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CAESAR II: AN ITALIAN DECISION SUPPORT TOOL FOR THE SEISMIC RISK. THE CASE STUDY OF TORRE PELLICE, VILLAR PELLICE AND PINEROLO MUNICIPALITIES

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Abstract

Italy is a country with high seismic risk; however, a broad seismic classification of the national territory has been introduced only in the last twenty years. Therefore, most of the existing buildings stock do not comply with the current anti-seismic codes. In recent years, the seismic events that occurred in Italy have highlighted the complexity of emergency management and the great challenge for public authorities called to answer to the post-event reconstruction and the planning of effective risk prevention and mitigation measures implemented in "peacetime".

In this perspective, the CAESAR II project (Controlling, Mitigating and Managing Earthquake Emergency: Cost-Benefit and Multi-criteria Analysis of Impact Scenarios for Risk Reduction and Increased Resilience) has been developed as a decision support system for public authorities engaged in the development of seismic disaster risk reduction plans. CAESAR II includes a module for the simulation of retrofitting measures applied at the municipal scale, integrating different categories of anti-seismic and energy improvement measures based on the vulnerability analysis of the existing buildings stock. The CAESAR II tool's core is the module for evaluating "seismic impact scenarios" based on the end-users' hazard. The output of the model includes information on expected damage levels for buildings (from D0-no damage to D5- total collapse) and population (dead, injured and homeless). Impact scenarios can be customised according to the minimum unit of analysis assumed (municipality or 250x250m square mesh grid) and the availability of exposure data (from national census data or survey on the spot building by building according to the PLINIVS form). Scenarios include geo-referenced data managed by geo-servers to exchange data in a format compliant with OGC (Open Gis Consortium) standards and the European INSPIRE Directive. Simulation results can be further processed through the Multi-Criteria and Cost-Benefit Analysis modules to support the comparative assessment of alternative seismic and energy measurements.

In this work, the procedures included in CAESAR II are described and a case study is reported. It concerns the analysis of the expected damage assessment on buildings and population for three municipalities in northern Italy, Torre Pellice, Villar Pellice and Pinerolo (Piedmont Region).

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1. INTRODUCTION

Effective planning and programming in seismic emergencies require preliminary assessments of the effects on the territory. Due to the different objectives, it is possible to distinguish two types of assessments based on risk analysis and scenario analysis.

Risk is the probability that a prefixed level of damage (on people, buildings, infrastructures, economy, etc.) caused by seismic events will occur within a given period in a specific geographical area. Therefore, the risk should be intended as a cumulative assessment, which considers the total potential damage in the same area generated by different events in a fixed time frame. Scenario, instead, represents the probabilistic distribution, in a particular geographical area, of the damage induced by a single seismic event with an assigned probability of occurrence (assumed as the reference scenario).

In both types of analyses, three random variables come into question: hazard, exposure, and vulnerability. The "hazard" is the probability of occurrence, in a specific area and a specific period, of all possible seismic events, for risk analysis, or of a single event, in the case of scenario analysis. The "exposure" is the geographic distribution in quantitative and qualitative terms of the different elements at risk that characterise the area under consideration (people, buildings, infrastructure, activities and movable property). The conditions and/or operation may be damaged, altered or destroyed due to the occurrence of the natural event. The"vulnerability" is the sensitivity of an exposed element to a natural event. It can be evaluated as the probability that the exposed element will suffer a certain level of damage or change of state, concerning an appropriate scale, because of a seismic event of assigned intensity.

In emergency planning, both risk and scenario analyses can be used in response to the different goals that are to be pursued. Risk analyses allow comparative evaluations of areas subject to planning both for decisions on intervention strategies (e.g. evacuation priorities, etc.) and the definition of damage mitigation interventions. Scenario analyses, through the identification of the extension of the area of interest and the evaluation of the territorial impact, help quantify the resources necessary for the emergency planning and the organisation of the operative intervention.

In the literature, there are many works related to risk analysis in a broad sense or to some specific factor. Some specific studies on the vulnerability can be found in [1], [2], [3] and [4], and the exposure in [5], [6] and [7] About the costs analyses some works are reported in [8]and [9]and on the multi-criteria there are [10] and [11].

In recent years, research has focused on creating comprehensive tools for every aspect of the process. One of the newcomers is the IRMA (Italian Risk MAps) platform [12], developed by the the Department of Italian Civil Protection (DPC) . It integrates tools for calculating damage scenarios and risk maps for the Italian territory. The IRMA platform is designed for the scientific community and allows to create and load different exposure/vulnerability databases and different sets of fragility curves. The hazard for calculating risk maps is instead preloaded and is the hazard model developed by INGV (National Institute of Geophysics and Volcanology) and adopted at the national level.

In this framework, the CAESAR II project (Controlling, Mitigating and Managing Seismic Emergencies: Cost-Benefit and Multi-Criteria Analysis of Impact Scenarios for Risk Reduction and Increased Resilience) is born. It is a web-service procedure conceived as a decision support system for public authorities engaged in the development of disaster risk reduction plans, with the possibility to plan medium and long-term investments, as well as to define customised financial support mechanisms and fiscal incentives.

The project, developed as a follow-up to the CRISMA EU-FP7 (http://www.protezionecivile.gov.it/resources/cms/documents/CRISMA_locandina.pdf) and CAESAR I projects (a seismic impact model developed for the Campania region operations room in 2005), is funded by the Agenzia per la Coesione Territoriale (National Territorial Cohesion Agency), within the framework of the PON (National Operative Project) Governance and Institutional Capacities 2014-2020, as an intervention aimed at the transfer, evolution and dissemination of best practices among Public Administrations. CAESAR II includes a module for the simulation of retrofitting measures applied at the municipal scale, integrating different categories of anti-seismic and energy improvement measures based on analysing the existing building stock's vulnerability.

The CAESAR II tool's core is the 'seismic impact scenarios' evaluation module, based on the hazard assumed by the end-users. The output of the model includes information on the expected damage levels for buildings (from D0- no damage to D5- total collapse) and population (deaths, injuries and homelessness). Impact scenarios can be customised according to the minimum unit of analysis assumed (municipality or 250x250m square mesh grid) and the availability of exposure data. The exposure is estimated by exploiting the ISTAT (National Isnstitute of Statistics) Census 2011 [13], an Italian database that provides, for census zones, aggregated information on the buildings and the number of residents.

The scenarios include geo-referenced data managed by geo-servers capable of exchanging data in a format compliant with OGC standards and the European INSPIRE Directive. Simulation results can be further processed through the Multi-Criteria and Cost-Benefit Analysis modules to support the comparative evaluation of alternative seismic and energy measures. One of the CAESAR II tool's main strengths is that it does not require specific technical or engineering skills from the user, as it is offered as a complete package that needs some input data.

The paper has been structured in two main sections: the former one describes the calculation models and assumptions on which the CAESAR II procedure is based and the format of the information that is requested from the user; the latter one shows an application example on three Piedmontese municipalities (Pinerolo, Torre Pellice and Villar Pellice) made possible thanks to the data provided by the RISVAL project (https://www.interreg-alcotra.eu/it/decouvrir-alcotra/les-projets-finances/risvalrischio-sismico-e-vulnerabilita-alpina).

2. THE CAESAR II MODEL

Caesar II is a web-service procedure developed for the Territorial Cohesion Agency, producing scenario and seismic risk analyses in terms of economic, building and human life losses and evaluating their possible reduction through cost-benefit and multi-criteria analyses to support decisions. The application works on municipalities on a grid of 250x250m for which hazard and exposure factors are defined. CAESAR II is based on three models of analysis, described below:

1. Seismic Impact Risk and Scenario Analysis Model;
2. Post-seismic economic loss forecasting Model;
3. Multi-Criteria Analysis Model.

The three models have been synergistically implemented in as many modules within the so-called reuse kit.

2.1. Seismic Impact Risk and Scenario Analysis Model

Hazard

The seismic hazard adopted in CAESAR II is a function of the type of analysis to be developed. In the case of "risk" analysis, the primary seismic hazard is adopted, i.e. the maximum value of horizontal ground acceleration (PGA, peak ground acceleration), calculated by the INGV. The PGA values are given in correspondence of a grid of 10.751 points, defined by latitude and longitude coordinates, covering the whole national territory (**Figure 1**).

For each node in the geographic grid, parameters are provided at specified return periods, TR (30, 50, 72, 101, 140, 201, 475, 975, and 2,475 years). PGA maps are calculated for different exceedance probabilities over 50 years (9 in total, ranging from 2% to 81%). For each estimation, the 50th percentile distribution (median map, which is the reference map for each exceedance probability) and the 16th and 84th percentile distributions are available, indicating the variability of the estimates.

In the case of "scenario" analysis, the seismic event taken as a reference can be assumed through: 1) an attenuation law as a function of some seismic parameters, such as the coordinates of the hypocenter and the magnitude value, or 2) a shaking map (ShakeMap). The distribution over the territory of the parameters that define the extent of a seismic event (e.g., the PGA) can be derived through the adoption of an attenuation law, as a function of other seismic parameters (usually the magnitude) and epicentral (or hypocentral) coordinates. CAESAR II adopts, as attenuation law, the relation of Blake [14], which assumes a decimal logarithmic decay, and the conversion law determined by Faenza and Michelini [15], [16] between the observed shaking parameters and the MCS intensity scale. In Italy, shaking maps are provided by INGV for all earthquakes with magnitude $M \geq 3.0$ occurring in the national territory and surrounding areas. They are published on the website http://shakemap.rm.ingv.it. When new information or additional earthquake data become available (e.g., the size of the earthquake fault -extended fault-, new data from networks operated by other agencies), the maps are updated to improve the definition of ground shaking, particularly in epicentral areas. They provide an immediate visualisation of the level of shaking of an area affected or interested by an earthquake, reporting the peak values recorded by accelerometers and seismometers, mainly provided by the National Accelerometric Network (RAN) of the Department of Civil Protection and the National Seismic Network (RSN) of INGV, present in the area of the earthquake. If there are no observed values, an ad hoc software interpolates the data using, for example, the attenuation laws of the shaking with the distance available for the centre of each cell of the grid belonging to the area under examination.

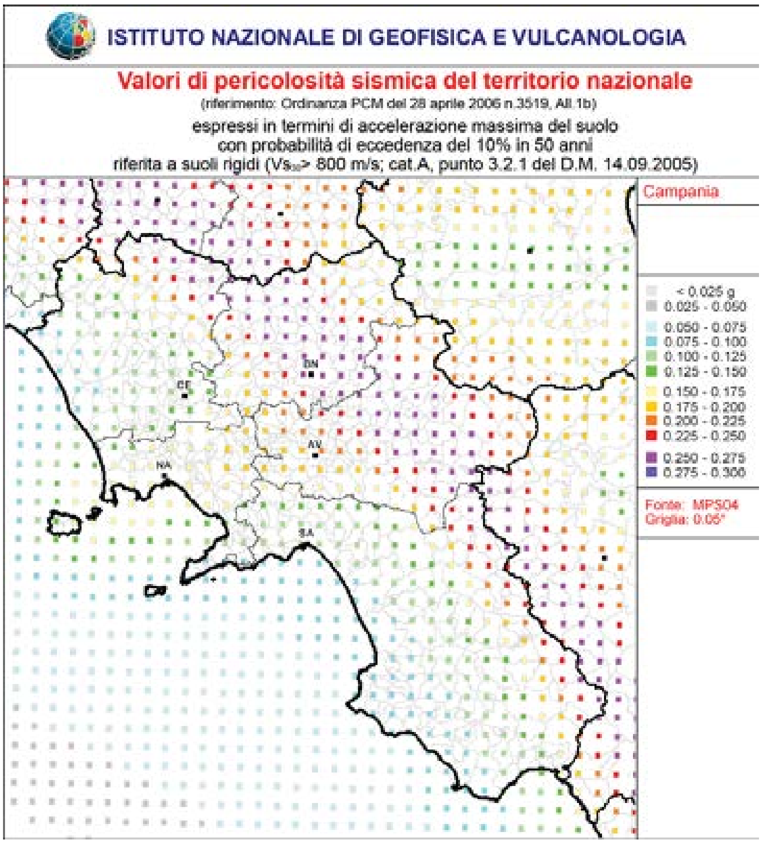

Figure 1. Seismic hazard values of the national territory expressed in terms of maximum ground acceleration with a probability of exceeding 10% in 50 years, referred to rigid soils.

Exposure

Exposure and vulnerability are closely related factors. For each category of elements at risk, the estimate of vulnerability to the seismic event must be accompanied by "a qualitative and quantitative analysis of the exposed property" (exposure), in order to identify the spatial distribution, and possibly temporal, of typological classes of elements at risk, called classes of vulnerability, each of which is a set of elements that for characteristics present similar behaviour (Vulnerability) concerning the earthquake. In other words, it is necessary to identify the salient characteristics of the element at risk (vulnerability factors), to which a specific capacity to respond to the natural phenomenon is attributed.

CAESAR II refers to two types of elements at risk: ordinary buildings and their occupants. The estimation of the buildings in the area under examination can be based on a statistical analysis, which evaluates the percentage distribution of the different classes of vulnerability of the buildings (A, B, C, D for decreasing vulnerability) based on their different behaviour towards the natural event. A similar procedure is adopted to estimate the population and the distribution of occupants for buildings divided by class of vulnerability.

The exposure model uses a procedure that can take into account both the ISTAT data only and the ISTAT data combined with information coming from a data collection activity on the investigated area. These input data are processed by the tools S.A.V.E. [17] and B.I.N.C. [7], two procedures developed by the PLINIVS Study Centre which aim to characterise the seismic vulnerability of specific building typologies (S.A.V.E.) and to evaluate a probable geographical distribution of these building typologies according to their recurrence in the ISTAT census data (B.I.N.C.).

In particular, the S.A.V.E. model is used to assign vulnerability classes to single buildings, detected in the data collection campaigns on the territory, according to their typological and structural characteristics. The B.I.N.C. model exploits the S.A.V.E. method and defines a probable distribution of the ISTAT buildings on the vulnerability classes, starting from the population density of the considered municipality and from the ages of construction of the buildings identified on each census section.

The distribution of vulnerability classes (exposure) is defined for each minimum reference unit of the model (250x250m cell of a regular square-mesh grid). However, ISTAT data on buildings refer to individual census sections, which may also contain a large number of cells, so a criterion for assigning census data to each cell was adopted, following relations (1) and (2), having defined "zones" as the areas of intersection between census sections and the grid (**Figure 2**):

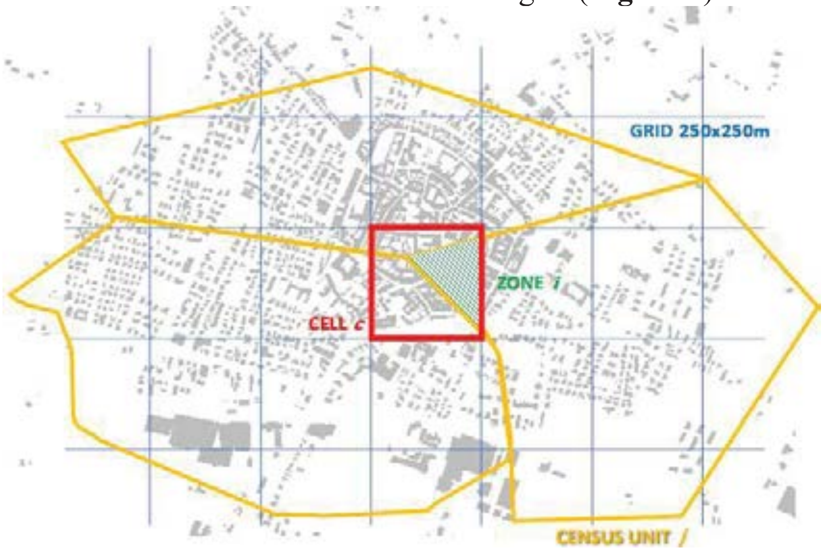

Figure 2. Illustrative representation of the "zones" (green), defined as the areas of intersection between the ISTAT census sections (yellow) and the 250x250m cells (red) of the model's reference grid (blue).

The number of buildings in zone i of census section j of vulnerability class k are estimated as in the equation (1); the number of buildings in cell c of vulnerability class k are obtained by the relation (2):

$$E_{i,j}^{k} = \begin{cases} E_{ij}^{k,R} & se\colon\ E_j^{ISTAT}/E_j^{R} \leq 1 \\ E_{ij}^{k,R} + E_{i,j}^{k,\cancel{R}} = E_{i,j}^{k,R} + E_j^{k}/E_j^{ISTAT} \cdot (E_{ij} - E_{ij}^{R}) & se\colon\ E_j^{ISTAT}/E_j^{R} > 1 \end{cases} \quad (1)$$

$$E_c^k = \sum_{i=1}^{n} E_{i,j}^{k} \quad (2)$$

Where:

c is the cell
j is the census section

i is the zone, intersection of the reference grid and census section
k is the vulnerability class (k = A, B, C, D)
n is the number of zones constituting cell i
E_j^{ISTAT} is the number of buildings in census section j
E_j^k is the number of buildings of census section j of vulnerability class k (BINC)
E_j^R is the number of buildings of census section j surveyed
$E_{i,j}^k$ is the number of buildings in zone i of census section j of vulnerability class k
$E_{ij}^{k,R}$ is the number of buildings detected of zone i of census section j of vulnerability class k (S.A.V.E.)
$E_{i,j}^{k,\cancel{R}}$ is the number of undetected buildings of zone i of census section j of vulnerability class k
E_c^k is the number of buildings in cell c of vulnerability class k.

Regarding the occupants' exposure, the CAESAR II model considers the assumption that the population is uniformly distributed over the homes. The data collected by the PLINIVS Study Centre and processed with the SAVE method have allowed to define a correlation between the number of houses present in a building and the vulnerability class to which the building belongs (**Table 1**).

average of dwellings	Vulnerability class of the building			
	A	B	C	D
M_{Ab}	2.0	2.7	3.45	6.90

Table 1. average of dwellings for buildings related to the vulnerability class

Therefore, the population distribution over the vulnerability classes is calculated as in equation (3).

$$N_{P_k} = \frac{E_k \cdot M_{Ab_k}}{\sum_{t=A,\dots D} E_t \cdot M_{Ab_t}} P^{ISTAT} \tag{3}$$

Where

E_k is the number of buildings of vulnerability class k,
M_{Ab_k} is the average of dwellings for the buildings of vulnerability class k,
E_t is the number of buildings of vulnerability class t,
M_{Ab_t} is the average of dwellings for the buildings of vulnerability class t,
P^{ISTAT} is the population indicated in the ISTAT data

Finally, the average number of occupants as the seismic class k (N_{O_k}) of each cell in the reference grid varied was evaluated using relation (4).

$$N_{O_k} = N_{P_k} \cdot Q_{m,O} \tag{4}$$

Where:

N_{P_k} is the number of people per seismic class k estimated, cell by cell, based on ISTAT data;
$Q_{m,O}$ is the average percentage of occupants, assumed to be 65%, of the total population.

Vulnerability

A building's vulnerability is the probability that the system (entire building), subsystems (walls, framing, roofs, etc.), or components of the system (beams, columns, infill panels, windows, doors, etc.) will be damaged as a result of an assigned action to which they are subjected. The concept of vulnerability requires to define unambiguously the level of "damageability" of the exposed asset due to the natural event.The damage scale adopted in CAESAR II refers to the six levels of damage of the: D0: no damage; D1: not structural damage; D2: light structural damage; D3: structural damage; D4: partial collapse; D5: total collapse.

The propensity of a building to sustain damage is a function of its constituent elements. The strength and technological aspects of structural (walls, beams, columns, floors, roofs, etc.) and non-structural (infill panels, openings, protective panels, etc.) elements strongly influence the vulnerability of the building itself [18].

The vulnerability of a building to an earthquake can be assessed through the so-called vulnerability curves. For an assigned class of vulnerability, they express the probability of exceeding a certain level of damage as the hazard measurement parameter varies, which may be the peak seismic acceleration, spectral intensity, macroseismic intensity, etc..

CAESAR II uses the model of vulnerability curves for ordinary buildings. These curves were calibrated on data from damage probability matrices produced through a statistical analysis of observed damage following earthquakes that have occurred in Italy since 1980, and converted to PGAs via Margottini's law [19]. The mean and standard deviation parameters of the vulnerability curves are shown in **Table 2**.

The vulnerability of the population to the earthquake is determined with reference to the damage suffered by the buildings occupied by the people. In **Table 3**, the percentages of dead QD and injured QI are reported as a function of the building's level of damage. The values shown were calibrated based on data collected from past earthquake events [20].

CLASS	PERCENTILE	D1		D2		D3		D4		D5	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
A	16%	-3,50	0,80	-2,70	0,80	-1,95	0,70	-1,35	0,60	-0,75	0,60
A	50%	-3,35	0,80	-2,60	0,80	-1,74	0,80	-0,95	0,75	-0,40	0,75
A	84%	-3,25	0,80	-2,25	0,80	-1,65	0,80	-1,00	0,80	-0,15	0,80
B	16%	-2,80	1,20	-1,55	1,10	-0,70	1,10	0,00	0,80	0,50	0,55
B	50%	-2,45	1,20	-1,20	1,00	-0,45	0,90	0,10	0,70	0,40	0,70
B	84%	-1,90	1,00	-0,90	0,80	-0,35	0,70	0,20	0,40	0,45	0,40
C	16%	-2,60	1,60	-1,20	1,20	-0,35	0,90	0,20	0,70	0,55	0,45
C	50%	-2,10	1,30	-0,80	1,00	-0,15	0,80	0,40	0,80	0,70	0,70
C	84%	-1,50	1,20	-0,50	0,80	-0,03	0,60	0,20	0,45	0,55	0,40
D	16%	-1,40	1,40	-0,10	1,00	0,40	0,60	0,70	0,55	1,30	0,60
D	50%	-1,00	1,20	0,00	0,80	0,60	0,60	0,80	0,50	1,50	0,60
D	84%	-0,40	1,00	0,40	0,70	1,10	0,80	1,20	0,60	1,70	0,60

Table 2. logarithmic mean and logarithmic standard deviation of the vulnerability curves

Percentage of death (Q_D) and injured (Q_I)	Level of damage						Vulnerability Class
	D0	D1	D2	D3	D4	D5	
Q_D	0	0	0	0	0.03	0.14	A, B, C
Q_D	0	0	0	0	0.06	0.28	D
Q_I	0	0	0	0	0.10	0.56	A, B, C
Q_I	0	0	0	0	0.12	0.42	D

Table 3. Percentage of death and injured regarding the levels of damage and vulnerability class

Finally, The EASE model (Zuccaro et al., 2008; Zuccaro and Cacace, 2010), developed and engineered by the PLINIVS centre for DPC, was adopted to estimate the effects of risk related to the chosen reference period. The model discretises the territory through a square-mesh grid of size 250x250m. To each cell is assigned: hazard data, in terms of PGA; and exposure data, in terms of the number of buildings for each structural vulnerability class and the number of occupants. Combining these data with seismic vulnerability (percentiles 16, 50, and 84%), the model yields the following products on a cell-by-cell basis:

- Number of collapsed buildings, as the sum of buildings with D4 and D5 damage.

- Number of uninhabitable buildings, as the sum of buildings with D4 and D5 damage and 60% of buildings with D3 damage.

- Number of deaths N_D and injuries N_I, as assessed through the equations (5) and (6):

$$N_D = (1 + TI_c) \cdot \sum_{t=1}^{4} \sum_{j=1}^{5} N_{t,j} \cdot NO_t \cdot Q_{Dt,j} \tag{5}$$

$$N_I = (1 + TI_c) \cdot \sum_{t=1}^{4} \sum_{j=1}^{5} N_{t,j} \cdot NO_t \cdot Q_{It,j} \tag{6}$$

Where:

t is the seismic class of the building (A, B, C, D);

j is the damage level of the building (D1, D2, D3, D4, D5);

$N_{t,j}$ is the number of buildings, per cell, of seismic class t having damage level j;

NO_t is the average number of occupants per building of seismic class t;

TI_c is the tourism index of the city [0-100%];

$Q_{Dt,j}$ is the percentage of deaths per seismic class t and damage level j;

$Q_{It,j}$ is the percent injured per seismic class t and damage level j.

- Number of homeless assessed through the relationship (7):

$$N_H = \sum_{t=1}^{4} [(0.5 \cdot N_{t,D3} + N_{t,D4} + N_{t,D5}) - N_D] \tag{7}$$

Where:

$N_{t,D3}$ is the number of buildings, per cell, of seismic class t having damage level D3;

$N_{t,D4}$ is the number of buildings, per cell, of seismic class t having damage level D4;

$N_{t,D5}$ is the number of buildings, per cell, of seismic class t having damage level D5.

2.2. A post-seismic economic loss forecasting model

Seismic emergency management requires specific programs for identifying the objectives to organise an adequate and quick response. They manage a complex workforce, equipment and resources arranged and coordinated by local administrations both in space and time.

The introductory knowledge basis, necessary to allocate resources, is represented by damage scenarios, useful to predict possible damages due to an earthquake impact and following population involvement in the affected area [21]. Such scenarios contain data like territorial seismic vulnerability with particular attention to the built environment. Moreover, they can provide valuable information about the extension of the most seriously affected area, working of transport infrastructures, roads and service networks, damage on buildings and the expected casualties, as well as the corresponding financial burden.

Within this dense framework, an earthquake can be described as a phenomenon characterised by a two-phases temporal sequence, each of which has direct and indirect economic consequences. For what that concerns the directly related ones, it is possible to find all those connected to protection, improvement, and structural seismic adaptation to reduce the general vulnerability of ordinary buildings. Equation (8) can assess these mitigation costs (MTC). In **Table 4** the Average cost of mitigation interventions from a vulnerability class to another (€/m^2) are summarized.

$$MTC = \sum_{j=A}^{D} emc_j \cdot sm_{emc_j} \cdot cm_{emc_j} + \sum_{j=A}^{D} emc_j \cdot cman_{emc_j} \tag{8}$$

Where:

emc_j is the number of j-th vulnerability class buildings to be mitigated;

sm_{emc_j} is the average area of the j-th vulnerability class building to be mitigated;
cm_{emc_j} is the average mitigation cost for the j-th vulnerability class building (**Table 4**);
$cman_{emc_j}$ is the average maintenance cost for the j-th vulnerability class building ($cman_{emc_A}$= 1.500 €/year; $cman_{emc_B}$= 1.800 €/year; $cman_{emc_C}$= 2.000 €/year; $cman_{emc_D}$= 2.600 €/year).

Class	B	C	D
A	360	510	624
B	-	390	540
C	-	-	378

Table 4. Average cost of mitigation interventions from a vulnerability class to another (€/m²)

Inside the area hit by an earthquake of a given magnitude, all post-event operations can be immediately translated into costs directly linked to the buildings' damage and affected population. As part of the post-event costs, those related to reconstruction, on-site or in a new different location, involve buildings irreversibly damaged by the earthquake (damage level D4-D5 under the EMS'98 classification). The relation (9) can assess these reconstruction costs (RC).

$$RC = \sum_{i=4}^{5} edl_i \cdot sm_{edl_i} \cdot crl + \sum_{i=4}^{5} edd_i \cdot sm_{edd_i} \cdot crd \tag{9}$$

Where:
sm_{edl_i} is the average area of the *i-th* damage level building to be rebuilt on-site;
crl is the reconstruction cost for a residential building on-site (1.235,94 €/m^2);
edd_i is the number of *i-th* damage level buildings to be rebuilt delocalised;
sm_{edd_i} is the average area of the *i-th* damage level building to be rebuilt delocalised;
crd is the reconstruction cost for a residential building delocalised (1.250 €/m^2).

The Restoration costs (RT) are, instead, connected to the activities planned for recovery buildings and infrastructures damaged in a non-irreversible way by the earthquake (damage level D1-D2-D3 under the EMS'98 classification) and can be calculated as in the formula (10).

$$RT = \sum_{i=1}^{3} ed_i \cdot sm_{ed_i} \cdot cr_{ed_i} \tag{10}$$

Where:
ed_i: number of *i-th* damage level buildings to be restored;
sm_{ed_i}: average area of the *i-th* damage level building to be restored;
cr_{ed_i}: restoration cost for a residential building as a function of damage level (cr_{ed1}=360 €/m^2; cr_{ed2}=458 €/m^2; cr_{ed3}=545 €/m^2).

At this stage, all those costs related to the *demolition and rubble removal (DR)* of lost buildings are certainly not negligible, as well as the management cost for specialised landfills. The formula (11) can assess these efforts:

$$DR = \sum_{i=4}^{5} ed_i \cdot vm_{ed_i} \cdot cd + \sum_{i=4}^{5} ed_i \cdot vm_{ed_i} \cdot ct \cdot dm + \sum_{i=4}^{5} ed_i \cdot vm_{ed_i} \cdot cg \tag{11}$$

where:
ed_i is the number of *i-th* damage level buildings to be demolished;
vm_{ed_i} is the average volume of the *i-th* damage level building to be demolished;
cd is the demolition cost for a lost building as a function of vulnerability class (cd_{A-B}=12 €/m^3; cd_C=14 €/m^3; cd_D=16 €/m^3);
ct is the cost of rubble transportation to the landfill (0,6 €/m);

dm is the average site distance from the landfill (300 m);
cg is the average landfill management cost (1,4682 €/m^2).

As part of the costs associated with safeguarding the population affected by the earthquake, it is possible to include *health care* costs *(HT)* for establishing medical equipment, strengthening existing local public facilities, as well as physical and psychological support. These costs can be calculated as in the equation (12).

$$HT = f \cdot cm \cdot tm \tag{12}$$

where:
f is the number of people in need of medical care;
cm is the unit cost of medical care operations (200 €);
tm is the average time for medical care (10 days).

The formula (13) calculates the *evacuation* costs *(EV)* of the population, split up according to the destination and the means of transport employed:

$$EV = s_{nm} \cdot cm_t + cm_c \cdot \frac{s_t}{s_c} + cm_{pc} \cdot tu_c + cm_{kp} \cdot s_t + cg_{at} \cdot \frac{st_t}{sm_t} \cdot tu_c + cg_t \cdot s_{te} + cg_h \cdot s_h \tag{13}$$

Where:
s_{nm} is the number of homeless people with no vehicle;
cm_t is the total cost of public transport (15.599 €);
cm_c is the cost of checkpoints set-up (7.050 €);
s_t is the total number of homeless people;
s_c is the number of homeless people evacuated at checkpoints;
cm_{pc} is the daily cost of checkpoints staff (5.930 €);
tu_c is the checkpoints' time usage;
cm_{kp} is the unit cost of the emergency kit (10 €);
cg_{at} is the daily depreciation cost per tent set up (20,55 €);
st_t is the number of homeless people evacuated in tents;
sm_t is the average number of people for each tent set up;
cg_h is the daily cost for the stay in the hotel (45 €);
s_h is the number of homeless people accommodated in hotels;
cg_t is the daily cost for accommodation in the tent;
s_{te} is the number of homeless people placed in tents.

The last cost item estimated is related to *emergency management (EM)* activities following an earthquake, which includes the construction of operational structures and the deployment of vehicles and employees to prepare equipped areas. The formula (14) is used to this purpose.

$$EM = pg_{pc} \cdot cm_{cc} + c_r + cpg_{pc} \cdot tp_{pc} + cpg_{po} \cdot tp_{po} + cpg_{mo} \cdot tp_{mo} + cm_{pv} \cdot tp_{pv} \tag{14}$$

Where:
pg_{pc} is the average daily presence of Department of Italian Civil Protection staff;
cm_{cc} is the unit cost for coordination centre set-up (3.000 €);
c_r is the cost of communication networks and IT services (5.000.000 €);
cpg_{pc} is the cost for daily presence of Department of Italian Civil Protection staff (126.18 €/day);
tp_{pc} is the presence of the Department of Italian Civil Protection staff;
cpg_{po} is the cost for daily presence of operating structures staff (130 €/day);
tp_{po} is the presence of operating structures staff;
cpg_{mo} is the cost for daily presence of operating structures means of transport (20 €/day);
tp_{mo} is the presence of operating structures means of transport;
cm_{pv} is the cost for daily presence of volunteer staff (100 €/day);
tp_{pv} is the presence of volunteer staff.

All the parametric costs showed are from the Department of Italian Civil Protection's elaborations about the L'Aquila 2009's earthquake.

2.3. The multi-criteria analysis model

The amount of damage caused by earthquakes can be minimised by adopting systematic measures of emergency management. Within this context, it is crucial to intervene immediately by making decisions that result as accurate and objective as possible, by recognising all the viable alternatives and analysing their consequences. Decision-making problems framed into this background involve a multiplicity of relevant aspects and the presence of various goals and constraints, often not explicit or even contrasting. These items can be inserted in a so-called *decision tree* with a general objective at the top and at least a decision-maker. Such models can keep account of the conflicting nature of uncommonly complex situations and explain the criteria for selecting the alternatives in terms of specific targets to reach.

The multi-criteria analysis' main point is not a pursuit for objectively optimal solutions but the support to rationalise the decision-making process and optimise a set of criteria weighted according to the decision-makers' preferences. This new kind of evaluation scheme identifies alternatives that satisfy a certain number of explicitly defined standards. It is possible to sort the elements of a decision tree as:

- Objectives: statements regarding the condition to achieve, made operational by allocating one or more qualitative and quantitative attributes;
- Criteria: standards of judgment or rules useful to test the worth of decision alternatives, including both the concept of goal and attribute;
- Alternatives: elements of evaluation and choice that must be ordered based on dominance scores representing the entries of the decision matrix.

One of multi-criteria's most powerful tool is undoubtedly the *Analytic Hierarchy Process* [22]. Such a complex algorithm makes it possible to evaluate the priority of actions, programs, intervention strategies, plans and projects by applying mathematical concepts to decision-making, as well as quantitative methodologies to evaluate mostly intangible and subjective judgments. They oppose the classic single-criterion linear analysis models suitable only to straightforward cases and under enough simplified hypotheses. The main advantage is now the flexibility in solving difficult problems by adopting a typical human mind's cognitive model.

It is possible to obtain reliable scales by only using personal judgments, identifying all the single elements of a problem, placing them inside homogeneous sets and sorting each set at a different level. In hierarchies, intricate schemes are top-down analysed in their basics, simulating how the human brain analyses complexity and breaks down the objects perceived by the senses into categories and sub-categories, building a so-called dominance hierarchy (**Figure 3**).

The first level contains the general objective, while the second level contains its further specifications. A possible third level can add more details to the upper level and so on. Finally, alternatives are placed at the base of the dominance hierarchy. Once completed this initial phase, pairwise comparisons are performed for each element of a certain level, with reference to the element placed at that immediately higher. According to the hierarchy shown in Figure 1, second-level criteria are pairwise compared with reference to the overall objective. Third-level sub-criteria are pairwise compared with reference to each second-level criterion until the alternatives are compared according to each third-level sub-criterion, each second-level criterion and, finally, the overall objective.

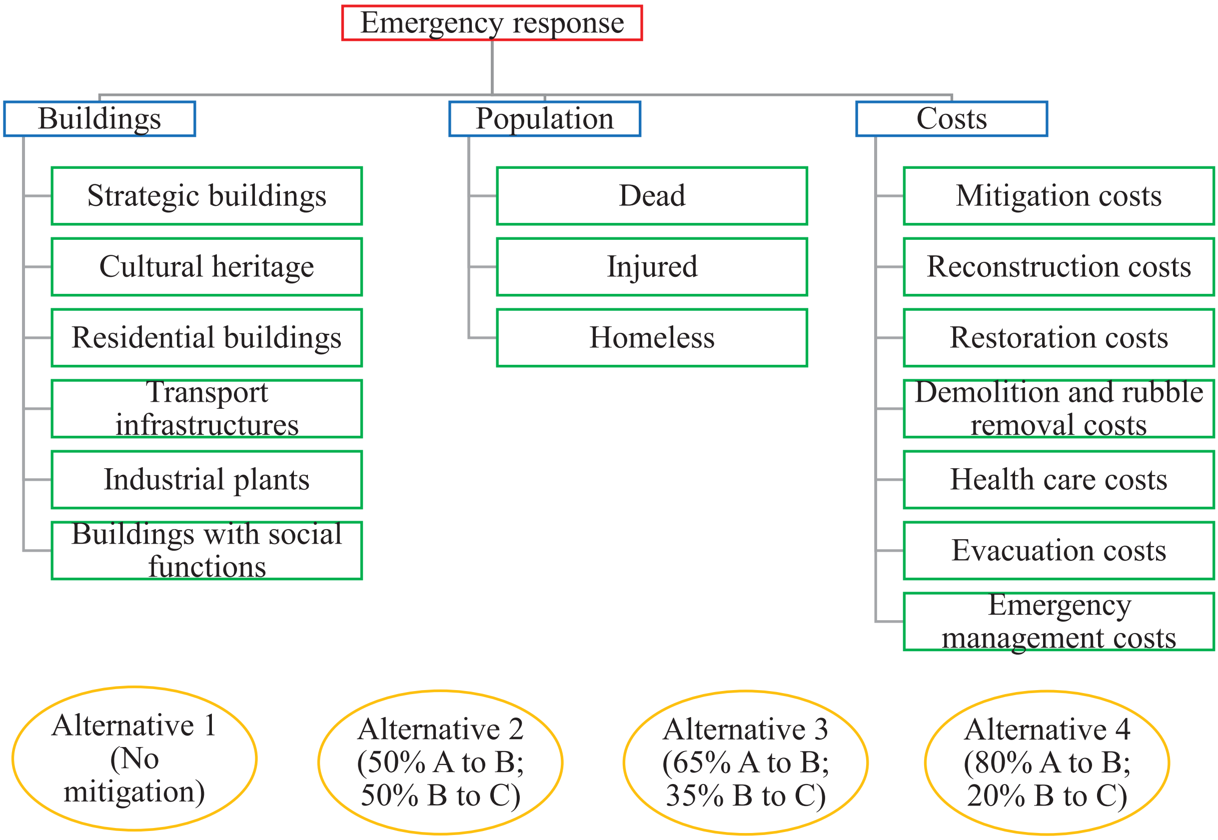

Figure 3. The dominance hierarchy

These operations provide a series of comparison coefficients placed into a so-called dominance matrix and a priority vector that measures all the alternatives' relative reasonability. When the use of judgments is necessary, these can be expressed via the semantic scale of Saaty (Table 5). Such a scheme links natural numbers to qualitative linguistic variables making it possible to answer the crucial question behind all pairwise comparisons: "How much does an element dominate another with reference to a specific criterion or attribute? ".

Intensity of dominance (a_{ij})	**Judgement**
1	Equal importance
3	Weak predominance
5	Moderate predominance
7	Strong predominance
9	Absolute predominance
2 **4** **6** **8**	Values of compromise

Table 5. The semantic scale of Saaty

Denoting by n the number of criteria to be considered, the dominance matrix A^k, built by an individual decision-maker, will be square and symmetrical (Equation (15):

$$A^k = \begin{vmatrix} a_{11}^k & a_{12}^k & \dots & a_{1n}^k \\ a_{21}^k & a_{22}^k & \dots & a_{2n}^k \\ \dots & \dots & \dots & \dots \\ a_{n1}^k & a_{n2}^k & \dots & a_{nn}^k \end{vmatrix} \quad (15)$$

where a_{ij}^k denotes the *k-th* preference of the generic decision-maker, referred to the *i-th* criterion concerning the *j-th* one. If there are more than one decision-makers, individual preferences are averaged and inserted into a new dominance matrix A (Equation (16))

$$A = \begin{vmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{vmatrix} \tag{16}$$

Following the Analytic Hierarchy Process, every criterion's normalised weight w_{Ni} is calculated as in the (17).

$$w_{Ni} = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n} w_i} \quad i = 1, \dots, n \tag{17}$$

The eigenvalue for each row of the dominance matrix A is computed as in the (18).

$$\lambda_i = w_i \left(\frac{\sum_{i=1}^{n} a_{ij}}{\sum_{i=1}^{n} w_i}\right) \quad i, j = 1, \dots, n \tag{18}$$

and so the maximum eigenvalue is calculated as in (19), that represents the limit value that n must take in order for the (20).

$$\lambda_{max} = \sum_{i=1}^{n} \lambda_i \tag{19}$$

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{(\lambda_{max} = n)} \to \sum_{j=1}^{n} a_{ij} w_j = \lambda_{max} w_i \tag{20}$$

The following *consistency index* CI measures the deviation of A from the coherence and allows to measure the overall difference between the two sets of values, as in the (21).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{21}$$

Impossibility to make reliable judgments, lack of data and inexperience can drive inconsistency. However, it is crucial to establish its maximum admissible value to avoid having completely erroneous data, so the consistency index is compared with arbitrary *random index* RI. The ratio between CI and RI provides the *consistency ratio* CR expressed in the (22).

$$CR = \frac{CI}{RI} \leq 0.10 \tag{22}$$

3. A CASE STUDY: PINEROLO, TORRE PELLICE AND VILLAR PELLICE MUNICIPALITIES

This section shows the application of CAESAR II system on three municipalities in the Piedmont Region: Pinerolo, Torre Pellice and Villar Pellice.

First of all, the impact model requires the choice of the kind of analysis (risk or scenario). In case of risk, the return period must be defined, while in case of scenario a shakemap has to be uploaded or coordinates and depth of the epicentre have to be provided

.

The analyses proposed for the Piedmontese municipalities have been done considering the area's risk, with reference to a seismic hazard expressed in acceleration (ag) and a probability of exceedance in 50 years of 10% (return period of 475 years). The hazard value is almost homogeneous on the three municipalities.

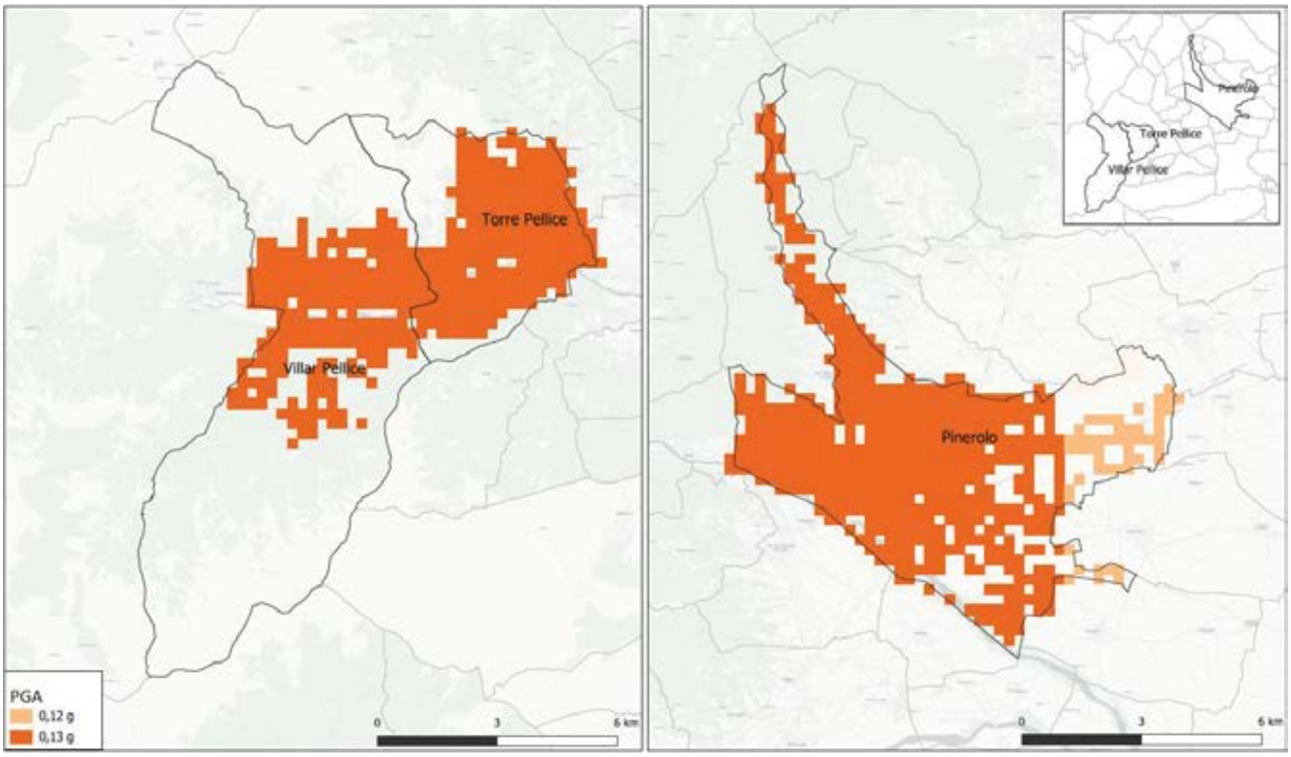

Figure 4. Hazard distribution on the cells of the investigated muncipalities

Also, a dataset of 1,642 detected buildings has been provided by the Piedmont Region.
With reference to the exposure model, estimated based on equations (1) and (2), the buildings distribution on the vulnerability classes summarised in the **Table 6** has been obtained. It is shown that all the investigated municipalities have a high percentage of buildings in class A (Villar Pellice 66%, Torre Pellice 52 % and Pinerolo 41%). With reference to class D, the high percentage is found in Pinerolo (28%), followed by Torre Pellice (21%) and, at the end, Villar Pellice (11%). The intermediated classes have similar values: class B occurs with a frequency of 18% in Pinerolo and Torre Pellice, and 17% in Villar Pellice; instead class C is manifested by a percentage of 13% in Pinerolo, 10% in Torre Pellice and 6% in Villar Pellice.

municipality	buildings	VULNERABILITY CLASS A		B		C		D	
		n°	%	n°	%	n°	%	n°	%
Pinerolo	4211	1723	41	750	18	543	13	1195	28
Torre Pellice	1180	616	52	207	18	114	10	243	21
Villar Pellice	802	533	66	134	17	50	6	85	11

Table 6. Buildings distribution on the vulnerability classes for each investigated municipality

municipality	buildings	COLLAPSED BUILDINGS min		med		max		UNHABITABLES BUILDINGS min		med		max	
		n°	%	n°	%	n°	%	n°	%	n°	%	n°	%
Pinerolo	4211	93	2	196	5	357	8	295	7	502	12	764	18
Torre Pellice	1180	33	3	69	6	125	11	103	9	174	15	262	22

Villar Pellice	802	28	3	59	7	106	13	88	11	147	18	219	27

Table 7. Impact on the buildings

municipality	population	DEATH						INJURIED						HOMELESS					
		min		med		max		min		med		max		min		med		max	
		n°	%	n°	%	n°	%	n°	%	n°	%	n°	%	n°	%	n°	%	n°	%
Pinerolo	34854	11	0,03	25	0,07	49	0,14	38	0,11	89	0,26	180	0,52	284	1	477	1	715	2
Torre Pellice	4573	2	0,04	5	0,11	9	0,20	7	0,15	17	0,37	34	0,74	101	2	169	4	253	6
Villar Pellice	1120	1	0,09	2	0,18	3	0,27	3	0,27	6	0,54	12	1,07	87	8	145	13	216	19

Table 8. Impact on the population

The impact estimated by the CAESAR II model with reference to the buildings and the population have been summarised in the Table 7 and Table 8 respectively, on the basis of the vulnerability model in the Table 2. The minimum values has been obtained with the vulnerability parameters related to the 16%, the medium values with the ones related to the 50% and the maximum values with the ones related to the 84%.

Although Pinerolo is the municipality with a high impact on the buildings and the population in total terms, it has a low percentage term. Contrary, Villar Pellice shows the low impact in full terms and the high impact in percentage terms. These results are perfectly consistent with the input data. The three municipalities are affected by an almost homogeneous hazard, so the exposure model dictates the differences. As shown, Villar Pellice is the most fragile municipality (high percentage of class A buildings), while Pinerolo has higher percentages of class C and D buildings. However, the buildings and inhabitants in Villar Pellice are 19% and 3% respectively of those in Pinerolo, so in total terms, the incidence is much lower.

The cost analysis model does not require information; the input data are the impact model's casualties and losses. In **Table 9** the costs analyses for each municipality, with reference to minimum, medium and maximum values, have been summarised. Since there are no hypotheses of mitigations in this phase, in all the cases, this value is equal to zero. The higher costs are always related to the restoration that in each case represent more than the 50% of the total costs.

The multi-criteria analysis's input data are provided by the casualties and economic losses resulting from some possible scenarios. In the case study four scenarios have been considered: the first one (SCENARIO 0) is related to the actual state while the remaining three are obtained by assuming forms of mitigation on existing buildings (SCENARIO 1: 50% of class A buildings are transformed into class B buildings and 50% of class B buildings are transformed into class C buildings; SCENARIO 2: 65% of class A buildings are transformed into class B buildings and 35% of class B buildings are transformed into class C buildings; SCENARIO 3: 80% of class A buildings are transformed into class B buildings and 20% of class B buildings are transformed into class C buildings). For each scenario have been considered the data estimated with the vulnerability model at 50%.

	PINEROLO			TORRE PELLICE			VILLAR PELLICE		
	MIN	MED	MAX	MIN	MED	MAX	MIN	MED	MAX
mitigation	-	-	-	-	-	-	-	-	-
reconstruction	76 MLN€	162 MLN€	298 MLN€	27 MLN€	56 MLN€	102 MLN€	23 MLN€	47 MLN€	87 MLN€
restoration	695 MLN€	862 MLN€	977 MLN€	218 MLN€	258 MLN€	282 MLN€	164 MLN€	185 MLN€	195 MLN€
demolition and rubble removal	1.84 MLN€	3.76 MLN€	6.57 MLN€	0.66 MLN€	1.32 MLN€	2.28 MLN€	0.55 MLN€	1.12 MLN€	1.93 MLN€
health	0.07 MLN€	0,17 MLN€	0.36 MLN€	0.01 MLN€	0.03 MLN€	0.07 MLN€	0.01 MLN€	0.01 MLN€	0.02 MLN€
evacuation	0.20 MLN€	0.21 MLN€	0.23 MLN€	0.19 MLN€	0.19 MLN€	0.20 MLN€	0.18 MLN€	0.19 MLN€	0.19 MLN€
emergency management	252 MLN€	252 MLN€	252 MLN€	252 MLN€	252 MLN€	252 MLN€	252 MLN€	252 MLN€	252 MLN€
TOTAL	1,026 MLN€	1,281 MLN€	1,534 MLN€	498 MLN€	568 MLN€	640 MLN€	439 MLN€	486 MLN€	535 MLN€

Table 9. Costs analyses for each municipality, with reference to minimum, medium and maximum values

In **Table 10** the impact (on the buildings and on the population) and costs of each scenario has been resumed. Also, the percentage of the impact aspects of each hypothesised scenario with reference to the actual case (SCENARIO 0) has been indicated.

		scenario 0	scenario 1		scenario 2		scenario 3	
human losses	death	49	26	53%	21	43%	15	31%
	injuried	107	56	52%	43	40%	30	28%
	homeless	703	384	55%	306	44%	230	33%
buildings losses	uninhabitable	824	510	62%	429	52%	346	42%
	collapsed	324	181	56%	142	44%	101	31%
costs	mitigation	- MLN€	501 MLN€	n.e.	456 MLN€	n.e.	321 MLN€	n.e.
	reconstruction	267 MLN€	155 MLN€	58%	122 MLN€	45%	89 MLN€	33%
	restoration	1,306 MLN€	1,283 MLN€	98%	1,284 MLN€	98%	1,284 MLN€	98%
	demolition and rubble removal	6.20 MLN€	3.55 MLN€	57%	2.76 MLN€	44%	1.99 MLN€	32%
	health	0.22 MLN€	0.11 MLN€	52%	0.08 MLN€	39%	0.06 MLN€	27%
	evacuation	0,58 MLN€	0.56 MLN€	96%	0.56 MLN€	95%	0.55 MLN€	94%
	emergency management	756 MLN€	756 MLN€	100%	756 MLN€	100%	756 MLN€	100%
	TOTAL	**2,221 MLN€**	**2,620 MLN€**	**118%**	**2,553 MLN€**	**115%**	**2,394 MLN€**	**108%**

Table 10. Impact (on the buildings and the population) and costs of each scenario and percentage of the impact aspects of each hypothesised scenario with reference to the actual case (SCENARIO 0)

The objective of this case study is to draw up an adequate response to a seismic emergency. Such a program represents a dynamic tool open to updates and revisions, subject to the identification and definition of multiple criteria articulated on different levels and configured to anticipate, prevent or deal with an earthquake that hits territory and social community

The dominance hierarchy proposed for this case identifies an objective O represented by the *emergency response* and three criteria C_i that specify the contents and meanings of the objective. *Buildings*, *population* and *costs* represent these first-level criteria. Sixteen second-level sub-criteria S_i further characterising the criteria in the higher level are expressed by *strategic buildings*, *cultural heritage*, *residential buildings*, *transport infrastructures*, *industrial plants*, *buildings with social functions*, *dead*, *injured*, *homeless*, *mitigation costs*, *reconstruction costs*, *restoration costs*, *demolition and rubble removal costs*, *health care costs*, *evacuation costs* and *emergency management costs*. The four decision alternatives A_i are described by the four scenarios derived from the two impact models already mentioned.

The first phase of the decision-making process is the composition of a team in which each member involved has specific skills within disciplines related to the strategic resolution of the problem. Based on the semantic scale of Saaty, every opinion expressed by the single decision-maker on an explanatory and simplified questionnaire represents the intensity of dominance to each pairwise comparison between elements belonging to the same hierarchical level. Results are averaged to take account of the multidisciplinary nature of the problem and transferred into the Analytic Hierarchy Process in the form of matrices of pairwise comparisons.

The first matrix of pairwise comparisons contains the criteria *buildings* C_1, *population* C_2 and *costs* C_3 that are compared with each other regarding the objective *emergency response* O. Consequently, the normalised weight of each criterion is calculated.

O	***C₁***	***C₂***	***C₃***
C₁	1	1/5	3
C₂	5	1	6
C₃	1/3	1/6	1

Table 11. Matrix of pairwise comparison of criteria regarding the objective *O*

The second matrix of pairwise comparisons contains the sub-criteria *strategic buildings* S_1, *cultural heritage* S_2, *residential buildings* S_3, *transport infrastructure* S_4, *industrial plants* S_5 and *buildings with social functions* S_6 that are mutually compared regarding the criterion *buildings* C_1. The third matrix of pairwise comparisons contains the sub-criteria *dead* S_7, *injured* S_8 and *homeless* S_9 that are mutually compared regarding the criterion *population* C_2. The fourth matrix of pairwise comparisons contains the sub-criteria *mitigation costs* S_{10}, *reconstruction costs* S_{11}, *restoration costs* S_{12}, *demolition and rubble removal costs* S_{13}, *health care* S_{14}, *evacuation costs* S_{15} and *emergency management costs* S_{16} that are mutually compared regarding the criterion *costs* C_3. Therefore, all the weights are calculated and inserted into specific vectors.

Finally, sixteen matrices of pairwise comparisons are assembled: the alternatives *seismic vulnerability condition 1* A_1, *seismic vulnerability condition 2* A_2, *seismic vulnerability condition 3* A_3 and *seismic vulnerability condition 4* A_4 are compared with each other concerning the various sub-criteria S_i by an automatic algorithm able to assign a value from the semantic scale of Saaty to every ratio. All the matrices so calculated can provide the weight of each alternative with reference to each sub-criterion.

These decision alternatives are subsequently weighted in relation to the criteria *buildings* C_1, *population* C_2, *costs* C_3 and, ultimately, with reference to the objective *emergency response* O.

The decision alternative *seismic vulnerability condition 4* A_4 turns out to be the best compromise between expected losses and economic burden for the community.

O	C_1	C_2	C_3	w_{Ai}
w_{Si}	0,195	0,717	0,088	
A_i				
w_{A1}	0,230	0,045	0,419	0,114
w_{A2}	0,238	0,143	0,126	0,160
w_{A3}	0,252	0,248	0,164	0,242
w_{A4}	0,280	0,563	0,291	0,484

Table 12. Calculation of the weights of the alternatives regarding the objective *O*

4. CONCLUSIONS

CAESAR II is a web-service procedure conceived as a decision support system for public authorities engaged in disaster risk reduction plans. The platform gives the possibility to plan medium and long-term investments and define customised financial support mechanisms and fiscal incentives. The 'seismic impact scenarios' evaluation module estimates the impact on the buildings and the population based on the user's few values on the hazard and, eventually, on the exposure. Simulation results can be further processed through the Multi-Criteria Cost-Benefit Analysis modules to support the comparative evaluation of alternative seismic and energy measures.

This paper described the procedure and the parameters included in each module of the tool and shows an application on three municipalities of the Pedimont region: Pinerolo, Villar Pellice and Torre Pellice. It is shown that CAESAR II requires few and easy data to the user, although it is able to provides a complete package of outcomes useful to support the emergency management and the mitigation decisions.

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