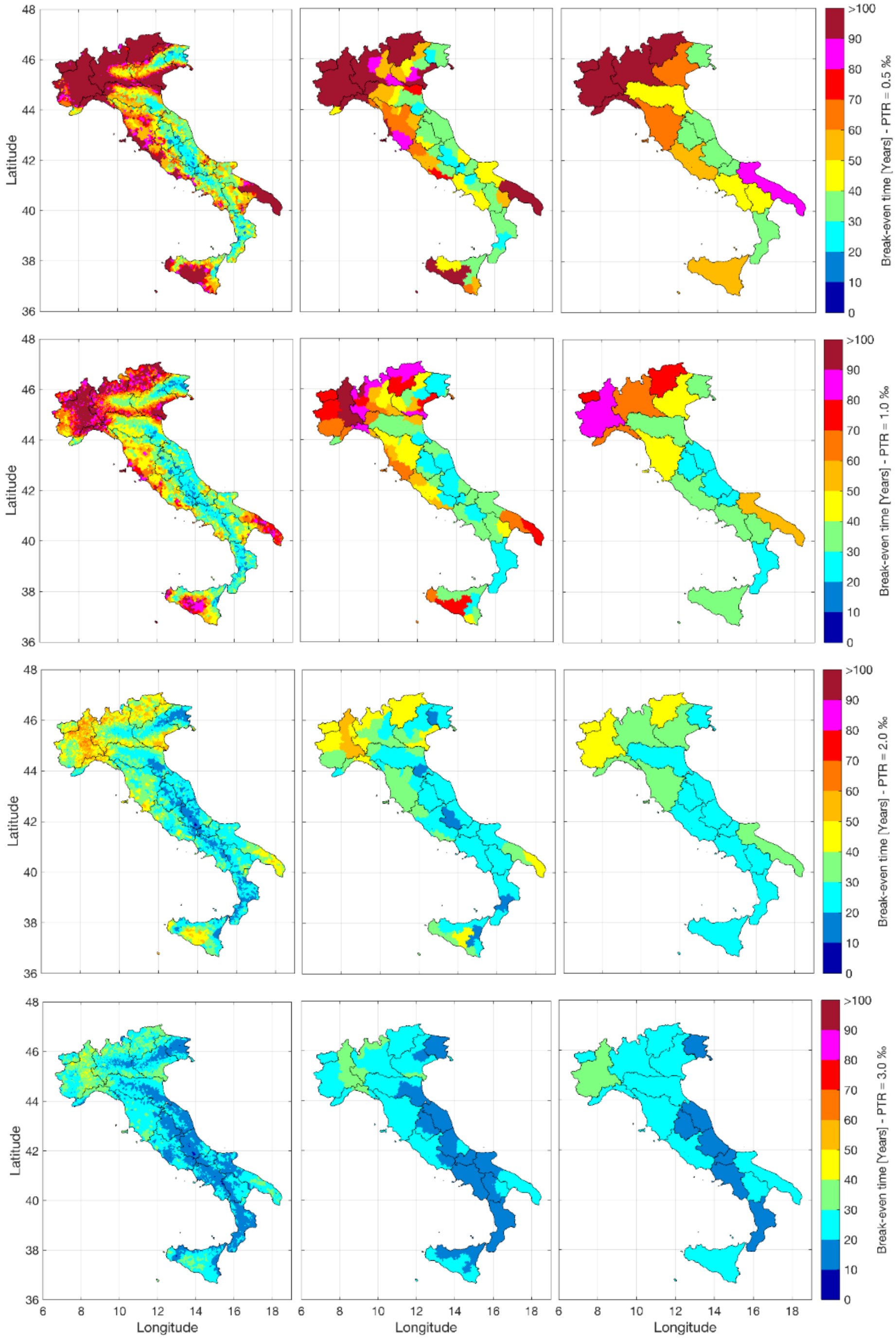

Fig. 7. Break-even time map with PTR equal to 0.5 ‰, 1 ‰, 2 ‰ and 5 ‰ at municipal, provincial and regional level.

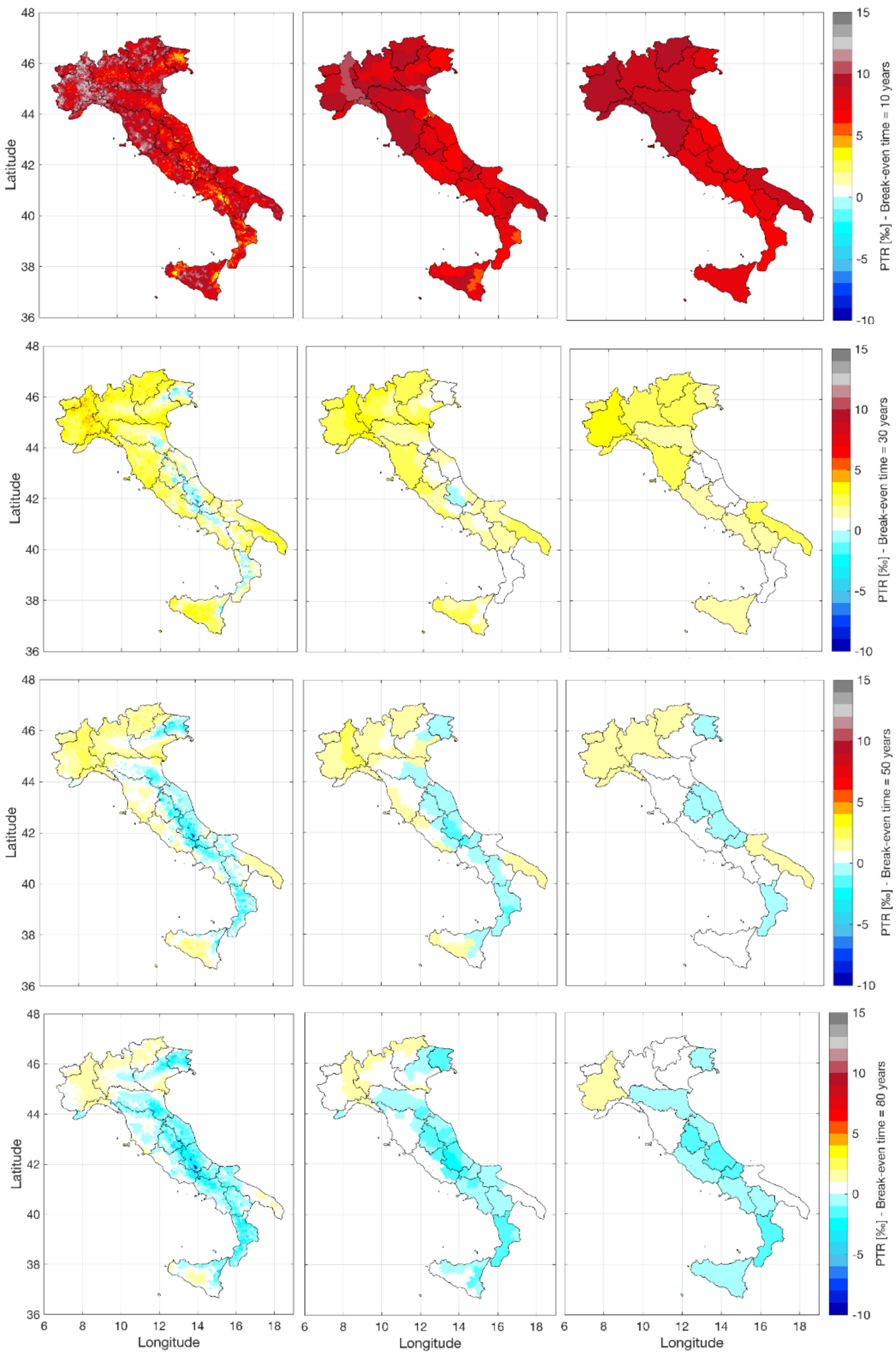

Fig. 8. *PTR* map with T_{BE} equal to 10, 30, 50 and 80 years at municipal, provincial and regional level.

5. Conclusions

In earthquake-prone countries, the development of financially sustainable risk reduction programs, is a key issue that has to be addressed starting from a deep knowledge of the risk at which the national territory is exposed. For this scope, suitable hazard, vulnerability and exposure models have to be defined, and then combined for computing the seismic risk map of the area of interest. The seismic risk map is the representation of the current *as-built* condition, from which the benefit due to seismic retrofit has to be computed. It is thus possible to compute the seismic risk map for the *retrofitted* configuration, and by subtraction the map of the expected benefit. The cost-benefits analysis performed for the Italian territory, showed a wide range of variability for the payback period, highlighting Italian regions in which seismic retrofit is highly recommended, and others in which it has a lower impact with high break-even times. For this reason, this work proposed a financially sustainable risk reduction strategy, based on the introduction of a property tax to be paid by citizen for achieving in a shorter time the financial break-even. The flexibility of the proposed strategy allows computing the expected payback period corresponding to a given level of property tax rate, or vice versa, the property tax rate to be applied for re-entering the investment in a specific number of years. Results shows as a property tax rate of 2 ‰ assures for almost the entire national territory a payback period lower than 30 years. Furthermore, in this paper, all calculations are performed at three granularity levels, i.e. municipal, provincial and regional level, showing the beneficial effects of considering a less refined granularity.

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