ENSURE PROJECT

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ENSURE E-LERNING TOOL

F31

Methodological framework for an Integrated multi-scale vulnerability and resilience assessment

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Area "Environment"
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Reference reports:

Del. 4.1: Methodological framework for an Integrated multi-scale vulnerability and resilience assessment (chap.1 to 3)

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See references in ENSURE Del4.1

1 The development of the framework for assessing vulnerability and resilience within the Ensure research path

In this section the basic assumptions that constituted the common ground for the project at its beginning are discussed, so as to make explicit what was the starting point, how vulnerability was addressed in the initial submitted proposal. The path traced in the latter have determined to a certain extent the project development and the aspects that have been focused upon.

Since the proposal, ideas and positions regarding vulnerability have evolved and new issues have emerged. The general vision on vulnerability has changed according to innovative literature that has been published in the very last years, after long discussions among partners, and the first applications of the methodological framework to the test case study areas.

Changes and advancement with respect to the initial position taken in the proposal deserve to be shortly discussed, for two good reasons.

On the one hand such an introductory part gives a potential reader the opportunity to understand the project logic without necessarily go through all previous rather long deliverables and reports, on the other to clarify to ourselves the process we went through in the last months and the achievements we deem to have reached collectively.

1.1. The project starting point

The table shown in figure 1.1 represents the starting point of the project and was included in the proposal. It enlightens the recognition of the multifaceted, multidimensional, and multidisciplinary character of vulnerability. In the meantime it represents an interpretation of what is available in literature. In a rather instrumental way, some “schools of thought” had been identified (represented in columns) as they offered definitions and assessment methods that were considered significant (summarized in the first large raw). In the lowest part of the table (the second smaller raw) weaknesses or constraints of the approach followed by each “school of thought” or by some of its relevant scholars are briefly reported.

With respect to the scientific and technical domain, the fundamental contribution of the seismic scientific community is acknowledged, while the tendency to overlap the two concepts of vulnerability and damage is depicted as a weak point.

The second column reports some literature taken from the geographical school, that has always considered vulnerability as a key concept to differentiate between societies’ ability to cope across regions and nations. Vulnerability is clearly linked to sustainability issues, involving qualitative and quantitative aspects of socio-economic development. The major limitation to this kind of otherwise enlightening studies is that they do not provide parameters to measure differences among places (Cutter, 2000).

The third column derives from systems engineering, at the core of industrial risk analysis, where failure and top events are considered as the result of long chains of minor failures, finding their way through latent vulnerable elements in the system. Interesting aspects of this approach relate to the need to consider human and physical elements as strictly interconnected and vulnerability as the result of interaction among various systems and subsystems. Furthermore, the notion of "latent element" introduces the idea of "slow onset" of disasters, any disaster, as mentioned by Lewis (1999, p.161).

Scientific and technical domain	**Geographical and sociological domain**	**Systems Engineering**	**Ecological field**	**Climate change studies**
Aa.Vv., ***Natural disasters and vulnerability analysis.*** Report of expert group, Rep. Undro, July, 1979. *Petrini V **, Overview report on vulnerability assessment** in Proc. of the V International Conference on Seismic Zonation, Nice, France, Oct. 1995, vol. III, pp. 1977-1988*	Dow K., ***Exploring differences in our common future(s): the meaning of vulenrability to global environmental change,*** in Geoforum, vol. 23, n.3, 1992 Ramade F., ***Les catastrophes écologiques*** , McGraw Hill, Paris, 1987 K. Hewitt, ***Regions of risk. A geographical introdu-ction to disasters,*** Longman Singapore, 1997	Giarini O., H. Loubergé, ***La delusione tecnologica. I rendimenti decrescenti della tecnologia e la crisi della crescita economica,*** Mondadori, Milano, 1978. Perrow C., ***Normal accidents Living with high risk technologies,*** Basic Books, New York, 1984. V. Bignell e J. Fortune, ***Understanding systems failures,*** Open University Series, Manchester University Press, 1984. J. Fortune e G. Peters, ***Learning from failure. The systems approach,*** John Wiley &Sons, London, 1995	Gunderson L., C. Holling, ***Panarchy. Understanding transformation in human and natural systems*** Island press, 2002 Holling C.**, *Resilience and stability of ecological systems,*** Annual Review of Ecology and Systematics, vol. 4., 1973	J. Kasperson, R. Kasperson et al., ***The human dimension of global environmental change,*** MIT University Press, 2003. Turner B. et al., ***A framework for vulnerability analysis in sustainability science,*** PNAS, July 8, vol. 100:14, 2003 Folke C., S. Carpenter, ***Resilience and sustainable development: building adaptive capacity in a world of transformation*** , Env. Advisory Council, Ministry of the Env., Sweden, 2002
** Confusion regarding vulnerability and exposure factors should be avoided* ** Concepts of damage and vulnerability should not overlap*	** The vulnerability factor has to be considered in spatial, regional and social terms* ** Vulnerability with respect to economic developoment and underdevelopment*	** Vulnerability as the result of systems interaction* ** Vulnerability compounds physical, organizational, functional factors as well as managment failures*	** Vulnerability as the result of systems interaction* ** Vulnerability compounds physical, organizational, functional factors as well as managment failures*	** Vulnerability as the result of systems interaction* ** Vulnerability compounds physical, organizational, functional factors as well as managment failures*

Figure 1.1: Table showing the different interpretations of vulnerability considered at the beginning of the project

The fourth column refers to ecological approaches, that have recently developed into a more coherent and complete resilience theory, stating that biological and ecological systems have the ability to resist collapse, by enhancing their level of interconnectedness, complexity and diversity. This perspective has entered into risk studies through the scientific groups working on climate change. Turner et al., (2003) state: "Vulnerability rests in a multifaceted coupled system with *connections operating at different spatio-temporal scales* and commonly involving stochastic and non-linear processes".

The last column widens the perspective to the climate change approach, where the notion of vulnerability has evolved significantly in the last years, shading light on fundamental aspects of coping, adaptive capacity of societies and individuals in the face of change. Within the climate change research, the concept of vulnerability blends together the notion of local sensitivity to an "external global stress" and the idea developed within ecological studies that the capacity to resist and adapt to change requires much more than just being able to resist without being damaged. The dynamic adaptation to changes is considered essential not only for ecosystems but also for human systems.

The first need arising from the description of figure 1.1 is in terms of *integration*. A large number of studies and vulnerability assessment proposals have been produced in the last decade in particular, looking at all the facets that are shown in the table. Yet, there is still the need to integrate social vulnerability with other types of vulnerability (economic, cultural, systemic and physical) into a single unified and satisfactory model. What seems to be predominant in the field of vulnerability studies is a net separation between "soft" and "hard" sciences approaches. Here, social vulnerability stands alone, while civil and structural engineers are trying to develop parameters helping judge if and at what conditions a given building or infrastructure would be able to sustain the pressure of an extreme event. Such a separation should be avoided, by considering physical and non-physical aspects as components of the same environment.

The need for integration derives from the principal scope of the project, which is developing a methodology and relative tools to assess the vulnerability of complex natural and built up environments, including rather than excluding the connection with social and economic vulnerabilities. All the dimensions searched by the various disciplines are essential to this main aim, as each provides a piece of the very complex puzzle needed to describe why and how an urban or a regional context responded to an extreme stress, like an earthquake, a flood or a volcanic eruption.

In the historic development of "disaster" studies, such response has been for long attributed to the severity of the stress itself, so that losses and damages were explained with the magnitude of the earthquake, the peak discharge, velocities and height of floods, or the grade on the explosive index for a volcanic eruption. As Weichselgartner and Obersteiner (2002) correctly put it in an article in which they analyzed the past and the future of risk research, a strong need to move from hazard oriented assessments towards more comprehensive approaches putting at the centre the vulnerability and resilience of exposed systems has been generally felt and not only among social scientists, traditionally more attentive to the response capacity of societies and individuals.

Such a strong need is testified not only by the decision to choose vulnerability as one of the leading topics in natural hazards research for the VII FP, but also by its inclusion in even the most technically oriented conferences and in its increasing role in international organisations' documents.

It was clear to the Ensure project since the beginning that the several facets and the articulated interpretations of vulnerability constituted a richness and not a negative aspect: the challenge was therefore how to operationalize such complexity, how to build a method that enables administrations and any other interested stakeholder to carry out a vulnerability assessment providing a comprehensive and the most exhaustive possible picture of elements of strength and weakness in a given environment that could lead to failure or to successful overcoming of “calamities”.

In this regard a couple of further preliminary assumptions should be introduced before proceeding in the description of development and results of the Ensure project.

The first refers to the operational character of the tool that has been developed. Being able to operationalize the extremely rich and articulated interpretations of vulnerability was a key motivation for starting the project. A project milestone was the belief that proposed methodologies and scientific advancement in disaster studies should not be considered only per se, but should also serve the fundamental purpose of risk mitigation and losses reduction. In other words a fundamental question that is being asked along the entire project is how a given interpretation, a given tool, can be used for prevention purposes, how it may enhance the capacities of societies to avoid the most dramatic outcomes of natural extremes and to facilitate recovery. This is also the reason why the project attempts to build on previous knowledge, taking advantage of what has been already accomplished in the field, trying to embed as much as possible available results of risk and vulnerability assessment experiences, in the convincement that risk mitigation is inevitably a multidisciplinary, multi-stakeholders endeavour.

Apart from being operational, the tool that we aimed at developing needs also to be “explanatory” in the sense it should help stakeholders understand why given damages occur, how they can be eventually reduced acting on the different components of the risk function, where R = f (H, V, E, ..) (H being the hazard, V the vulnerability, E the exposure).

In this regard, since the beginning it was considered important to separate the expected damage from vulnerability, intended as a propensity to damage, as the compound of characteristics which make a given environment, a given society more prone than another to be severely affected by an “external” stress. On the other end, vulnerability was kept separated from exposure, the latter defining the elements, systems and populations that are located in a hazardous place. Vulnerability implies how “weak” or “strong”, how “fragile” or “resistant” is the exposed system, element or population. Both have been included in the evaluation framework, though bearing in mind the just mentioned distinction.

Within previous WPs, and particularly the first, devoted to the state of the art on the issue, the problem of definitions have been extensively tackled. Yet, there is the need to make a choice; the Ensure working group hold that a project, to accomplish successfully its task cannot simply remain at a definitional stage, comparing literature proposals; it must advance its own proposal, selecting, deciding on the interpretation that better fits partners’ previous experience, the results of discussions during meetings and the analysis of case studies, both those used for gaining new insight and information and those used as test areas.

Some choices were already implicit in the way the proposal was constructed, other relevant issues emerged during the project development The latter deserve to be considered before moving ahead to the description of the integrated framework.

1.2. Logic connection between the proposed framework and results of previous WPs

The framework that was finally proposed embeds, in fact, some fundamental theoretical and practical aspects searched in previous work packages, which will be discussed in the next paragraphs.

1.2.1. The need to adopt a systemic approach.

The Ensure project adopted systemic approach to vulnerability and resilience assessment. Yet it is important to exactly define what "systemic" actually means. In WP1 and WP2 the various facets of vulnerability (physical, functional, organisational) and the "types" of vulnerability that can be found in literature (social, economic, territorial) have been explored. The framework was conceived as intrinsically systemic, in that various factors, systems and components concur to create vulnerability and resiliency patterns, both individually and through their multiple connections.

More specifically, the framework adopts a systemic approach at three distinct levels:

- first, the vulnerability and resilience of systems is appraised (natural, built environment and social) as it will be further explained.
- second, the term "systemic" has been associated to vulnerabilities that arise as a consequence of systems interdependency and interconnectedness;
- third, the question of how the vulnerability and resilience of different systems interact with one another across temporal and spatial scale has been addressed.

1.2.2. Relationship among different vulnerabilities.

WP2 can be considered a sort of turning point in the project, as it permitted to extensively analyse and search the relationship between different types of vulnerabilities as described in the previous paragraph: between physical and systemic, between physical, systemic and social, between systemic, social, economic, institutional and territorial. The various types of vulnerabilities are not separated one from another, they actually influence each other. For example physical vulnerability is often the result of lack of good norms and regulations of the construction sector to build more resistant structures but it may be as well the result of poor inspection capabilities, of lack of compliance with existing rules and norms, no matter how well advanced they may be. Furthermore, as it was clearly raised during the development of WP2, the various types of relationships constitute an integral part of what has been labelled as "territorial" vulnerability. Referring to the concept of "territory" in Latin terms serves to make clear that the vulnerability of a region, a metropolitan area or an urban centre is much more than just the sum of the vulnerabilities of individual constructions. It has to do with the way regions, cities and their assets and facilities function, perform and are used by people, agencies and organisations.

1.2.3. Vulnerability in time and space.

The fact that vulnerability holds relevant temporal and spatial dimensions is well recognised in literature (while it may be stated that the relationship among different types of vulnerabilities described in WP2, even though well documented, has not been at the core of most investigations on vulnerability until now).

With respect to time, several aspects have been considered. First, it was recognized that vulnerability should be considered as a dynamic rather than static concept: vulnerabilities are shaped over time; vulnerabilities that we are able to assess today are the result of historic processes, shaping cities, communities, infrastructures in a way that builds their potential relationship with hazards. On the other hand, different types of vulnerabilities become more apparent and relevant at different stages of the disastrous event: at the impact, physical vulnerabilities transform into the direct physical damage provoked by the event; during emergency and recovery, systemic, social, institutional, organisational factors determine how slowly or how fast return to normalcy will be possible and at what conditions (for example with respect to the possibility/capability to reduce or increase pre-event vulnerability).

With respect to space, two main considerations constituted the ground for analysis: on the one hand the relevance of space per se, on the other the concept of scale.

As for the spatial dimension per se, we may found in literature since long ago, the distinction between places that are differently affected during the same event: the so called core of the disaster, its “epicentre”, where physical damage is more prominent, and the “periphery” of the event, which is directly and/or indirectly involved in the disaster. In fact, different types of long distance effects can be considered: areas from where help will be provided and to where people will be temporarily evacuated in case of need enter into a new type of relationship with the affected areas. New or increased transportation will be required; a flow of goods, services and resources will reinforce and sometime create new linkages. It would be limiting though to consider only the connections arising for emergency and recovery management purposes: remote areas may be affected by the lack of services, by the interruption of major transportation routes or simply because economic relationships exist with the stricken areas and, some firms will be affected by interruption of activities in the impacted zone.

The fact that different areas from those directly affected by an extreme event must be considered, leads to the need to enlarge the overlook from the “local” scale to larger scales, considering how the “local” is placed within larger economic and administrative regions. Some authors have stated that vulnerability assessment is inevitably local; the Ensure project aims at challenging such position by showing that a more complex approach is required, because some vulnerabilities are local, or are particularly relevant locally in shaping the damage (like physical), but others make sense only when larger scales are considered (see for example systemic or social, when the latter include administrative and institutional vulnerabilities). The same consideration regarding scales becomes relevant when the natural environment vulnerability is considered.

Furthermore, some vulnerabilities are actually evident at larger scale because of the nature of the threat and the intrinsic features of systems. The Eyjafjallajökull eruption in Iceland in spring 2010 showed how vulnerable the aviation system is to the consequences of a volcanic explosion provoking ash clouds endangering flights. A rather “local” event, the consequences of which may nevertheless spread over very large zones; an event that has not provoked significant physical damage, losses or victims, but with a very large impact over transportation system and through the ripple effects in economic activities on the entire aviation industry and on the tourist sector.

Finally the scale at which vulnerabilities are relevant depends on the institutional, economic and social arrangements in the different contexts, making clear that a unique rule for deciding a priori at what scales a certain analysis must be conducted does not make particular sense. The selection of relevant scales will depend on the context, and on the particular way in which different systems are connected and related to each other.

1.2.4. Vulnerability and resilience

In the project proposal, vulnerability was the main topic to be searched, with little consideration of other definitions that were considered in WP1 as part of the state of the art. Nevertheless during the project development, a consensus among partners was achieved regarding the need to make explicit the relevance of resilience. For the detailed discussion regarding the differences and overlapping meanings of vulnerability and resilience, it is worth to refer to the deliverables resulting from WP2; what is important here is to make clear how resilience entered in the Ensure project and how it is considered in the proposed integrated framework that will be described in subsequent sections of this report.

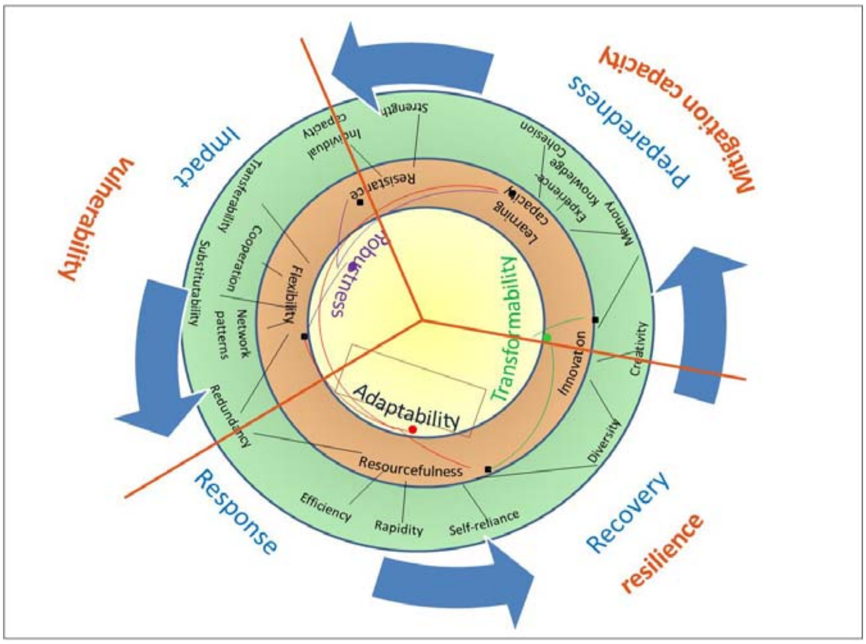


Figure 1.2: Diagram showing the conceptualization of vulnerability, mitigation capacity and resilience in the Ensure project

The main output of long discussions, readings and reflection is that resilience cannot be simply considered as the “flip-side” of vulnerability. In other terms, a resilient community is not just a community manifesting low levels of vulnerability. A community may be even vulnerable, particularly as far as physical vulnerability is concerned, and still be resilient in the aftermath of a disaster and manifest a high capacity to react and recover effectively. Also because what seems to emerge in literature is a different focus of vulnerability and resilience studies: the first are more oriented towards the identification of weaknesses, fragilities that make a given territory, a given community, a given country unable to resist the stress provoked by an “external” source. Looking at resilience we appreciate the capacities to react, to overcome the problems created by the same existence of vulnerabilities and to “bounce back” despite damages and disruption to ordinary life. Resilience entails the capacity to recover effectively, transforming the damage and losses into opportunities for a different territorial and environmental setting, in such a way that pre-event vulnerabilities will be reduced and the resulting societal, urban, and regional patterns are healthier and safer than before the event impact. Authors like Handmer and Dovers, 1997 and Norris et al, 2008 have rejected the idea that a resilient community or a resilient city is simply a community or a city that is able to bounce back to pre-event conditions. Sometimes getting back to the exact pre-event conditions is just the opposite of resilience, particularly when high level of vulnerabilities characterized that condition. Instead, resilience has to do with the capacity to adapt to changes, to manage creatively uncertainty, to find resources, both material and immaterial, to face the consequences of a disaster.

Resilience is perhaps an even more dynamic concept than vulnerability, in that it addresses the capacities to innovate and the ability to strategically orient complex processes like those implied by emergency, recovery and reconstruction.

As just mentioned, literature on resilience is as vast as that on vulnerability. Also in this case the Ensure project needed to choose a direction of work, an interpretation cutting across the various definitions and alternative views available so as to be able to include resilience in the integrated framework.

The diagram in figure 1.2, represents the interpretation provided by the project.

2 Methodological approach and framework description

The framework developed within WP4 represents the final output of a long process of reflection, discussions among partners, and was shared with external experts in a workshop hold before the 2010 summer (see second annex). It is an attempt to accommodate the various relevant aspects that have been shortly described insofar and which constituted the results of previous WPs. It also has the ambition to comprise some of the knowledge and information about resilience and vulnerability that has emerged from literature and previous projects.

The need to conceptualize the tools to be used in assessing vulnerability and resilience is strongly felt by the Ensure team. The large majority of articles and previous work simply couple theoretical thinking about the two (or more related) concepts and some applications where indicators and parameters are used (Eriksen and Kelly, 2007). Often it is not clear how the selected indicators are actually linked or derived from the most theoretical part. The associated risk is to use indicators that are taken for granted without further investigation that instead would be required. For example most studies consider the elderly more vulnerable, without making distinction within this rather large and too generically defined social group; in some instances (see Handmer, 2003), the elderly has performed much better than the younger generations, making evident that generalizations cannot be accepted without further analysis and that there is the need to relate indicators to specific spatial and temporal contexts before any convincing appraisal can be carried out.

A similar need had emerged at a certain stage within the field of sustainability, and the 90s were marked by a rather consistent work on methodologies to identify appropriate parameters and criteria for judging whether or not the latter were consistent enough and useful to understand to what extent a region, a city, a country were actually getting closer to a condition of sustainable development (see Mac Laren, 1996; Winograd and Farrow, and, Winograd, 2007). It is odd for us to see that until now at least, few articles have appeared in the same vein in the vulnerability and resilience arena, even though we are convinced that a season of a similar outbreak of studies on the validity of indicators chosen to assess vulnerability will open. There will be a strong need for such studies as vulnerability assessments will be increasingly required by legislation (as in the case of the Flood Directive) and will constitute basis to distribute resources for mitigation.

In summary, three answers can be provided for the legitimate question: why and what for a framework for vulnerability and resilience assessment.

First, within the framework the goals to be accomplished carrying out the assessment must be established. What for? How the assessment may help in finding ways to mitigate risk and better prepare for facing the consequences of events the residual risk of which cannot be eliminated?

Second, to “find the right place” for each indicator that is in any case used in currently adopted vulnerability assessment tools. Within the framework the questions we try to answer with each selected indicator have to be made explicit. In this way not only the questions at stake - but also the extent to which proposed indicators and their relative measures are actually providing a good proxy or synthesis of corresponding features and processes- become clear. In other words, are the proposed indicators (sometime driven by existing data) are actually representing the vulnerability aspect that we need to address?

Third, and more general answer: the framework represents a model that attempts to capture the most relevant features of vulnerability so as to permit to draw a satisfactory picture of a given place and community in terms of their expected response to the impact of an extreme natural event. In this respect, the framework shares with any other model the fate of being a selection of aspects that are considered as particularly relevant and representative of a given reality. Inevitably many things have to be left out of the model, which by definition cannot and should not be clone of reality, but a mean to make sense out of what is observed in the “real” world. As Slobodkin (1994, quoted in Bell and Morse, 2008) puts it:

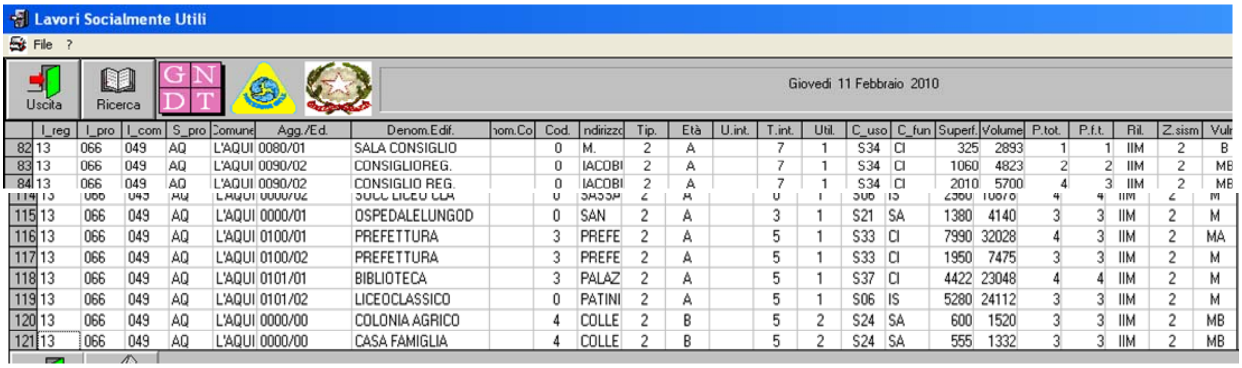
«Essentially all science is the study of either very small bits of reality or simplified surrogates of complex whole systems. How we simplify can be critical. Careless simplification leads to misleading simplistic conclusions».

2.1 Main Ensure objectives and methodological procedure

The Ensure project had set ahead two main objectives, one more general and theoretical, the second more specific.

The more general objective was to provide an interpretation of the relationship between vulnerability and related concepts (resilience, adaptation, coping capacity, etc.) within a framework strongly finalized towards prevention, following the rationale described in the previous paragraph. The framework must provide a sort of guideline to assess vulnerability before an even strikes, helping decision makers and even lay citizens take appropriate mitigation and anticipatory measures. In other words we are not satisfied with tools that permit only ex-post analysis, leading to a detailed and well developed description of what happened in a given area stricken by an extreme event, we wished to be able identify the weaknesses and fragility that combined with the severity of an event may lead in the future to damage and losses.

An example may clarify what is meant here. In the years 2001-2002 a rather interesting project was carried out by the Italian Ministry of Labour. In the context of social works for unemployed professionals with a master in architecture and civil engineering, it was decided to carry out an assessment of the seismic vulnerability of all public facilities (like schools, municipality buildings, governmental offices etc.) in Southern Italian regions. The final results is rather impressive, as there exist now records with fundamental data and assessments of the physical vulnerability to earthquakes of all facilities where a large number of people can be expected at the time of a seismic impact or that are critical to manage the emergency.



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114	13	066	049	AQ	L'AQUI	[illegible]	[illegible]		[illegible]	[illegible]	2	A		[illegible]	1	S06	IS	[illegible]	[illegible]	4	4	IIM	2	M
115	13	066	049	AQ	L'AQUI	0000/01	OSPEDALELUNGOD		0	SAN	2	A		3	1	S21	SA	1380	4140	3	3	IIM	2	M
116	13	066	049	AQ	L'AQUI	0100/01	PREFETTURA		3	PREFE	2	A		5	1	S33	CI	7990	32028	4	3	IIM	2	MA
117	13	066	049	AQ	L'AQUI	0100/02	PREFETTURA		3	PREFE	2	A		5	1	S33	CI	1950	7475	3	3	IIM	2	M
118	13	066	049	AQ	L'AQUI	0101/01	BIBLIOTECA		3	PALAZ	2	A		5	1	S37	CI	4422	23048	4	4	IIM	2	M
119	13	066	049	AQ	L'AQUI	0101/02	LICEOCLASSICO		0	PATINI	2	A		5	1	S06	IS	5280	24112	3	3	IIM	2	M
120	13	066	049	AQ	L'AQUI	0000/00	COLONIA AGRICO		4	COLLE	2	B		5	2	S24	SA	600	1520	3	3	IIM	2	MB
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Figure 2.1: Detail from vulnerability assessment records for the city of L'Aquila

Furthermore skilled professionals were trained in seismic construction, and were provided the capabilities to identify key vulnerability factors in buildings. L'Aquila was among the cities where the assessment was accomplished: several public buildings that collapsed or were severely damaged during the 6 May 2009 earthquake had been the object of analysis and ranked as very vulnerable (see figure 2). Were this information been used by authorities either to reinforce those structures or at least to check their residual resistance capacities after the first shocks recorded months before the main one, perhaps many lives could have been saved. Clearly what is apparent in this example is the potential utility of vulnerability assessments in very practical terms, but also the need to go beyond physical vulnerability to address the various deficiencies of complex social and environmental systems, that may lead to lack of compliance with norms and regulations, or to the poor management of information that holds the potential of saving lives and prevent the most severe losses.

Within the project the result corresponding to this more general objective is the integrated framework shown in figures 2.4 and 2.5 and described in detail in paragraphs 2.2 and 2.3.

The more specific goal of Ensure was to advance in the most "established" field of vulnerability assessment, providing an updated picture of what is already available in literature, in previous studies, and in applications worldwide. We may count already on a good number of proposals concerning vulnerability indicators, parameters and measures, related to physical, systemic and social aspects. Those have been analysed and a selection of what seemed to the working group as most advanced or appropriate was proposed as part of the tool for vulnerability assessment. The result of this more specific goal can be seen in the individual matrices that are part of the integrated framework, as described in paragraphs 2.3 and 2.4.

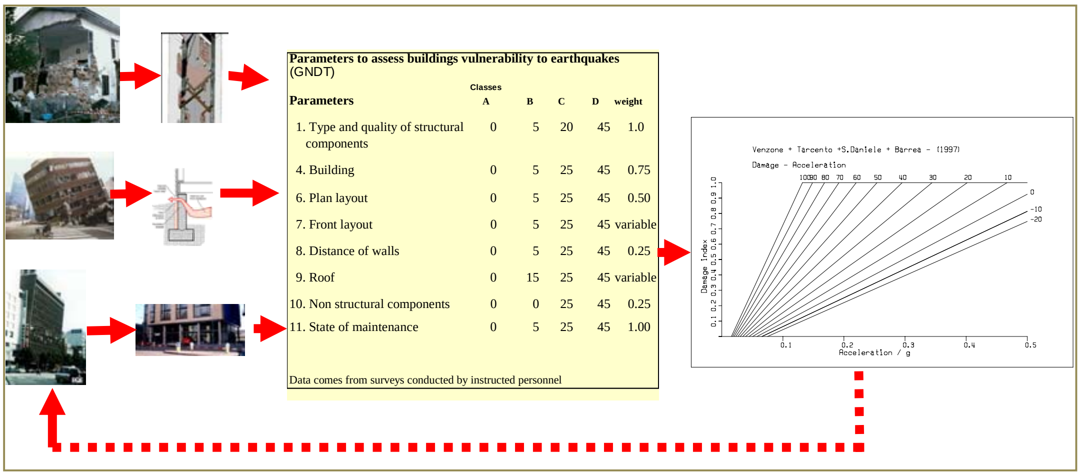

Figure 2.2: Methodological process for eliciting physical vulnerability parameters in the seismic case

From a methodological point of view, the seismic case was selected as a reference example. In the latter in fact, methods for assessing buildings vulnerability to ground accelerations provoked by seismic waves at a given site have been developed for at least the last thirty year, producing results that are reasonably shared by the scientific community. From a theoretical perspective, the methodological path that has been followed is of particular importance to us (figure 3). It can be conceived as a four step path organised as follows:

– First damages have been surveyed and analysed to identify what were the mechanisms leading to specific failure patterns. Surveyed damage buildings are now part of a huge database comprising thousands of cases.
– The large number of surveyed buildings allows for recognising recurrent failure patterns that are related to structural and non-structural characteristics that can be considered as an integral part of the failure mechanism, being the other relevant components the seismic input. Long years of study and discussions have led to the selection of a restricted number of indicators, summarizing the fundamental aspects that can be deemed as responsible for a given structural response, like shear resistance, plan and facade regularity. Those indicators serve as references to check the capacity of any regular structure to withstand the stress provoked by seismic shocks.
– Then the picture provided by the vulnerability assessment tool must be compared to the real damage when the latter unfortunately occurs during an earthquake. Fragility or vulnerability curves represent the result of the procedure correlating the level of damage to the earthquake intensity or acceleration as can be seen in figure 3: to moderate levels of stress resistant buildings suffer no or minor damage while vulnerable ones are already significantly affected. At increasing levels of stress, vulnerable buildings collapse, while the least vulnerable still show residual resistance.

– The last step requires refining vulnerability assessment tools and indicators any time new information or understanding of structural seismic response is available after damage surveyed in a real event.

Ideally this methodological path can be followed also as far as the vulnerability of structures to other types of stress (floods, landslides, fire, etc.) is concerned and experimental fragility curves are being proposed. Such methodological path can be seen as more general, not only for physical damage and physical vulnerability but as having a more general validity. The analysis of damage occurred in a severe event should lead to identify what "part" of the damage can be attributed to the weakness of the affected system, to its inherent characteristics, making it more prone to suffer damage with respect to similar cases in the same event or in similar situations.

By this we mean that also failures that cannot be labelled as physical structural performance can be analysed adopting a similar approach. What would be needed is a detailed reporting of malfunctioning in services, utilities, and critical infrastructures, the cause of which is due in part to the physical stress, but also (sometimes mainly) to the complex interaction of components and systems.

In this regard it can be said that the proposed framework may be beneficial not only for conducting vulnerability assessment but also as a guidance to produce better damage accounts than has been the case until today. Some types of damage (in particular indirect, secondary, induced) have been scarcely reported, while the attention of authorities go to the costs of reconstruction ignoring the ripple economic and systemic effects that may reverberate across regions and communities. Those damages, generally underreported, may be nevertheless very relevant in explaining subsequent patterns of vulnerability long after the hazard impact and in areas apparently remote from those actually hit.

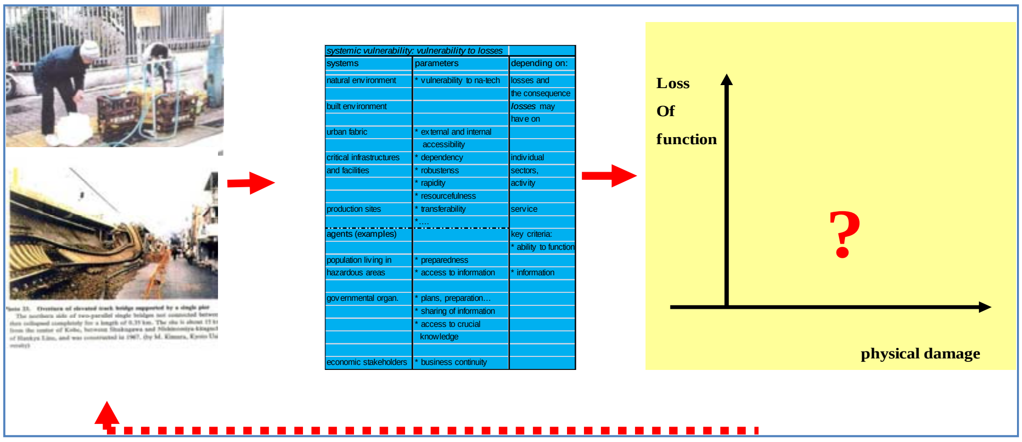

Figure 2.3: *Methodological process for eliciting systemic vulnerability*

The goals that have been set for the project entail a rather high complexity, representing a challenging endeavour for the project. It is therefore hard to imagine that they can be accomplished in a single phase or following a strictly top down approach. Instead a more pragmatic procedure has been adopted: a mixed top-down and bottom-up path have been followed. Several case studies have been analysed in the previous WPs of the project with the idea of extracting significant aspects and concepts that could make part of a framework with a more general validity (that is not strictly linked to the individual case study); on the other hand once developed the model has been applied to the test case study areas, so as to get feedback regarding what had to be changed and how in the framework.

The present report has been re-written at least a couple of times, to include “lessons learnt” from the initial application of the method. Such an iterative process has been followed also by other scholars pursuing similar objectives, representing for us a “relieving” reference (see Polsky et al., 2007).

2.2. Description of framework for integrated multiscale assessment of vulnerability and resilience to natural hazards

The framework responds to the requirement of general theoretical advancement that was one of the two main objectives of the project. Combining the different pieces of the puzzle (or what can be recognised as such) into a methodological framework comprising the various aspects that were deemed important by the working group is by no mean a minor result, even though we are aware of the long way ahead before all parts of it will be actually operationalized in a satisfactory way.

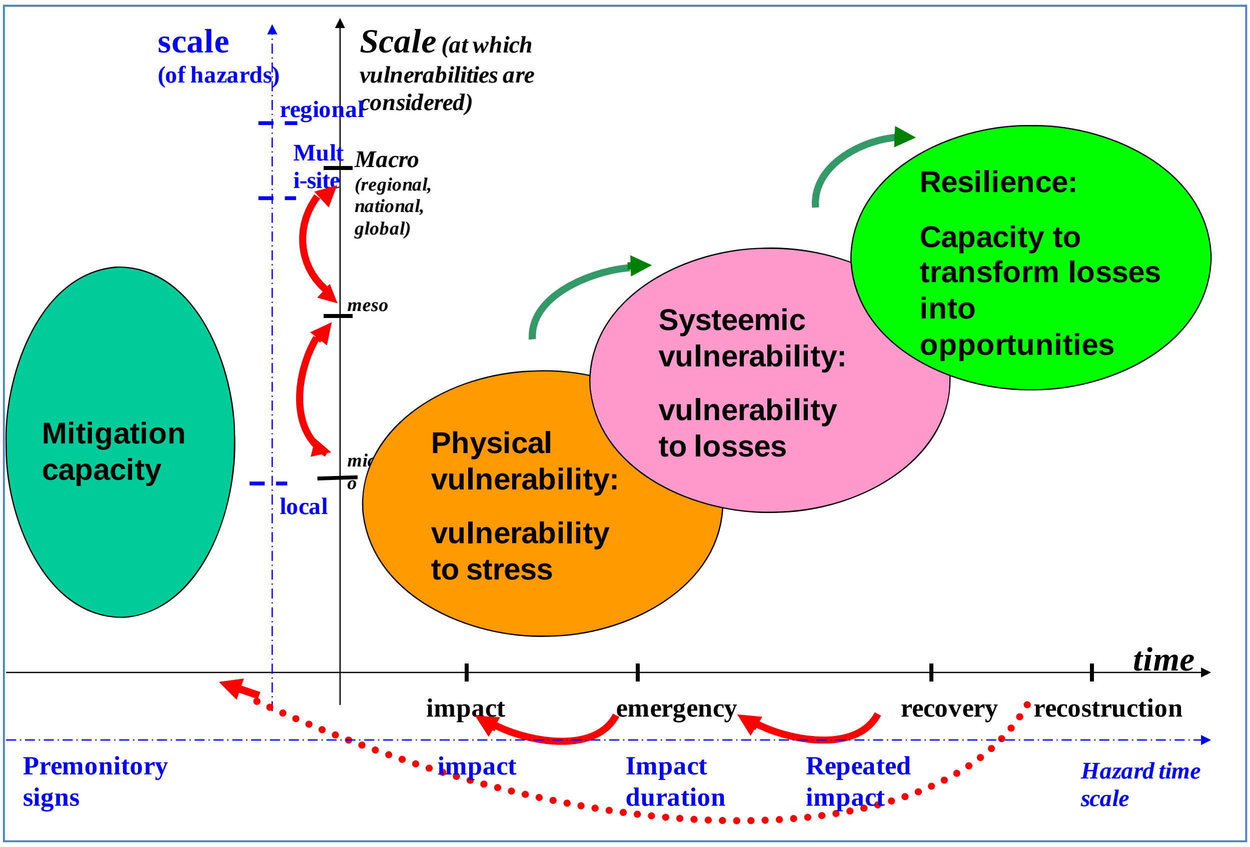

Figure 2.4: General representation of the integrated framework to assess vulnerability and resilience across time and scales

In figure 2.4 the framework is shown: as it can be clearly seen it is deployed over a plan where both the spatial and the temporal dimensions are evidenced. As for the spatial one, the scales at which both hazards and vulnerabilities should be appraised are represented in two distinct axes.

The reason is that not necessarily the scale at which hazards have to be analysed correspond to the scale at which the different types of vulnerabilities must be considered. For example, physical vulnerabilities are mainly addressed at the local scale, as the intrinsic fragility of structures, infrastructures, and people must be looked at in detail at the local scale. What appears at larger scale is the result of such analysis, in terms of comparison among places. As already mentioned, systemic vulnerability can be appropriately considered only linking the local to the large scale (provincial or county level to the regional an sometimes above regional). When it comes to consider the capabilities to recover effectively in a resilient fashion, all scales must be considered: what will be reconstructed is ultimately what has been locally damaged, but the needed resources cut across all levels of government and depend also on the type and strength of relationships among the affected places and a much wider region.

As for the temporal dimension, again, timing of hazards and vulnerabilities may differ: for example, the possibility of new occurrences of extreme events within a short period, when recovery is still going on, must be accounted for.

In the figure, it is shown how the various vulnerabilities and resilience are considered with respect to the phases of the disaster cycle. Before the impact, that is when a sufficiently long time has passed since the last big event, the mitigation capacities are considered. Rose (2004) suggests that it is more correct to talk about mitigation capacities in the period before the hazard impact, while resilience should define more appropriately capacity to recover from an extreme event. This is nevertheless a matter of deciding the most suitable definition; what is actually relevant here is the attempt to understand whether or not conditions to enhance coping capacity and resistance of a complex system exist or not and how they are manifested. At the impact, instead, the physical vulnerabilities play the major role: the direct physical damage that can be accounted for are strongly correlated on the one hand to the severity of the hazard, on the other to the level of physical fragility of artefacts and constructions. As the time from the impact passes, other forms of vulnerability gain relevance and, in particular during the emergency phase, precisely systemic vulnerabilities. Those express the response capacity (or lack of) not to the direct extreme event impact but rather the consequences of the latter, to the impairment in crucial systems and their components provoked by the physical damage. Finally, considering the time of reconstruction and recovery, resilience gain prominence: here again the response is not to the stress, but to the longer term induced, indirect, secondary effects it has produced. What we want to measure here is not merely a response capacity, but rather whether or not systems is able to recover by reducing pre-event vulnerabilities, to learn from the weaknesses that the event has revealed and to transform reconstruction into an opportunity to build and develop a better, safer and healthier place to live.

The red and green arrows represent the various connections and links that exist among the different types of vulnerability and resilience, in space and time. Those will be tackled in sections ahead.

2.3. Short description of the set of matrices comprising the framework

In each matrix the vulnerability indicators are proposed, taken from literature, ongoing and past research carried out by the Ensure team.

In the first set of matrices, the capacity to mitigate is addressed; this means concretely that the vulnerability of the natural environment, the characteristics of the hazard are known, mapped and monitored appropriately. With respect to the vulnerability of objects and artefacts what is checked here is whether or not vulnerability assessment has been carried out and taken into consideration in planning and risk prevention policies; in the case of critical facilities, not only the awareness of systemic vulnerability is addressed but also the capacity to reduce it in ordinary maintenance programs should be envisaged and new facilities or replacement of existing ones must be considered. With respect to agents, their awareness of existing threats and fragilities is assessed as well as their willingness/capacity to address them when the hazard does not seem to impede in any particular fashion and time has passed since the last catastrophic event.

In the second set of matrices, the physical propensity to damage of the natural environment, objects, critical facilities and people is assessed. All factors that may increase the potential damage are considered, including the possibility of enchained effects, both between natural hazards (like for example landslides triggered by earthquakes) or between natural and vulnerable built systems (like for example na-tech).

In the third set of matrices, the potential reaction to first level losses is addressed: secondary effects in the natural environment, like for instance lahars or debris flows consequent to fires denudating entire slopes is considered. With respect to artefacts, urban areas and critical facilities, the capacity to keep functioning despite some level of physical damage is evaluated, considering the interdependencies among systems and among components of vital systems. With respect to agents, the capacity to manage emergencies, to endure in time of limited facilities and restricted access to resources and markets is considered.

Finally, in the last set of matrices, the recovery potential is appraised. As for the natural environment the ecological resilience is referred to, particularly for those hazards like fire or drought that may significantly disrupt the natural environment itself with permanent damage. For buildings and cities, the capacity to embed the lessons learnt in the disaster while reconstructing artefacts and places is evaluated, as well as the capacity to couple the physical reconstruction with the symbolic one, accompanying the healing process of a

traumatized social system.

Regarding the latter, access to resources for reconstruction, availability of good administrative procedures, fast delivery of compensation are elements that seemed particularly relevant to recover in a satisfactory way. Fast access to compensation need not to be taken as an isolated indicator: the capacity to couple it to the control of how reconstruction will proceed and to what extent pre event vulnerabilities will be addressed is equally, if not more, important.

In this respect, but as a general consideration for all set of matrices, indicators should not be considered as standing alone. Some must be appraised in conjunction with others in order to draw a vulnerability and resilience assessment of a given area and environment.

Each matrix is in its turn divided in four parts (see figure 2.6).

1. The first relates to the natural environment. Indicators that can be found in this part respond to three main questions:

    a. Is the available knowledge, including its representation in maps, tables, and other forms, sufficient and sufficiently taken into account for decisions at each stage of the disaster event?

    b. Are enchained natural hazards considered in the hazard assessment. It should be noted that this and the previous question are not aimed at introducing surreptitiously hazard aspects into vulnerability analysis. Instead the point that is made here is that a given system is less vulnerable if hazards are well known, monitored and early warning systems are put in place when relevant.

    c. Finally there may be elements in ecosystems and in environmental settings that are particularly vulnerable to the consequence of an extreme event (this is particularly true for forest fires and droughts) or to the mitigation measures which are taken to protect some other systems (for example lava diverting systems to protect buildings and infrastructures that may lead to the destructions of forests).

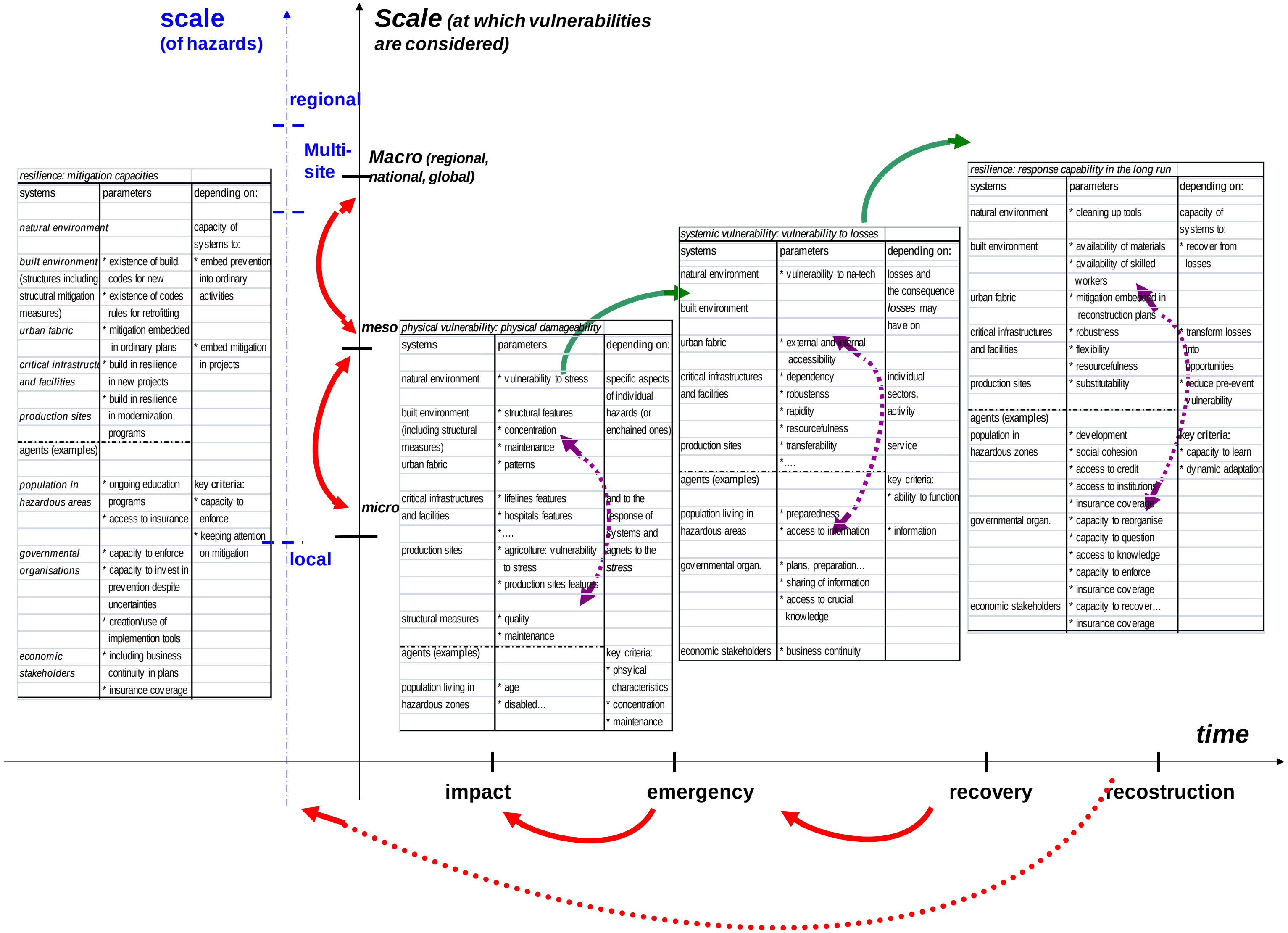

Figure 2.5: Ellipsoid translated into a set of matrices

2. The second relates to the built environment. In this part of matrices the following aspects are considered:

    d. Whether or not buildings have been built according to specific norms or to state of the art considering previous lessons learnt from past disasters. On the other hand, the position of buildings within hazardous zones has to be assessed. Clearly this is more the case of an “exposure” rather than a vulnerability factor.

    e. For public facilities, the question is if there are further vulnerability factors that must be accounted for, regarding internal machinery, assets, tools that are fundamental for the functioning of a given service.

3. As for the urban fabric, the point at stake is whether there are some vulnerability factors arising at the urban scale, going beyond the simple sum of the vulnerability of individual buildings and infrastructures, and which relate to the shape of the urban patterns, to the relationship between open and built spaces and with accessibility.The third regards critical facilities and production sites that are considered separately because of their importance in guaranteeing the survival of an urban system and for the well being of the potentially affected community. From a theoretical point of view they may be seen in conjunction with the vulnerability of the built environment, but from a practical and strategic perspective it makes sense to separate them. Critical facilities gain their prominence when systemic vulnerability must be appraised.

4. The last part is devoted to the assessment of social systems and economic stakeholders’ vulnerability. Social systems’ and agents’ vulnerability has been considered with respect to three main sub-groups:

    f. Individuals vulnerability, related to the level of awareness and preparedness to both mitigate and face the consequences of an external stress;

    g. Institutions’ vulnerability, in which all agencies and organisations that may have a key role in both disaster management and disaster avoidance are considered.

    h. Finally economic stakeholders, who, similarly to institutions, may have a leading role in shaping vulnerability, in creating coping capacity mechanisms.

    i. Finally economic stakeholders, who, similarly to institutions, may have a leading role in shaping vulnerability, in creating coping capacity mechanisms.

System	Component	Aspect	Aspect parameter	Criteria for assessment	Comments/ case study
Natural environment	natural hazards	existence and quality of mapping and monitoring	Specific parameters to permit assessment of the aspects that have been identified as relevant	Criteria may range from binary (yes/no) to degree (corresponding to judgements) or to more physical measures (for example related to time needed for ecosystems to recover)	Specific parameters to permit assessment of the aspects that have been identified as relevant
	enchained events	assessment of hazards triggered by other hazards			
	ecosystems	fragility to hazards and to mitigation measures			
Built environment	residential buildings	existence and compliance with codes and land use planning regulations	Specific parameters translating into measurable factors the aspect to be assessed	Criteria for multiple measurement modality are provided; they also depend on the scale at which the assessment is carried out	Building codes exist for some hazards (particularly seismic) and not for others; nevertheless research in the field of resistance assessment to various types of stress has evolved in the last decades
	public facilities	existence of vulnerability assessment and their consideration on mitigation strategies or in emergency plans			
Infrastructure and production site	critical facilities	existence of strategies addressing the interdependency and the functioning of critical facilities under extreme conditions	Parameters to specify conditions at which crucial lifelines and utilities cna keep functioning are provided, as well as to address the potential for na-tech	Criteria for assessment are provided; proposed criteria reflect the need to address the interaction across spatial scales of such facilities	Critical facilities and production sites are clearly part of the built environment. Nevertheless a specific group of rows have been dedicated to them because of their relevance.
	production facilities	existence of plans and procedures to maintain production in safe conditions given the possibility of an extreme event			
Social system (agents)	people/ individuals	weaknesses versus preparedness of individuals	Most of those are qualitative parameters to assess the general level of preparedness and recovery capacity (or lack of) to traumas and discomfort provoked by potential disasters	Criteria for evaluating the parameters are provided, taking into consideration the different spatial scales at which individuals, institutions and economic agents act	Whilst the previous groups of systems relate more to the "physical environment", clearly this one embeds the results of decades of social sciences research in the field of risk and disasters studies
	community and institutions	weaknesses versus preparedness of organisations and institutions			
	economic stakeholders	preparedness and recovery capacity (or lack of) economic stakeholders			

Figure 2.6 Set of matrices comprising the assessment framework

With the rather broad term of social vulnerability we address several components of societal coping capacity, ranging from individuals, to social groups, to communities, to organisations. Social vulnerability can be both physical and systemic, as people can be physically injured and harmed, but are also vulnerable to the lack of basic services, to the new conditions required by evacuation, temporary sheltering, et. In the same vein, organisations, like for example civil protection, can be harmed in their assets and personnel, or diminished in their capacity to react because of a variety of systemic failures, including the lack of coordination and collaboration among different agencies, problems in communication, problems in deciding about matters that hold significant juridical and moral challenges. An important distinction that has been introduced in WP2 is between social and human capital, intending that vulnerability of both should be appraised. For neither of these concepts universally accepted definitions can be found. Basically, we can assume that human capital refers to skills, dexterity (physical, intellectual, psychological) and judgement capacity, which may be lost during an extreme event; on the other side, social capital refers to the value of social networks affecting the productivity and capability of individuals and groups to cope and recover from an extreme event.

With economic vulnerability we refer to the response that economic sectors are able (or unable) to provide in the aftermath of an extreme event. Also in the case of economic vulnerability, both physical and systemic aspects must be considered. Economic assets can be physically damaged, but economic activities are clearly extremely vulnerable to interruption of transportation services, to deficient lifelines, etc.... Days without the possibility to work, to receive products or to send them to destination constitute a net damage measurable in monetary terms.

As can be seen in figure 2.6, each matrix is organised in columns:

- The first identifies the system to be assessed;
- The second identifies the components of the systems;
- The third clarifies the aspects that have to be considered in the choice of the indicator/parameter that may better respond to the question, shown in the third column;
- The fourth and the fifth determine how indicators/parameters can be measured and assessed, upon what criteria and using which tools (maps, diagrams, scores).
- In the last column references are made either to a case study that was analysed in detail or to several cases that are relevant to the specific indicator at stake.

It has been decided to produce a set of matrices for each "hazard" (see figures 9 to 13). Methodologically it seemed useful to check to what extent the individual parameters in each set of matrices had to be differentiated upon the expected threat. In fact not only the physical response to the stress is so to say dependant on the hazard type of forces and/or pressures exerted on structures. Each hazard may vary as far as duration of onset (sudden or creeping), location (point or area- shaped) are considered: those aspects must be taken into consideration defining monitoring and mapping systems as well as specific mitigation measures to be taken before and after the impact.

This does not mean that a multi-risk perspective is not considered. Actually it is pursued in two ways. First, in each set of matrices the possibility of enchained events (hazards triggering other natural or technological threats) is fully appraised. Second, in applications (see WP5), a set of matrices related to the hazard threatening a given area can be used in combination. Results of applications to the test case studies confirmed that not only the physical vulnerability matrix is somehow "hazard specific". An area, a community can be for example very well equipped and prepared for some events, while underestimate other hazards to which it is exposed.

2.4. Working with vulnerability and resilience indicators

As already mentioned, few studies have attempted insofar to clarify how different types of vulnerabilities should be accommodated in one integrated study and what process should lead to the identification of suitable indicators. Studies in this regard can be found regarding sustainability indicators and reports for countries or urban areas (see in particular MacLaren1996; Winograd and Farrow, n.d.). Those studies discuss the criteria that should drive any effort to develop sustainability indicators. The latter are rather useful for the present project, as the concept of sustainability is as difficult to measure as is vulnerability. Both require to capture the complex interrelationship among different systems which interact at various spatio-temporal scales, in a parallel and even in a cross cutting fashion.

One important difference seems to distinguish vulnerability from sustainability: while in the latter the verification process is extremely difficult, as it requires confronting the state and the process toward sustainability with impacts that cannot be fully envisaged, in the case of vulnerability indicators, the latter can be confronted once an extreme event occurs with actual damages. This is perhaps more true for physical, some kind of systemic, social and economic vulnerabilities than for others, in particular resilience parameters. At least in principle, though, it is possible to compare the vulnerability assessed before the event and the damage occurring afterwards as well as to compare the expected response capacity with the way an actual event has been managed. In the meantime the establishment of good vulnerability indicators permits to enlighten aspects and types of losses that should be considered and checked in any event aftermath, so as to gain a reference value against which the validity of vulnerability indicators and of key measures can be evaluated.

This means that the distinction between different kinds of vulnerability should encourage estimating coherently damages, distinguished among physical damage to buildings and infrastructures, damage to economic assets and activities, losses to human and social capital, secondary consequences in terms of functional failure of fundamental services an activities.

On the other end, studies which are currently addressing the issue of how to find the best fit vulnerability indicators are being developed in the climate change community (see for example Eriksen and Kelly, 2007, Adger et al., 2004). Those studies are particularly enlightening in that they drive our attention to the need to capture complex processes and relations among indicators, and not just provide a state diagnostic, which may be limited in relevance as far as potential usefulness by end users and decision makers.

Therefore, before entering into the discussion of the validity of each individual parameter that has been selected, the criteria that have driven the same choice should be discussed.

The latter can be synthetized according to the diagram shown in figure 2.7. Criteria are grouped along three main axes:

- On the x axe, the inherent characteristics of indicators are addressed;

– On the y axe, the characteristics of the data to be used to assess the indicators value in a given place are shown;
– On the z axe, the usefulness of indicators is appraised.

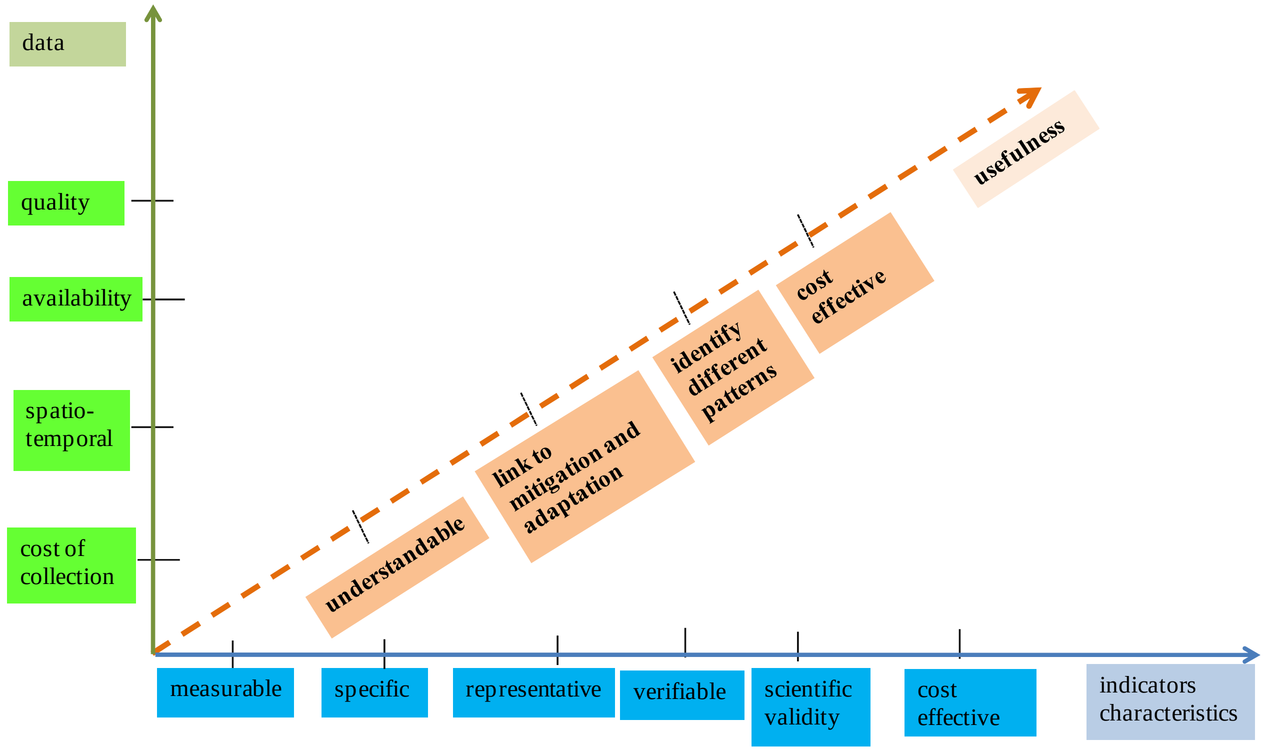

Figure 2.7: Criteria to identify and select vulnerability indicators

a. With respect to the inherent indicators characteristics, the following have been granted importance in the literature.

– **Measurability**. We are aware from the work that has been carried out in previous WPs that the complexity of phenomena and societal response to natural calamities cannot be fully grasped just using indicators. In the meantime we believe the latter should be intended as proxies of complex aspects and systems characteristics, so as to be able achieve some important goals. The first is comparability among places and communities, to establish priorities and identify key specificities as well as constant features; the second is the possibility to assess, though with large uncertainties, to what extent given policies and strategies are able to move the system towards increasing or decreasing vulnerability levels. By measurability we do not intend only quantitative measures, but also qualitative, which allow to construct some sort of qualitative grouping of values referring to a benchmark or value established by previous research and findings.
– **Specificity.** Indicators should address as much as possible specific vulnerability aspects rather than generic features that do not help in understanding what makes a given area or a given society more or less prone to suffer the consequences of an external stress. As mentioned in a previous deliverable, for example, economic disadvantage is not per se a measure of vulnerability: it becomes such when we are able to demonstrate how a poor

response and low coping capacity is linked to limited access to financial resources and to services.

- **Representativeness**. Indicators should represent a wide set of cases and situations rather than being constructed after each individual case. This requires that indicators are chosen after they have been recognised as constant elements in several similar cases or across scales and regions or across different risks. Indicators cannot be too tailored to the specific case at stake, even though calibration procedures must be carried out; on the other hand, they must guarantee a minimal level of generalization, to be supported by statistical analysis. While this requirement can be met for physical vulnerability, it is far more complicated and thus constitutes more an aim than an established feature, for the less investigated aspects, like social, systemic, and economic.
- As for **verifiability**, as mentioned at the beginning of this paragraph, there is the need to tune the search of correlations between indicators and surveyed damages after disasters, so as to be able to improve the capacity of indicators to elicit those systems characteristics that seem to be the root causes of poor or mediocre response.
- The features mentioned above can be all mentioned as part of **scientific validity**, particularly when we talk about measurability and verifiability. In the meantime, to be scientific, indicators should meet the agreement of a large scientific community, should strive toward objectivity, even though we are all aware about the large room for subjective and even arbitrary judgement that is inevitably involved in any complex environmental assessment requiring to bridge among natural and human systems. Nevertheless, what can be required is that indicators be chosen as rigorously as possible, be framed in a transparent conceptual framework linking the selected indicators to the notion that must be evaluated (in our case vulnerabilities).

b. With respect to data characteristics, the following criteria should be met, while looking for vulnerability indicators:

- **Data quality** is an important requirement, even though many times only poor quality data are available, particularly for indicators that are not part of a long and well established tradition. In this case, perhaps it can be recommended that at least the quality of data will be made explicit so that assessors can judge to what extent the related indicator can be considered reliable. In fact, in designing a general framework, it is rather hard to dismiss all indictors for which data are not available in a given country or region good: this would be too limiting, also considering the fact that data quality differ enormously from one region to another and sometimes even from one municipality to another. Therefore eliminate indicators on this basis would diminish the relevance of assessments also in areas where data quality is high and the information that can be obtained may be very valuable for mitigation purposes.
- Indicators of vulnerability are required to cover different spatio-temporal scales, when this is relevant for the final assessment. In this regard, we should make sure that data are available accordingly at the needed **spatio-temporal scales**. Similarly to what has been said for data quality, this requirement, while valid in principle, can prove to be too limitative in some situations and particularly currently, as many data are not available because they have never or poorly been considered until now for risk mitigation purposes. As said above,

the framework and the proposed indicators should set a sort of pathway for future damage assessment, to capture the attention of analysts on aspects that have been neglected insofar.

- **Availability** should be considered also **over time**, particularly when processes must be captured: data that are available only at a given time spot do not permit to follow processes or to monitor whether or not a given system is becoming less or more vulnerable over time.

c. The entire method is being designed to guide and orient amidst mitigation strategies. In this respect, how useful proposed indicators are in enhancing the latter must be asked as well. Usefulness in this regard does constitute an important criteria for indicators selection.

- The first requirement is that indicators be **understandable** by users, not only as far as terminology is concerned, but also in the way they are measured, reference values selected and actually used in the assessment. This is a fundamental requirement should indicators be discussed with concerned stakeholders and be used by them as part of their ordinary planning an programming activities (of land use and spatial planning, granting permissions, deciding about infrastructures modernization etc.).
- Indicators should provide directly or indirectly a door towards a set of strategies aimed at mitigating present levels of risk. In this regard they should not be only "descriptive" of a given situation, but also be **linked to potential intervention policies**, both as goals to be achieved and as factors against which achievements can be monitored and appraised.
- Perhaps the most important requirement with respect to all those defined insofar, relates to what extent proposed indicators permit to **distinguish different patterns** in a given areas, eliciting so called "pockets" or hotspots of vulnerability. In general, it is an important requirement that using the indicators, differences among conditions, individual areas, zones, parts of community, and communities are sorted out, so that priorities can be decided and tailored measures designed.

The "**cost effectiveness**" requirement has been left at the end to be considered collectively across all axes.

Talking about data collection, cost effective means that a reasonable cost is associated to the operations needed to gather the required data. In this respect it is commonly known that census data, data derived from national and international databases are often preferred, not only because they are cheaper, but also because they guarantee coverage over time and across scales, and can be used for comparative purposes. A balance must be obtained between the requirement of good quality data, optimised for the needed level of detail, and cost of collection.

Talking about usefulness, indicators that require too complex mechanisms to obtain data, or data that are privately hold or covered by secrecy are of limited use.

Finally cost effectiveness can be measures also from a cognitive viewpoint: indicators that are too complex to construct, that require sophisticated and opaque operations to be assessed should be carefully considered, given the large uncertainties they may entail. In the meantime, also the total number of indicators must be the object of reflection: endless lists of indicators are not only difficult to use, but also raise questions about the actual possibility to guarantee the other requirements of quality and usefulness that have been described until now. From a cognitive point of view, sustainability studies warn against the excessive number of parameters that nobody is able to handle nor master.

2.5. Example of the tailoring of matrices to a specific hazard (forest fires)

2.2 (forest fires)

In order to fully grasp the characteristics and the potential of the proposed method, an example of the application of the framework to the forest fires case will be illustrated. In the first matrix, the mitigation capacity in a given area is examined (table 2.1). In the first section, related to the natural environment, the key issues to be considered refers to the existence of hazard maps and particularly of early fire detection systems connected efficiently to triggers able to mobilize resources for firefighting on the one hand and the protection of the population on the other. In the meantime the vegetation characteristics are assessed as far as their inflammability is concerned. In the built environment section, the main questions refers to whether or not existing vulnerabilities are recognized and addressed in land use plans and in urban strategies, related to ordinary residential buildings and to public facilities.

System	Component	Aspect	Aspect Parameters	Criteria for assessment	Paramters value/ categories	weight	score	scale	Comments
Natural environment	*Natural Hazards*	Natural hazards identification and mapping	Hazard maps availability	Maps of areas prone to fires; map of inflammability of vegetation	yes/no; quality as judged with respect to international standards	1		At both municipal and county or regional levels	In many cases hazard maps are available; the point though is also to understand to what extent they are fit to support mitigaton strategies
			Do hazard assessment consider climate change	binary	yes/no	0,5			
		Available knowledge updating	Hazard maps updating	Frequency of updating	every 2 years and after each event/rarely	0,5			
		Hazard monitoring systems	Existence, distribution and quality of monitoring networks	technical monitoring systems linked to operation centre	yes/no	1			
				permanent staff dispaced in critical areas for direct monitoring and immediate intervention	yes/no	0,5			
		Connection of monitoring devices to modelling systems	Availability, quality of early detection systems and models	binary; quality of early detection and propagation estimation models	yes/no; models tailored to the geographical context/not tailored	0,5			Technologies and models to predict phenomena must be tailored to the sepcific context to be effective
		Structural defence measures	Existence of defenses for breaking the fire lines	binary	yes/no	1		At municipal/ county level	
Built environment	*Exposure and vulnerability of built environment*	Inclusion of vulnerability and exposure assessments in land use plans	Vulnerability assessment of exposed built stock	binary; updating frequency	yes/no; every time new building permits are given/only occasionally	1		At municipal / county level	
			Risk maps and scenarios, including enchained events	binary; year of production	yes/no	1			
			Vulnerability and exposure assessment considered in ordinary plans (example land use)	binary; mode of inclusion	yes/no; only formally/substantially with limitations and specific requirements	1			In most cases vulnerability assessment are not available; but even in cases where they are it is important to check if they are considered in planning decisions
	Rules and tools for risk mitigation	Availability, quality and efficacy of mitigation rules	Building codes/rules	binary; updated	yes/no; rules efficacy checked after each event/rarely tested	0,5		At national / regional levels	
			Property regime of houses	owned houses versus tenants	owners ow < 50%/ ow > 80%	0,5		At municipal/ county level	In literature it is hold that private owners may be more willing to take mitigation actions
			Traditional building practice based on hazard knowledge	binary; capacity to re-produce traditional techniques correctly	yes/no; judgement about the capacity to conform to the "code of practice"	0,5			
			Maintenance of fire suppression devices and clearing vegetation around houses	binary	yes/no	1			
			Land use plans embedding risk mitigation and vulnerability reduction	binary; specific indications for vulenrable locations	yes/no; specific rules for the wildland-urban interface and for accessibility	1			This parameter has to be considered together with the previous ones on quality of hazard maps and on inclusion of vulnerability assessments
			If previous paramters yes, then Implementation capacity	binary; frequency of inspections; trained personnel for inspections	yes/no; every year/seldom	1		At county/ regional or national levels	Implementation is a crucial aspect, inorder to translate mitigation decisions into risk reduction actions
			If previous paramters yes, then Integration to other measures (insurance)	binary	yes/no	1			Insurance per se can be even counterproductive in terms of mitigation, unless premium is set considering actual risk

Table 2.1.a - Matrix to assess mitigation capacity to forest fires

Infrastructure and production sites	*Critical infrastructures*	Existence of vulnerability assessments for critical facilities; level of consideration of vulnerability in programs regarding critical facilities	Vulnerability assessment of critical infrastructure	binary, particularly for roads and water for firefighting	yes/no	1		County/ regional level	
			Maintenance programs embedding mitigation	binary	yes/no	1			For critical infrastructures it is not likely that complete substitution will take place just for risk prevention purposes; therefore it is crucial that in future plans and maintenance programs prevention will be one of the criteria for designing and repairing/updating
			New projects based on hazard/risk assessment	binary	yes/no	1			
			Level of coordination among stakeholders	degree	low/medium/high	1			
	Production sites	Existence of vulnerability assessments for production sites; consideration of na-techs	Vulnerability assessment of production sites to wildfire	binary	yes/no	1		Municipal/ county levels	
			Retrofitting measures for existing production sites	binary	yes/no	1			
			New projects based on risk assessment	binary	yes/no	1			
			Na-tech explicitly accounted for in hazardous installations emergency plans	binary	yes/no; expert judgement on quality	1			Enchained hazards are considered in the framework both natural (in the natural system part) and technological (here)
Social system (agents)	*People/individuals*	Capacity of individuals living in prone hazard areas of coping with hazardous events, which largely depends on the perception and awareness of risk conditions before the event occurs.	Risk perception/ awareness	Degree	strong/average/low	0,5		Municipal/ county level	
			Reliance on institutional firefighting capabilities	Degree	strong/average/low	1			
			Felt responsibility for firefighting and fire mitigation	Degree	strong/average/low	1			It is in general important to understand if the community feels shared responsibility with government and agencies in risk mitigation
			Tools and plans to guarantee early warning reach the communities	Binary	yes/no	1			Here early warning are considered in the wider perspective, considering whether or not there are the conditions for their effective communication to the potentially affected ones
			Individual preparedness	regarding specific self protective measures; regarding measures included in emergency plans	hydrant available/not available; escaping routes known/not considered	1			
	Community and Institutions	Involvement of a community into decision-making processes related to risk prevention and mitigation, the capacity of Instituions of improving risk awareness	Contingency plans for firefighting	binary	yes/no	1		Municipal/ county level	
			Effectiveness of measures included in contingency plans	degree	strong/medium/low	1			
			Participation in development and prevention/mitigation strategies	degree	strong/medium/low	0,5			
			Education programs & media campaigns	binary; frequency	yes/no; every year/only seldom	0,5		County/ regional level	
				tailored to the community features	yes/generic	1			
				Inclusion in school programs	yes/no	1			
			Economic access to resources for firefighting	degree	vewry low/low/average/high	1			
			Coordination and cooperation among institutions in charge of risk prevention/ mitigation	degree	strong/medium/low	1			

Table 2.1.b - Matrix to assess mitigation capacity to forest fires

In the third section devoted to critical infrastructures, the main factor to be considered refers certainly to the existence and efficiency of water systems to be used in case of need; in the meantime the potential for na-tech in industries is addressed as well. In the last section, the preparedness of individuals and institutions is appraised, identifying parameters that "measure" the availability of extinguishers, masks as far as individuals are concerned, and presence of well equipped and trained volunteering firefighters. As it can be seen in the table, two columns are provided for weights and scores. The first represent the relative importance of parameters, as derived from literature and expert judgment; the second translates into a score (according to an arbitrary system that assign for example 5 to low vulnerability and 1 to high or viceversa) the evaluation carried out in the are of relevance.

System	Component	Aspect	Aspect Parameters	Criteria for assessment	Paramters value/categories	weight	score	scale	Comments
Natural environment	*Natural ecosystems*	Fragility of natural ecosystems to hazard(s)	land cover inflammability	Surface fuels	Only needle or leaf litter on the ground; sparse low vegetation; tall dense phyrgana or shrubs	1		Those paramters clearly have to be assessed at least at a county scale	In the case of forest fires clearly the vulnerability of the natural ecosystems is crucial (type of vegetation, density, etc.)
				Existence and cover of tall tree crowns	No tree crowns; tree crown cover of <40%; tree crown cover >= 40%	0,5			
				Type of trees (see next page for details)	according to the classification provided by Dimitrakopoulos and Papaioannou, 2001	1			
Built environment	*Exposure and vulnerability of built environment*	Factors that make the urban fabric and public facilities vulnerable to the stress	Average vulnerability at the municipal scale, considering settlements(rural) or urban parts	Considering parameters provided in the attached specific table	Low-medium-high vulnerability	1		This parameter makes sense at an urban /county scale,	This table looks at a municipal/county level, while some paramters clearly make sense only at larger scales. In the meantime for assessing the vulnerability of individual buildings a more local scale must addressed (see next table)
			Historic sites (archeological) and buildings (monuments and museums) in the hazardous areas	Binary; extent and relevance	no/yes; dimension; minor/relevant/very relevant	1			
			Built pattern (follwoing Lampin-Maiillet et al., 2009)	Building density and proximity is an indicator for assessing potential sources of ignition and surface to be cleared from vegetation	very dense; dense, scattered; isolated	1		This parameter makes sense at an urban /county scale,	The quoted study showed that sparse buildings are ore likely than grouped to create multiple sources of ignition
Infrastructure and production sites	*Critical infrastructures*	Factors that make critical infrastructures vulenrable (mainly lifelines)	Vulnerability assessment of critical infrastructure	water system pressure	normal/ too low pressure for hydrants	1		At a municipal/ county scale	
				self eater tank	available/not available	1			
			roads	interaction with fuel	large road sections in open zones/in the middle of fuel areas	1		Both a the scale of the assessment and at larger scale	
	Production sites	Factors that make production sites vulnerable (including na-tech potential)	Vulnerability assessment of production sites	as for buildings, but including attention to storage of hazmat	structurally vulnerable/low wulenrability; large storage/no storage	1		At a muncipal/ county scale	
			Vulnerability due to dependency on lifelines	depending on the degree of dependance upon external vulnerable lifelines	self eater tank available/not available	1		At a muncipal/ county scale	
Social system (agents)	*People/individuals*	Factors that may lead to injuries and fatalities	Sparse population	ratio between population living in isolated buildings and remote settlements and total population	r <5%; r > 20%	1		At the municipal/ county scale.	This parameter would make sense also at a regional scale analysis, but adopting statistical techniques and mapping
			Preparedness	self protection means	hydrants at home/lack of hydrants	1		At the municipal/ county scale	
				self protection against smoke	availability of masks/lack of	1			It is important in the methodology to be as specific as possible, so the generic assessment of the availability of means and personnel for mitigating the impact are tailored to the sepcific threats against which the population must be protected.
			Age; mobility impairment, other impairment	difficulties to comply with evacuation orders; difficulties in escaping	> 65; number of handicapped	1			
	Community and Instituions	Factors that may lead to large number of victims	Distance from firefighting resources	time of arrival	within 30 min; > 1 hour	1			
			Availability of trained personnel	professional training in the community	firefighters (professional+volunteers)/only professional	1			

Table 1.2: Extract of the matrix to assess physical vulnerability to forest fires

The next column is devoted to the spatial scale at which the parameter is evaluated. In some cases such scale has to be decided depending on the area to be covered and the context at stake. If the problem is assess the vulnerability of an entire province (as will be seen in the Ilia case in Greece, see WP5) the county or even the regional level must be taken for most parameters; if the focus restricts on one sub-area, a municipal scale can be addressed. For some parameters, like for example law and norms provision, that have clearly a relevant impact on mitigation, a national level must be taken, or regional in those states that grant legislative power to regions regarding the topic of interest (in this case protection against fires).

System	Component	Aspect	Aspect Parameters	Criteria for assessment	Parameters value/ categories	weight	score	scale	Comments
Natural environment	*Natural ecosystems*	Fragility of ecosystems to potential secondary effects of hazard(s)	soil deterioration	increase of erosion	<= 30 %; 30 x x < 50%; x>= 50%	1		At the county or regional scale	
			landslide hazard	degree of increase of landslide potential based on survey and exprt judgement	low/medium/high	1			
Built environment	*Exposure and vulnerability of built environment*	Factors that make buildings, the urban fabric and public facilities vulnerable to losses	Existence of public facilities and resources to face the emergency	Availability of movable fire fighting equipment or of an automatic fire-fighting network (E3)	yes/no	1		At the county or regional level	
			Accessibility to vulnerable areas	Buildings density and proximity (follwoing Lampin-Maiillet et al., 2009)- total perimeter to be protected	very dense; dense, scattered; isolated	1		At the municipal/county level	Various studies attempted to assess the vulnerability of the urban fabric based on features like house density, totla perimeter to be cleared by vegetation and total surface to be protected in case of fire
				Roads characteristics	Type of roads serving the various settlements			At both muncipal and county or regional level	
					Plain roads/mountain roads				
				Signs in roads and streets (names, numbers, etc.)	yes/no			Local/municipal level	
			Accessibility to public facilities	existence of public facilities in the area	yes/no			At the county or regional scale	
				expected travel time	t > 30 min/ t <= 30 min				
				road network to public facilities	as for accessibility to vulnerale areas				
Infrastructure and production sites	*Critical infrastructures*	Factors that make critical infrastructures stop functioning	Existance of lifelines	Availability of water for firefighting	Yes/no; in sufficient number/insufficient	1		At the muncipal and county level	
					Existence of a swimming pool or a water tank of more than 3 m3 in the plot	0,5			
	Production sites	Factors that may lead to halting production	Degree of dependance of production sites from lifelines	water for fighting	existence of tanks and devices for firefighting			At the muncipal, county and regional level depending on the focus of the assessment	
			Accessibility to the plant and to markets	redundancy; quality of roads; usability; expected increase in travel time	as for roads network to vulnerable areas				
			Contingency plan for na-tech	binary	yes/no				
			Business continuity plan	binary	yes/no				
Social system (agents)	*People/individuals*	Factors that may reduce coping capacity during crisis	Trust in information provisers	binary	yes/no	1		Clearly this can be assessed only at regional scale	Apart in some very special context where the local perception and situation is different from the regional/national
			Tenants, landowners and neighbours have been trained in fire-fighting	binary and frequency of training	yes/no; every x months/only occasionally	1		At a muncipal or county scale	
			Voluntary fire fighers	binary; number	yes/no; number /neighborhood	1			
			If previous yes, then Training	degree of training and means availability to volunteers	good/average/low	1			
			Presence of impaired groups (elderly, sick persons, etc.)	binary; number and accessibility to leaving areas	yes/no; numbr/neighborhood and accessibility	1			
	Community and Instituions	Factors that may hamper effective crisis management	Existance of contingency plan fro threats at stake	binary; date of last production or update	yes/no; recent/>2 years with no updating	1		At acounty or regional scale	
			If previous yes, Training using the contingency plan	binary; frequency of training	yes/no; every year/only occasionally	1			
	Economic stakeholders	Economic stakeholders preparedness to face crises	Capacity to run economy and respond to crises	degree	yes/partially/no	1		At a county or regional scale	
			Capacity to invest in recovery and take preventive actions	Binary or degree	Yes/no or none/partial/high	1			

Table 2.3: Extract of the matrix to assess systemic vulnerability to forest fires

The mitigation table for forest fires has been provided integral, comprising all parameters that have been selected; in the next tables, only an extract of the tables will be provided to facilitate readability of the individual parameters and comments.

Regarding the physical vulnerability (table 2.2), the main aspects that have to be considered are clearly:

- Inflammability of vegetation, buildings and infrastructures. In this regard some studies highlighted that the pattern of the urban fabric is important to determine ignition points and frequency. For example Lampin Maillet et al. (2008) show that sparse and isolated buildings pattern produces more ignition points than dense pattern, based on their studies of fires in Southern France;
- As for the built environment, important is also adherence to rules of construction and maintenance of open spaces that reduce flammability and avoid fast development of fires;
- As for critical infrastructures, the conditions of roads, their interaction with flammable areas (crossing forests for example) are fundamental parameters to be accounted for;
- Addressing social and individual preparedness, self protection means and adequate behavior (which requires prior preparedness) determine to a significant extent survival rates, particularly in extremely severe fires.

As for systemic vulnerability (see table 2.3), all factors that may worsen the response to emergency are considered, as the possibility of soil erosion and landslides as secondary effects of slopes denudation. Furthermore, conditions that favor or constrain successful firefighting are considered. Therefore accessibility factors within and towards potentially stricken areas become crucial elements to evaluate how fast and effectively it will be possible to evacuate on the one hand and for firefighting and rescue teams to arrive to the burnt zones. In this case the same parameter considered in the physical vulnerability table, buildings density and proximity is used to determine what will be the total perimeter to be protected by firefighters. Clearly it is both easier to reach and to protect dense built block with respect to a large number of isolated buildings sparse over large areas.

Finally regarding resilience (table 2.4), the capacity of the natural environment to “bounce back” has an ecological meaning: some species may recover faster than others, the extent to which plants have been damaged condition post fire recovery. In literature it is hold that also post fire management (for example types of plants selected for re-vegetation and availability of maps and pictures to document pre-fire situation) are crucial to determine what will occur in the affected area. The resilience of the natural environment has repercussion also on economic sectors like tourism and agriculture, for which the integrity of landscape is an essential condition for production.

What has to be taken into account in both the post and the pre-event phases is that to a certain extent successful fire prevention practices may lead to more severe and devastating extreme fires once the latter finally occur. In this regard, parameters attempt to capture the need for judicious practices that acknowledge the fact that fires are natural events and are part of the ecosystem of forests and woods.

As for other natural hazards, the “hazard” is part of the natural functioning of the environment, while it becomes a disaster when vulnerable communities and settlements are exposed.

System	Component	Aspect	Aspect Parameters	Criteria for assessment	Paramters values/ categories	weight	score	scale	Comments
Natural environment	*Natural ecosystems*	Ecosystems capacity to recover from damages	Fire recovery	Post fire vegetation re-growth	South facing slopes/North facing slopes	0,5		At a municipal/ county level	A post vegetation fire study took place in Mount Carmel, Israel. Unlike the study from Delgado, the recovery of vegetation was seen to occur better in north face slopes in contrast with south facing slopes. This seems to be a dominant assumption on the fire comunity. The choice for 4 and 2 vulnerability scores reflect that the difference is not very extreme, as highlithed by the study.
				plants used for reforestation	use of endemic species for reforestation/use of fast growing vegetation	1			This parameter is very country specific. In theory salvage harvesting can indeed lead to decreased regeneration after a fire, but harvesting can also lead to lower fuel loads at the stand and therefore make the fire less intense... It is a tricky issue. Maybe one can focus instead on post burnt fire policies. How is the reforestation of burnd areas planned? do they use endemic species or do they relly on fast growing vegetation (in general less resiliant and more prone to fires)?
		Structural and non structural recovery measures	availability of maps and pictures to document regeneration	binary	yes/no	0,5			Usually studies make use of satellite pictures to document changes in post-fire vegetation.
Built environment	*Exposure and vulnerability of built environment*	Urban fabric/built environment capacity to recover reducing pre-event vulnerability	Existance of plans and provisions to encourage mitigation in buildings and surrounding zones	binary	yes/no	1		National/ regional level	Difficulties in vegetation clearance around buildings due to ownership obstacles
			Level of integration of physical reconstruction with community healing processes	Room is given for interpreting in the new/restored setting the meaning of the destruction (After Valen and Campanella, 2005)	High/low	0,5		muncipal/ county level	
			Existence and strength of norms prohibiting building in burnt areas	binary; degree of compliance/inspection capability	yes/no; low/high			national/ regional level	This is clearly a crucial resilience factor, very specific to forest fires that are many times man made with the objective to create conditions for urbanisation
Infrastructure and production sites	*Critical infrastructures*	Availability of tools to recover critical infrastructures rapidly and at low costs	Water system for firefighting	level of improvement after disaster	low/high	1		Municipal/ county level	
			In site devices for quick survey of damaged parts	binary	yes/no	1			
			Availability of spare materials for fast repairs	binary	yes/no	1			
			Availability of personnel for repairs	binary	yes/no	1			
			Existence of protocols to proceed with repairs requiring inter-lifelines interventions	binary	yes/no	0,5		county/ regional level	
	Economic activities	Availability of tools to recover production sites rapidly and at low costs	Relevance of the area as a tourist attraction	degree	low/average/high	1		municipal/ county level	Clearly in the case of forest fires the burnt areas constituted a unique landscape that until recovered will not be available for activities strongly dependent on it
			Activities depending on the existence of woods	binary	yes/no	0,5			
			Economic sectors	Diversified or concentrated on few sectors	Few/many different economic sectors in the area	1			
Social system (agents)	*People/individuals*	People's resilience in the face of the catastrophe induced trauma	Availability of private resources for recovery	degree	yes/no			Municipal/ county level	
			Access to insurance	binary; coverage	yes/no; percentage of coverage				
	Community	Affected community's resilience to the consequences of a catastrophe	Age structure	Aging population; low fertility rates	indexes				Those parameters as well as others that are not reported in this sample are aimed at assessing the strenght, cohesion and recovery capability of the local comunity affected by fires
			Local condition of aged population	autonomous/not autonomous; relatively healthy/not healthy	autonomous/not autonomous; relatively healthy/not healthy				
			Employment rate	degree	high/medium/low				
	Institutions	Transparency, reliability and trustability of institutions in charge of reconstruction	Trust in institution	degree	high/medium/low (from sociological surveys when available)				
			Transparency in funds allocation	Existance of public information and independent control mechanisms	yes/no			regional /national level	
			Long term vision	Existance of strategic development/land use plans	yes/no			regional/ county level	It is deemed very important to have a long term vision to strenghten resilience, that will consider the development in a longer time horizon, including the possibility of further hazard impacts
	Economic stakeholders	Capacity and willingness of stakeholders to reinvest in affected areas	Insurance coverage	binary; coverage	Yes/no;percentage			municipal/ county/regional level	
			Dependance of economic actors on loss of environmental goods	Prevalent tourist acitvity; agricultural activity	percentage				

Table 2.4: Extract of the matrix to assess resilience in areas exposed to forest fires

Considering the resilience of communities and population, an important aspect to be considered in reconstruction after a devastating event like a fire, which causes in many cases the total loss of people's belonging and memorabilia, is the cohesion of society, the capacity to develop a long term vision and the positive conditions for permitting healing of trauma and not just physical rehabilitation.

3 Critical discussion of the integrated framework (largely based on first application to the test case study areas)

The application of the framework to the test case study areas (see WP5) provided a crucial return in terms of acquired experience and highlighted both strengths and weaknesses of the methodology.

The framework is at a stage of a prototype; some difficulties in applying it to concrete cases derive from this inherent character. On the other end, the experiences gained in applying the framework evidenced some points that could be hardly raised based on theoretical perspectives only. The most relevant relates to the need to include the framework into a larger assessment procedure, where the fulfillment of the matrices is still the most relevant part, but not the exclusive one.

In other terms, one must consider the evolution (both in time and ??? as far as research efforts must be taken into account) of the framework and the related matrices. First a general scheme has been produced, in the attempt to capture the most relevant components, features, issues raised in the discussion about vulnerability and resilience. Second, the general scheme was specified, producing matrices in which parameters and criteria to appraise vulnerability and resilience were tailored to distinct hazards.

Indicators received a specific connotation, showing what were the main features and aspects making a given environment (natural/built/social) more or less prone to damage and more or less capable to mitigate and/or recover. Such tailoring entailed a choice which is somehow questionable, as reference to individual hazards is explicitly made while the ambition to be general/comprehensive/multirisk is temporarily abandoned in favor of a more traditional kind of approach. The pro of such choice though, has been the potential of exploring vulnerability and resilience across several cases, defining in a much more precise and concrete manner what makes a given environment more or less fragile.

Still, even with this level of specification, matrices remain at a “general” level, somehow independent from specific contexts. And here the issue of how to adapt the assessment to the understanding of the context pops out in a very relevant fashion. Application to test case study areas evidenced that a clear cut straightforward application of the methodology, and in particular of the framework and the matrices, is not possible. One may even say that this could have been expected since the beginning and that actually an obvious process of tailoring and adaptation, this time to the context at stake, had necessarily to be forecasted. In any case, testing showed in a very evident way this need. Therefore a clarification of how to use the framework, even at an experimental stage, before moving from the prototype towards a more ready-to-use tool has to be provided (see paragraphs 3.2 and 3.3).

3.1 Quantitative or qualitative vulnerability and resilience assessments: a misplaced question

As stated at the beginning of this paper, and as explicitly stated since the beginning of the Ensure project proposal, one of the main needs felt by the partners was to integrate both "hard" and "social" sciences issues to assess vulnerability and resilience.

"Hard" sciences provide information and insight to understand why given infrastructures and structures fail under given stress, be it the physical stress of the natural agent or the malfunctioning provoked by a certain level of physical damage to critical systems or components. Social sciences in their turn provide explanations and example showing how and why given communities are better equipped than others to face natural calamities. This has to do with the physical and functional consistency of assets, but also, in a meaningful portion, to less "tangible" facts, entailing social cohesion, robustness of economy, cultural and human resources. The Ensure project started its own research path from the recognition that mitigation policies must take into account the "two" sides of the coin. (A coin is certainly a simplification, as we should talk about a multifaceted prism, yet it can be accepted for the purpose of the following discussion).

Conditions for better overcoming a crisis, a calamity depend on several circumstances and conditions that partially have to do with material components and partially with social, institutional and economic arrangements. Not to mention the fact that the "hard" and the "soft" sides are not separated, they continually interact and such interaction produces fragilities and strengths. Therefore, any attempt to assess the response capacity to an extreme event, must consider both sides of the coin and possibly their mutual interconnection.

At the end, as stated by Winograd (n.d.), the goal of vulnerability assessments should be «turning the data into relevant information and information into action».

Be it in the form of a list of factors to be considered or in more complicated schemes, as the one proposed in Ensure, an agreement has to be reached (even a temporary one) between – to simplify- social and "hard" scientists/engineers.

The very first level is mutual respect and recognition of importance of matters which are studied by the other discipline; the second step is to face the objective difficulties and obstacles in making the coexistence of two different mindsets and models of thinking and analyzing.

In this respect, in the vast literature devoted to this certainly not new issue, a particularly insightful perspective is offered by Ginzburg in an article written in "History Workshop" in 1980. In the article, he discusses the main obstacles to mutual understanding and recognition, referring to the irreducible difficulties whenever the "human" component has to be considered, something which sounds certainly familiar to most "hard" scientists working in the field of risk. Whilst a couple of decades of interdisciplinary research have set the floor for a different attitude with respect to the past, and as more mature positions have emerged recently, overcoming complete lack of communication and disciplinary barriers, there are still key issues that require further reflection and settling of divergent positions. This is deemed to be relevant not only to improve communication and knowledge exchange between “social” and “hard” scientists to limit the discussion to the “big” categories (whereas we are perfectly conscious that large gaps exist also within each “block”) but also to answer a key question for the project: are vulnerability and resilience assessment “science”? And, as a next question, going after a similar one posed by scholars in sustainability “science” (Bell and Morse, 2008): are vulnerability and resilience assessment “good” or “bad” science or even “bad transposition of otherwise good science”?

Ginzburg suggests that there are two main irreducible differences between what he calls Galilean and social sciences: on the one hand the treatment of the individual as opposed to the typical and therefore treatable in statistical (quantitative) terms and the capacity to predict the behavior of a variable, the evolution of a given phenomena.

As for the first point, clearly social sciences cannot avoid studying the individual, without losing critical information and understanding; attempts made by some social scientists to get closer to hard sciences resulted in rather “meager” results according to Ginzburg. In the meantime the author asks whether or not we can get to a situation where the understanding of the individual is somehow “scientific”, if conjectures that characterize “soft” sciences can be as rigorous as quantitative modeling. Without entering into the much wider debate of the so called “post normal science”, in which for example Funtowicz and Ravetz (1990) demonstrated that even “hard” sciences have undergone a significant mutation that has brought them quite far from the Galilean model, the point made by Ginzburg is still relevant. He points at the divergent mindsets, according to which “hard” and social scientists judge method and rigor, which still constitute a formidable obstacle to working together.

In the case of vulnerability and resilience studies, we may even go further and state that the point is not just making the two fields communicate, but actually develop possibly good science at the border of the two fields (and the many more disciplines within each) to address issues that are in the meantime material, physical and human, social. Continuing referring to Ginzburg’s article, resilience and vulnerability assessments resemble to a “medicine” type of effort, where classifications of diseases (in our case classes/categories of vulnerability) and the symptoms to be considered (the indicators) and how to judge their relevance and severity (criteria for assessment) are at stake. Within the framework, some indicators respond more to a Galilean type of science, when statistical methods and sufficient data can be used for their assessment (typically most of physical vulnerability parameters and some systemic in the sense adopted by the project). Many others (typically all those referring to social systems) will remain at a “classificatory level”. The point is therefore whether or not the two types of assessments can or even should coexist in the same framework. We think that even though in a rather imperfect way, the framework provides an acceptable level of integrated vision of the different aspects that must be taken into account in vulnerability and resilience assessments, without sacrificing relevant fields where knowledge on response of social, built and natural environments to extremes has been produced.

We are of course aware of some inevitable limitations such an endeavor implied since the beginning.

First, it is clear that the different indicators and parameters do not simply address different issues, but actually manifest also different ways of capturing vulnerability. Their co-existence in the framework is somehow arbitrary, as they actually play at different levels, not only in spatial and temporal scales, but also conceptually.

Nevertheless, given this minus, the framework offers a synoptic vision of what current literature and experiences have produced insofar, posing in a transparent way and in open access terms the question of how different views can/cannot coexist to provide a more articulated and nuanced picture of a system or a territory at risk.

Second, it is as well recognized that the tool that has been developed is currently a prototype and should be managed as such. It cannot be simply given to potentially interested stakeholders leaving them “alone” in the application of the framework and associated matrices.

As the application to the test case study areas evidenced, a number of intermediate steps must be followed in order to use it at best and none of them can be at the moment “standardized”. Some of those preliminary steps as described in paragraph 3.2 can be considered part of a more general and thorough procedure, where the use of the framework is certainly a core component but not the exclusive one. On the other hand, tuning and adaptation to the specific context at stake have to be made because of the prototype character of the framework and the related matrices. Therefore, in a further evolution of the methodology, a sort of discussion and participatory approach should be taken, involving different stakeholders to understand with them for what specific purposes, how, to what extent, and with which changes the methodology can be successfully applied.

Apparently, considerations made by the various teams working on the test case study areas showed that the methodology, and the framework which constitutes its skeleton, are valid in that they set the floor for a comprehensive evaluation, considering multiple dimensions and facets of vulnerability and resilience. Difficulties arise in the assessment of some parameters, because of the way they have been conceived and constructed. Further research in this domain could enhance the applicability of parameters (see in this regard also paragraph 3.3 and section 4). On the other side, getting acquainted with the methodology requires some time and practice. Guidelines to help follow the methodology may certainly help, but as stated by Ginzburg «in medicine, history/human sciences (and we may add in vulnerability and resilience assessments), the elastic rigor – to use a contradictory phrase – of the conjectural paradigm seems impossible to eliminate. Nobody learns how to be a diagnostician simply applying rules».

This leads us to the second important difference between “hard” and “soft” sciences as discussed by Ginzburg: that is the prediction capacity (or lack of). Because of the relevance of the individual in social and human affairs, only a retrospective prediction can be attempted. The “conjectural” paradigm of history or criminology may reconstruct a posteriori an event or the scene of a crime. Much more difficult and even questionable is the possibility of “prospective” prediction, to forecast how the future will unfold, how and if a crime will be committed.

Whilst clearly even in “hard” sciences the capacity to predict is not that obvious and banal, particularly when large uncertainties are implied (see Sarewitz et al, 2000), still the evolution of variables with constant characteristics can be reasonably forecasted. As for disasters, the debate between those who held that each event is unique and those who privilege constant and repeated behaviors and patterns is still very harsh. Again the metaphor of medicine can be useful for vulnerability and resilience assessments: indicators can be treated as “symptoms” of a condition the quality of which can be fully grasped only within a scenario type of exercise. Whilst the development of damage scenarios was beyond the application set for the Ensure project, it became clear through the test case studies that only conditioning certain indicators to a predetermined scenario it was possible to fully appraise them, particularly when cross scale relationships were crucial.

3.2. Temporal and spatial scales: a viewpoint from the Ensure project

The issue of scale has been rather neglected or poorly appreciated for a rather long extent, while in the meantime the concept of vulnerability, coping capacity, resilience and related concepts were undergoing a significant evolution process. It has become the centre of interest and studies with the first applications of climate change scenarios, particularly when the latter had to be regionalized, and with the development of the first global integrated assessments of the state of the environment and risks. The main question that the latter analyses have raised regards the relevance for local places but even for regions of projections and scenarios that have been drawn considering global trends and processes, while neglecting the information that can be gathered locally. It was clear for the scientists in climate change and those involved in global environmental assessments that for some phenomena, what happens in a given place, or at a micro level cannot be always neglected, as sometime it may contribute to change the evolution or patterns at much larger scales. Therefore a reflection on the meaning and use of scale in such studies and conversely in natural hazards has broken through various research groups, producing insightful thoughts that are relevant also for the Ensure project.

The reason why the scale issue is crucial can be derived from the rather enlightening and systematic discussion by Willbanks and Kates (1999):

- For the “tractability” of the problem at stake: when considering for example the vulnerability of buildings, a one by one survey can be carried out in very small municipalities and in any case only locally; when the vulnerability of entire provinces, counties or regions must be appraised, sampling techniques or even statistical analysis based on poor data (like census data) has necessarily to be adopted. This does not mean that studies at larger scales are less reliable: they obviously serve another purpose, which is the setting of strategies and policies identifying priorities, rather than deciding about individual interventions. Many other examples can be presented; in general it is true that vulnerability assessments regarding several components of vulnerability are much more tractable at the local scale, and the quality of information that can be gathered is much higher. Nevertheless, the limitations of investigations conducted only at the local level should be pointed out as well. First, the resources necessary to carry out a thorough survey are limited and therefore many localities will not be covered because of lack of time, money, personnel; second, at the local scale some relevant factors influencing trends and conditions can be missed, as they operate at other scales or levels. It is rather hard, perhaps impossible, to identify the “right” scale or level at which to analyze a given problem, as the latter depend on the purpose of the assessment, on the available resources but also, importantly, on the type of patterns and phenomena that have to be investigated. This leads us to the next point.

- A multi-scale, multi-level approach is relevant whenever “emergent” aspects, patterns, relations emerge at higher (or lower) scales and levels and therefore missing them may invalidate the entire assessment. An example is provided by lifelines vulnerability assessment: because of their intrinsic hierarchical structure and of their mutual interdependence, studies conducted at a local level may completely miss the relevant interconnections that are both spatial and systemic. Furthermore not just one level is implicated in infrastructures organization: actually it depends on the specific arrangements in a given country or even continent. Before moving to the analysis of the local vulnerability of lifelines, one must estimate where the vital links, nodes, segments are. In this respect, it may be suggested that physical vulnerability assessment is more likely to be “local”, whilst “systemic” vulnerability as defined in the Ensure project is more likely to be grasped at higher levels, regional or national. Following Root and Schneider (1995) a “cyclical scaling” method has to be preferred to rigidly pre-defined “top-down” or “bottom-up” approaches, going from the local to the regional or national and back to the local, depending on the question to be answered with the vulnerability and resilience assessment.
- Considering multiple scales and levels supports even more strongly the need for a methodological strong framework as the one suggested by the Ensure project. In fact, a definite rule valid for all types of assessments cannot be established, as the choice depends on the objective of the assessment but also on the systems to be analyzed and on the specific context where the analysis is carried out. Such a framework, by establishing how given parameters and topics must be addressed at what level and scale, is better fit than case by case analyses to accomplish what Willbanks and Kates (1999) see as key requirements: put localized observations into a reference context; increase the comparability of studies conducted at the same spatial level and across time. This is a requirement that has been stated, even though phrased in other ways, by the Asean group producing the Post Nargis Cyclone assessment of needs and damage in the affected Myanmar areas (2010). The latter shares with Ensure a similar philosophy, according to which vulnerability and resilience evaluations are useful exercises only at the condition that they support and offer insight for deciding mitigation and prevention strategies.

It must be acknowledged that introducing scale into vulnerability and resilience assessments is not easy; there are not available standards or references that can be taken as a guidance. But even in more general, theoretical terms «improving the understanding of linkages between macroscale and microscale is one of the great overarching intellectual challenges of our age in a wide range of sciences» (Willbanks and Kates, 1999). The authors continue suggesting that «weaknesses in appreciating the interaction of processes moving at different time scales and extents, in fact, underlay a great deal of the current scientific interest in complexity, non linear dynamics, and the search for order amid seeming chaos». The issue of scale is particularly important when different scientific perspectives must cooperate together in a truly interdisciplinary way. As suggested by Root and Schneider (1995) «the scale at which different research disciplines operate make multidisciplinary connection difficult and necessitate devising methods for bridging scale gaps». Having said that, it is clear that what can be realistically achieved within the Ensure project is first an explicit recognition of the importance to consider the scale issue as a central one and second a proposal of how it can be operationalized within the proposed methodology.

In accordance with the already quoted definition of vulnerability provided by Turner et al (2003), we may well take the definition of scale as suggested by Gibson et al (2000): «We use the term scale to refer to the spatial, temporal, quantitative or analytical dimensions used by scientists to measure and study the objects and processes. Levels on the other hand refer to locations along a scale».

In the suggested framework, both the spatial and the temporal scales of disasters are considered to structure the analysis of vulnerability and resilience. It is also suggested that even though both concepts are dynamic and dynamism is a crucial aspect to understand how and why given levels of vulnerability or resilience can be "measured" today, what can be practically achieved is a "picture" of frames at meaningful levels of the scale.

In order to operationalize the concept of scale, then two main aspects will be discussed in the following paragraphs: first what are the relevant levels for each scale to investigate for what purpose; second how we may treat cross-level and cross-scale relationships.

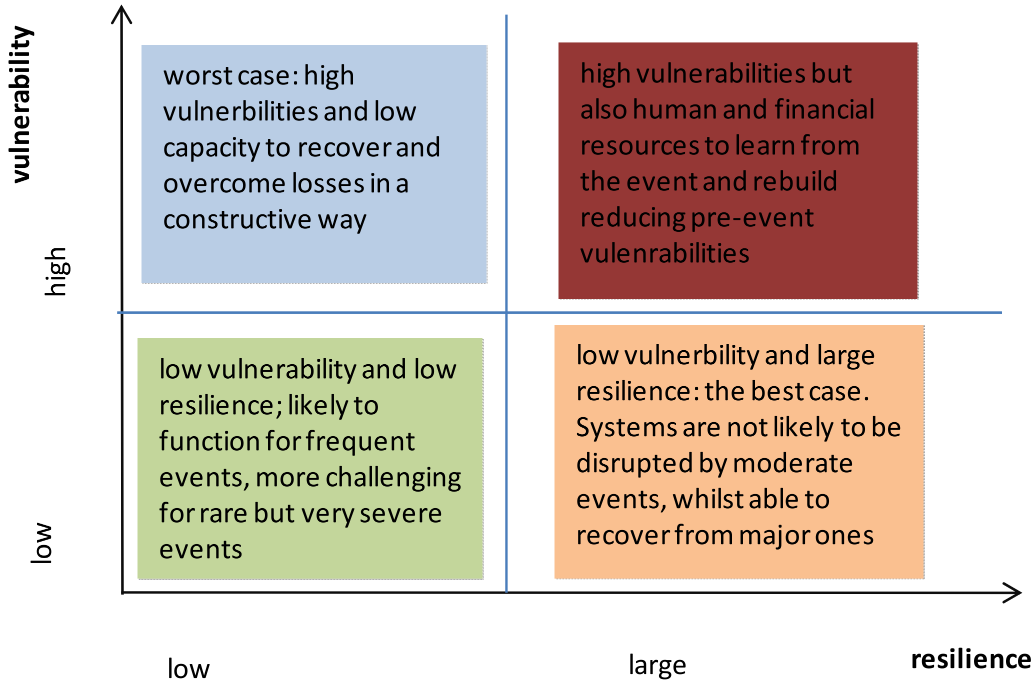

Figure 3.2: Scheme to sketch the cross temporal scale relationship in a given area and context

Following what has been discussed until now, the following can be proposed for the Ensure project in practical terms:

a. Scale up and down, adopting statistical and sampling techniques for those aspects (particularly physical vulnerability) that are cumulative (which means that the physical vulnerability of buildings in a region can be seen as the additional vulnerability of every single building);

b. For systemic vulnerability, a cycling scaling approach may be adopted, going up to the largest spatial scale necessary to identify functionality at the lower (or local) level of concern;
c. For mitigation and resilience, the appropriate spatial scale depends very significantly on the purpose and the end user of the assessment. In this case, a “mapping” approach following the one proposed by Briguglio et al (2008, see figure 3.2) can be followed. In other words, one has to first identify in the case at stake what are the agents and the economic stakeholders that are most relevant for understanding a given pattern of preparedness (or lack of) and of capacity (or lack of) to influence physical and systemic vulnerability and then direct the efforts into the assessment of the elements at different spatial levels that are relevant for the case at stake. For example, while talking about the physical seismic vulnerability of buildings in a given region in Italy, it may be relevant to search at the national level when laws providing economic incentives for retrofitting have been passed and what are the authorities in charge of controlling the correct use of those incentives. Then the appropriate level at which to analyze agents’ behavior in this specific case can be decided.

3.3. Dealing with cross-level and cross-scale relationships

Insofar the framework description has provided a static picture of the vulnerability assessment, providing the explanation of what can be viewed as a skeleton comprised by subcomponents and indicators to enlighten and evidence that the various factors that have been recognized in literature and past applications as relevant for understanding the potential response of a complex territorial system to the “external” stress due to a natural extreme.

The Ensure team though has acknowledged since the first WPs (in particular the second one) that links, connections, coupling relations exist among indicators. More than that: the validity of a vulnerability assessment requires the understanding of such connections to avoid misleading results that do not take into account how the various factors interact in a real setting.

Given that, the issue of how to play on the relationships that have been sometimes grasped in back analysis within the framework has still to be fully understood.

At least three types of relations can be recognised.

The first (see figure 3.1) relates to how the different indicators within the same matrix may be connected to each other. In general term, it can be assumed that social agents in various forms may have a direct or indirect, strong or loose influence on all other types of vulnerability, that is on the vulnerability of natural systems (for example the decision to change the type of vegetation coverage for economic profitability may induce instability in slopes or give room for more inflammable species), on the vulnerability of the built environment (here the all issue of compliance with norms and state of the art techniques enters), on the vulnerability of critical infrastructures (not only the way they are constructed, but also to what extent they are privatized, whether or not managing companies are controlled, coordinated by public bodies, etc.).

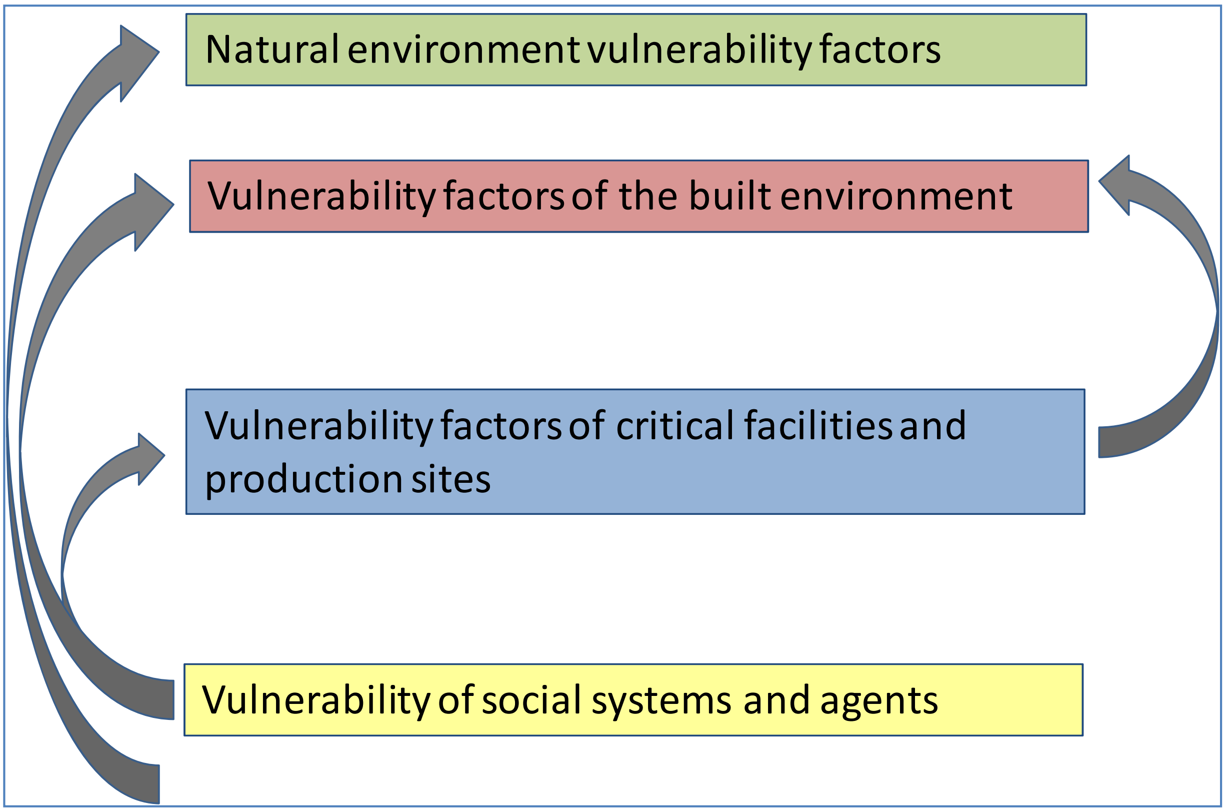

Figure 3.1: Relations among indicators within the same matrix

The second and the thirds relate to spatial and temporal cross-scale and cross level connections.

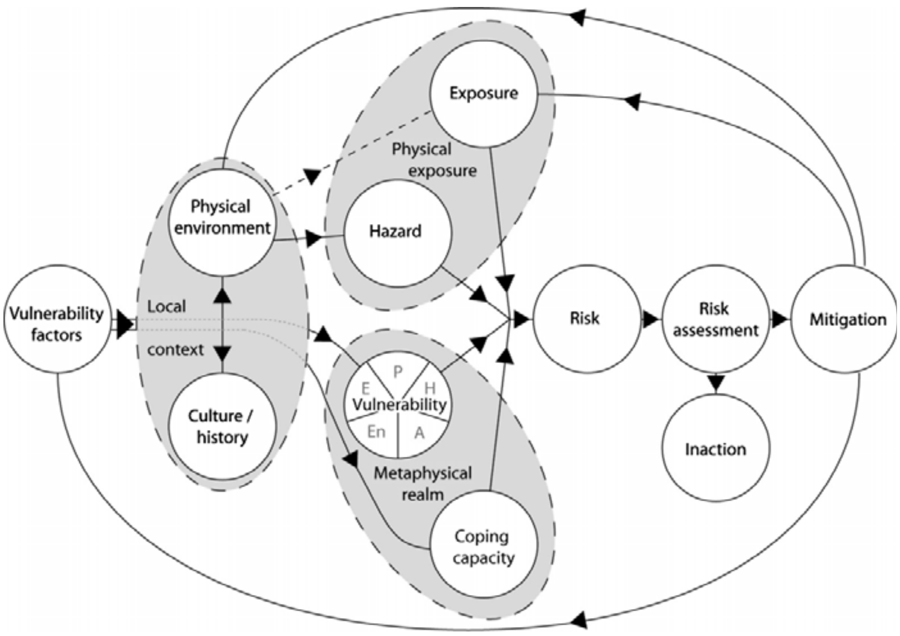

Figure 3.3: Proposed model for vulnerability conceptualization within risk assessment

context by Roberts et al (2009)

As it is already very complex as shown in the previous paragraph to address scale issues per se, it is even more challenging to tackle such cross-scale relationships. As already said, whilst the relevance of such connections has been recognised theoretically, it is still rather difficult to achieve it in real applications. Having a conceptual framework is already a good advancement as suggested by Roberts et al (2009, see figure 3.3). Actually, their framework has a lot in common with ours, and can be suggested as a visualization of the kind of pre-vulnerability assessment that must be carried out in order to identify what are the relevant links among indicators at different spatial and temporal scale for a specific case at stake.

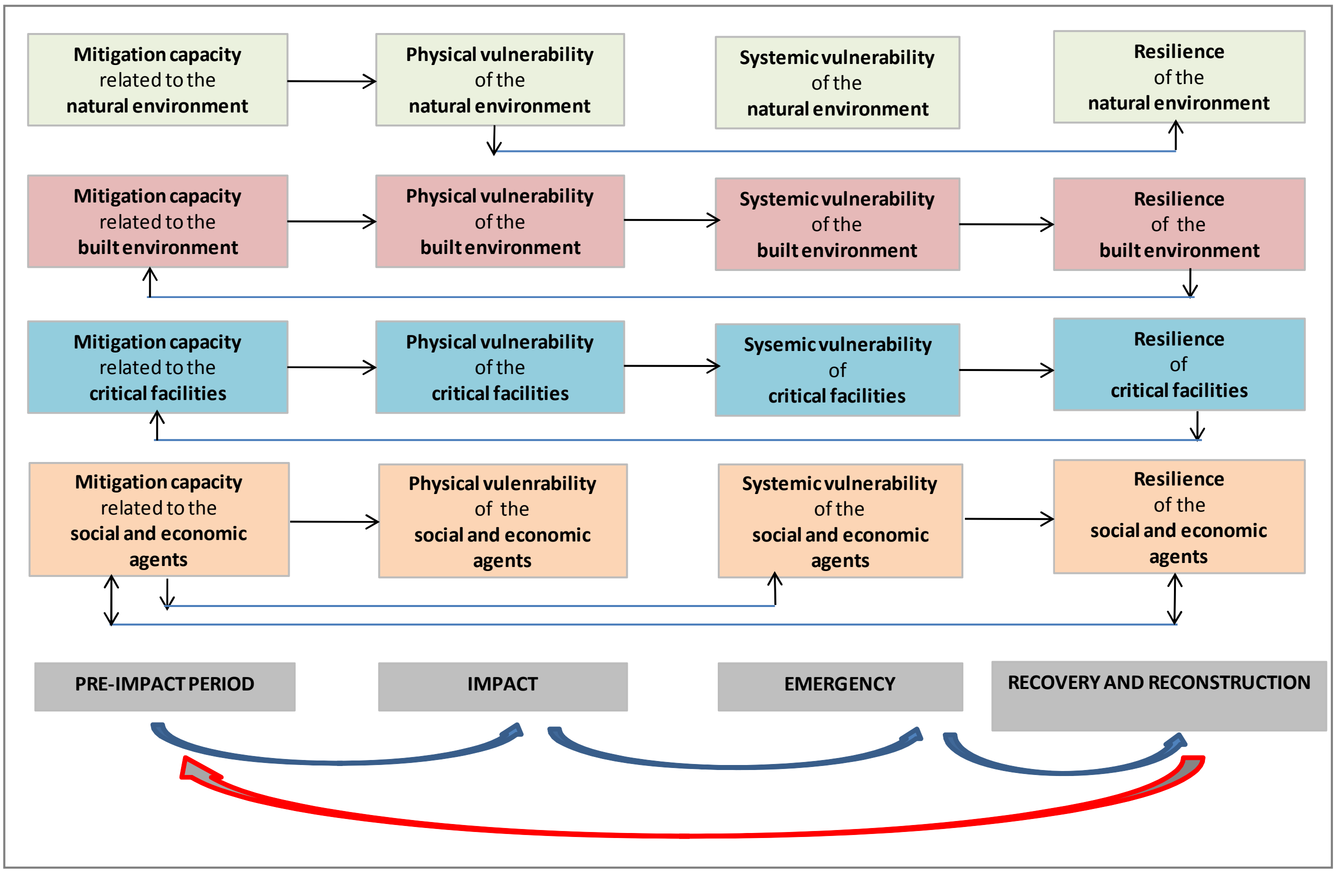

Figure 3.4: Relations among indicators across the set of matrices (referred to time-scale levels)

Again, it is deemed that a general theoretical statement of how those connections work is impossible at the state of the art (or perhaps even counterproductive form a conceptual viewpoint); instead, what can be practiced is the definition of a "scenario" where conditional relations among indicators are recognised as relevant and therefore for those indicators at the appropriate level of spatial scale the full assessment will be completed. The others will be as if "turned off" and not examined in that particular case.

Similarly for time scale (see figure 3.4); whilst it can be hold in general that what is decided in the period before the impact, the capacity or incapacity to mitigate have direct consequences on physical vulnerability, and on the systemic. The resilience of the system is not dependant only on pre-event decision, as emerging positive capacities may arise from society and territories in sometimes unexpected ways, difficult to fully envisage before the event. In this regard, while recovery and reconstruction clearly pave the floor for creating or eliminating vulnerabilities and are therefore always part of “mitigation” to the next, future, extreme event, the relation between mitigation and resilience is not necessarily so linear. Resilience, though, has to do with the expected level of damage, the extent to which places and communities are disrupted in the aftermath of the event.

In figure 3.4. the mitigation capacity, physical, systemic vulnerability and resilience of the four main systems that have been represented in the matrices are shown across the temporal phases of a disastrous event. The long arrows below the phases labels indicate that there is no linearity and that the pre-impact event sort of starts when the reconstruction is over (or, better, when enough time since the last event has passed so that the pre-impact event is felt as a “normal” time). The other arrows among the various systems’ vulnerability and resilience boxes show the relations that exist inevitably over time among mitigation, physical vulnerability, vulnerability to losses, resilience. The links among systems shown in figure 3.1. should be ideally superimposed so as to represent the complexity of such cross temporal scale relationships. In the figure only some of the links are evidenced, while it is clear that many other may be found in real cases.

In summary, it is clear that as it is already very challenging to account for cross-level and scale relations as well as for interactions among indicators in back analysis, in prospective assessments this becomes an unachievable goal, if prescribed in too strict terms. It is inevitable to simplify and propose a more pragmatic approach, that will first make explicit what kind of interactions among stress → physical damage → systemic vulnerability → response to losses → assumed capacity to recover can be envisaged in a given place, in a given region at the time when the assessment has to be conducted, and then identify the most relevant relations among what indicators at which spatial or temporal level.

Even though the proposed solution is partial and not fully satisfactory, it must be reminded though that it is in line with some current proposals that have been strongly supported by some end users. An example is provided by the already quoted Asean post Nargis assessment, where a very similar approach to the practical one we propose here was adopted, under extreme circumstances under the urgency to provide quick results for the affected communities. In fact, first a spatial grid was established to identify the key levels at which the assessment would be carried out; then an indicators’ framework was set to guarantee both comparability and emergence of specific needs and problems in different localities; third, the assessment looked ahead at recovery, providing a tool that could be used also across time to verify the efficacy of aid and intervention policies.

3.4. How temporal and spatial cross scale relationships can be analysed in practice within the Ensure approach: an example applied to the forest fires case.

Regional patterns of forest fires depend on numerous human, landscape and climatic factors that change frequently in time and space (Cueva 2006). For example, forest vegetation type and structure, biomass of live and dead surface fuels, land topography, weather factors, population density. Countries in the Mediterranean region of Europe are frequently subjected to the economic, ecologic and human consequences of forest fires (Bassi et al. 2008). Here a dynamic adaptation of the Ensure framework is proposed, to account for the very relevant linkages between actors and objects, across spatial and temporal scales. Although in theory the concept vulnerability demands for a thorough investigation of biophysical, cognitive and social dimensions of human-environment interactions (Polsky et al., 2006), in order to make the assessment of vulnerability meaningful an intermediate level of complexity needs to be found. In this light, wildland-urban-interface (WUI) emerges as an adequate focal system. WUIs are defined as areas where urban lands meet and interact with rural lands (Lein and Stump, 2009). Some of WUIs are characterized by increased human activities and land use conversion (Lampin-Maillet et al. 2009). In general, as people and wildland interact, the potential for forest fires becomes elevated and risks to fire hazard rise.

The suggested model depicts agents, objects and their interactions contributing to physical and economic vulnerability of the WUI's. Agents and objects are positioned according to a time and spatial axis (see Figure 3.5). The time axis denotes the traditional stages of the disaster cycle (from pre-disaster to recovery) while the space axis highlights the scales of influence for each agent and object (from macro to micro). For explanatory reasons let us focus on the pre-event stage. At this level, agents and objects influencing fire ignition and/or fire propagation are investigated, e.g. flammability and fuel structure, human activities or climate patterns (Chuvieco and Salas 1996). After *agents* and *objects* are placed in the appropriate spatial scale of influence, their interactions (represented by arrows 1 to 13) are elaborated from forest fire literature. For example, a demographic decrease in the rural areas of Portugal has lead to the abandonment of arable areas and their subsequent conversion to woodland. The resulting increase on fuel loads made these regions more susceptible to the occurrence of fires (Pereira et al., 2005). The phenomenon of land abandonment driving fires was also reported in Greece. As forests and villages were gradually abandoned, the number of forest fires and area burned annually started growing steeply since the end of the 1970s (Xanthopoulos, 2004). This relation can be abstracted by the *agent* population modifying the *object* land use and flammability (see arrow 6).

In a similar way, the agent *governance* (usually present at macro- and meso-scales of the pre-event phase) was found to shape physical vulnerability at the micro-scale via the agent *population* and their interaction with the objects *built* and *natural environment*. It was observed that residential risk management decisions (arrows 7 and 8) are made in reference to institutional incentive provided by the existence of public fire suppression (arrow 3). If residents believe that fire-fighters have the capacities to protect local homes they are less likely to implement measures to reduce home ignitability (Collins 2005).

Resulting physical vulnerability during the impact phase translates to economic consequences on the course of the recovery phase. Examples from the 2007 Greek mega-fires showed that around 78000 ha of agricultural land burned on Peloponnese were primarily olive groves. In the Prefecture of Ilia alone 50% of the olive production potential was lost, such damage should be seen in relation to the main source of income in this area (WWF 2007). Access to insurance by the agents *economic stakeholders* (arrow 11) or the existence of governance funds to cope with disasters provided by governance (e.g. European solidarity fund, see arrow 12) have a positive effect in reducing economic vulnerability at the micro-scale. The agent *economic stakeholder* revealed to play a double role in influencing economic and physical vulnerability. While its effect is positive at the recovery phase, the continuous maintenance of insurance structures might, in the long run, have a negative effect on physical vulnerability at the micro-scale. Using focus group methods Winter (2003) found evidences of a substitution effect in which residents believed "their responsibilities relative to wildfire risk are fully discharged by maintaining insurance coverage on their home" (arrow 13). This might result in difficulties in changing the spatial arrangement of settlement patterns (built environment) that is in turn linked with ignition sources in the natural environment (Cardille et al., 2001; Syphard et al., 2007).

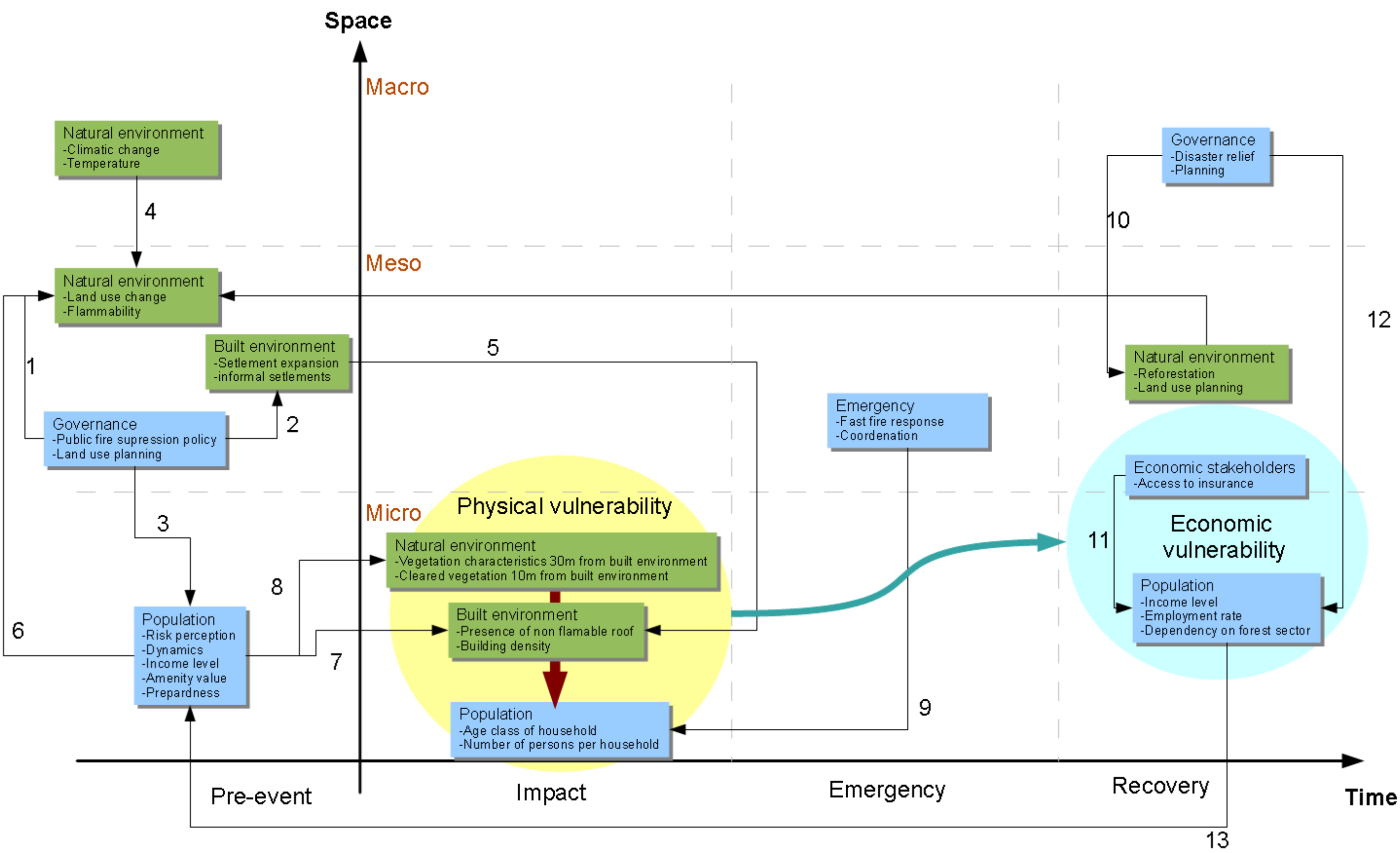

Figure 3.5: Conceptual framework for the assessment of vulnerability of people and build environment to forest fires in the WUI

The modified framework is now the basis to construct a dynamic qualitative model of vulnerability to forest fires. First a few words why such approach was taken. Investigating how different agents and objects shape the overall vulnerability requires necessarily the use of a dynamic approach. This approach allows the user to change at will selected parameters and observe the corresponding effect across the system components. Ideally, a quantitative analysis of a dynamic model would allow for more meaningful results. In the case shown here such analysis is pursued. This exercise is meant to set examples on how the original vulnerability framework produced by the Ensure project can adjusted for investigating dynamic links of vulnerability factors. For example, what parameter or combination of parameters can more effectively increase or reduce vulnerability? The overall structure of the model conceived is presented in Figure 3.6.

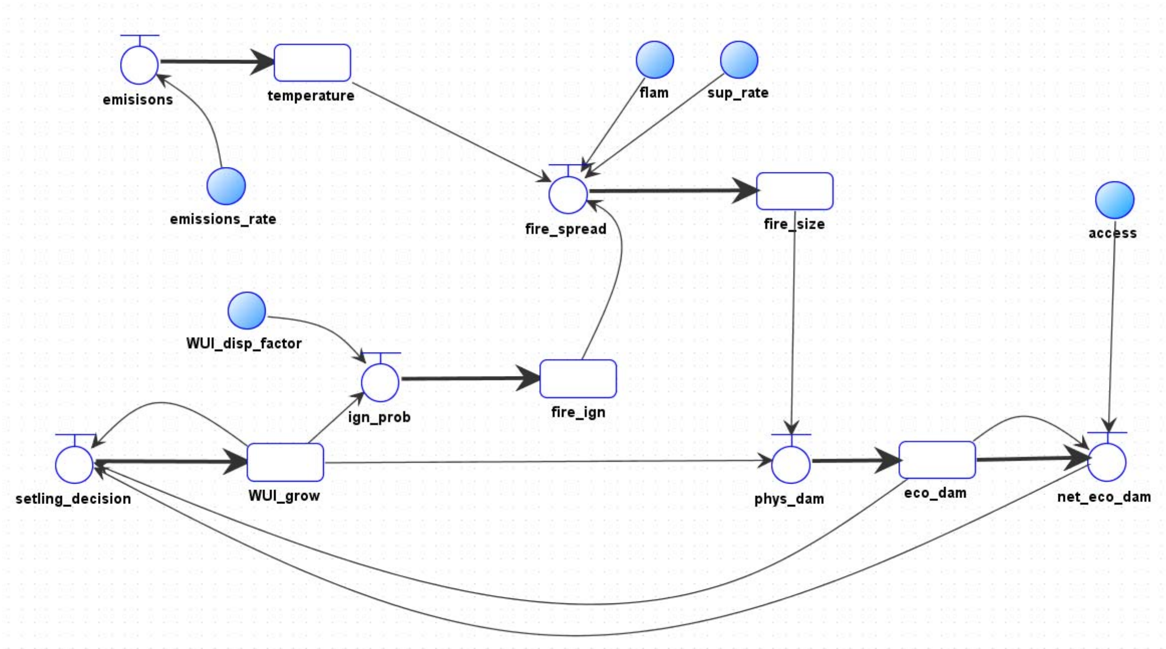

Figure 3.6: *Graphic representation of the operated model*

The model shows the dependencies between the variables temperature, fire size, fire ignition economic damages and WUI growth (represented by the squares temperature, *fire_size*, *fire_ign*, *econ_dam* and *WUI_grow* respectively in Figure 3.6). The dependency is of course not a direct one; for example, additional parameters such as emission rate (*emissions_rate*), flammability of the vegetation (*flam*), settlement development (*WUI_disp_factor*) or access to insure (*access*) (highlighted by blue circles in Figure 3.6) control the dynamics of the main variables. Main variables and additional parameters are included in the model via abstraction from literature results. For example, the density of settlements that intermingle with forest vegetation cover have been found to influence the fire ignition density as shown in Figure 3.7

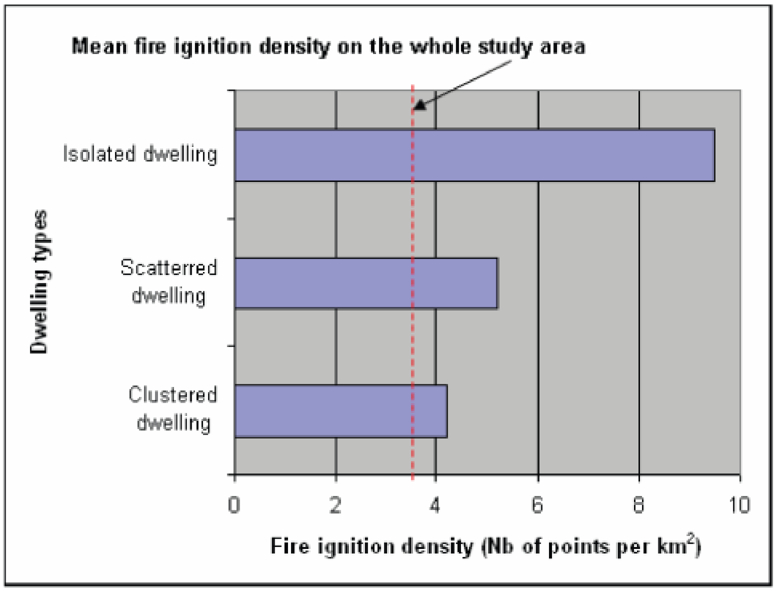

Figure 3.7: Fire ignition density value (Lampin-Maillet et al 2008)

For a case study in Southern France, fire ignition density values were found to increase greatly from clustered dwellings (4.2 fire ignition points per 1,000 ha), to scattered dwellings (5.2 fire ignition points per 1,000 ha) and finally to isolated dwellings (9.5 fire ignition points per 1,000 ha). This suggests that the spatial pattern of dwellings has a real impact on fire occurrence. Humans, and their spatial distribution, explain a part of the variability in the number of ignition points (Lampin-Maillet et al 2008). In our model the spatial pattern of dwellings is set by the parameter WUI_disp_factor that influences directly the probability of fire ignition represented by *ign_prob* in Figure 3.7.

We try to mimic the findings of literature by formulating *ign_prob = WUI_grow*(1-(1/WUI_disp_factor))* where *WUI_grow* is the total size of our settlement and *(1-(1/WUI_disp_factor))* the effect of settlement dispersion on ignitions so that when *WUI_disp_factor* decreases (this is more compact settlements) ign_prob increases. By changing the parameter WUI_*disp_factor* we can test the corresponding effect on fire ignitions across time.

A quick test shown in Figure 3.8 exemplifies how changing the WUI_disp_factor influences the probability in fire ignitions. For a WUI_disp_factor of 2 the range of ignition probabilities varies between 0.5 and 0.53 (lower panel). If we double the WUI_disp_factor, ignition probabilities range from 0.75 and aprox. 0.80. Note again that these are not quantitative numbers; they only depict a qualitative change towards higher ignitions probabilities in *WUI_disp_factor* increases. Similar exercises as the one exemplified where carried for the totality of parameters and variables that compose our model. Of particular interest in our model is the linkage of insurance access (access) and net economic damages (*net_eco_dam*) influencing the decision to construct new settlements in the WUI. This feature can be found in the lower region of Figure 2 where *net_econ_dam* links to s*ettling_decision* closing the “vulnerability” cycle of our model.

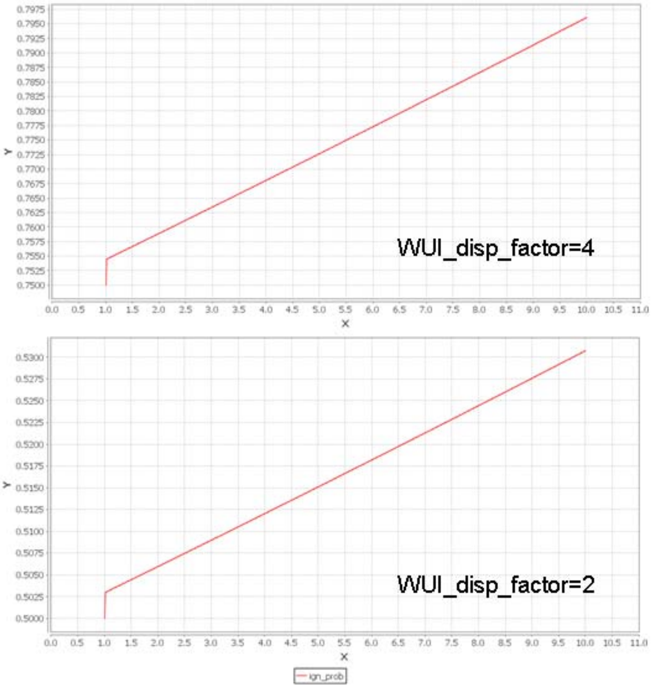

Figure 3.8: Evolution in ignition probability evolution for WUI_disp_factor=4 (top panel) and WUI_disp_factor=2 (lower panel) in time (x).

Although the positive feedback of insurance structures driving higher fire losses seems reasonable and consistent with previous studies, research has only begun to document situations in which the residential risk management calculus intersects with policy structures to create incentives for risk-amplifying behaviours (Collins 2005). Setting the mathematical formulation to mimic such complex aspect of fire prevention is therefore not a straightforward exercise. In the context of our modeling framework we have defined *net_eco_dam* as the net economic damages resulting from the application of an insurance access rate to the total expected damages (*eco_dam* in Figure 3.6). *Net_eco_dam* is therefore formulated so that *net_eco_dam = eco_dam-(eco_dam*access).* In a few words, the net economic damages are equal to total economic damages (eco_dam) minus the total economic damages that are offset by the application of an insurance access rate.

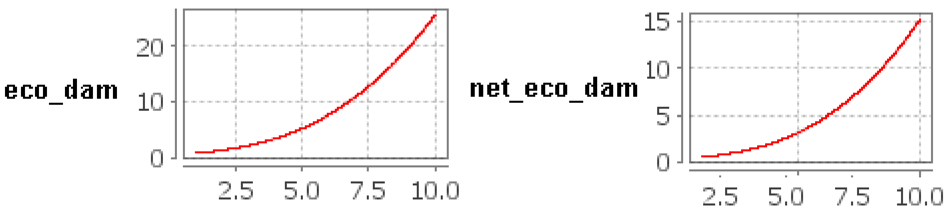

Figure 3.9: Total economic damage (left) and net economic damage (right) when and access insurance rate of 0.4 (access in Figure 2) is applied.

In Figure 3.9 we show the example of total economic damages and net economic damages after applying an access insurance rate of 0.4. The decision to settle in the WUI (*settling_decision*) in our model is a function the *net_eco_dam*, more specifically we construct settling decision so that *settling_decision = WUI_grow*(1/net_eco_dam).*

The ration *1/net_eco_dam* controls how much the WUI grows. If *net_eco_dam* assumes very high values then the WUI growth will be hindered since it is not economically feasible to build in the WUI*.* If *net_eco_dam* assume very low values, for example 0 (zero), this implies that all damages are covered by insurance practices and therefore the decision to settle in the WUI is made favorable.

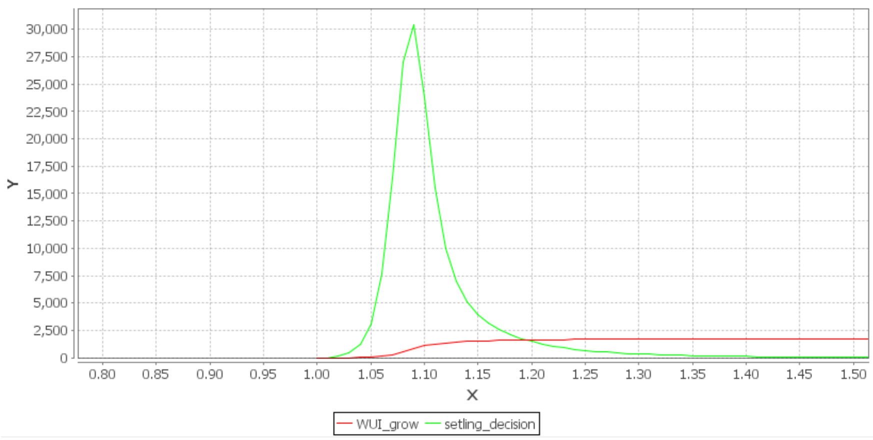

Figure 3.10 Dynamics of WUI growth and net economic damages

Results show that while losses can be compensated by the existence of insurance mechanisms (*net_eco_dam* in figure 3.10) settlement grows due to the substitution effect highlighted by arrow 13 in Figure 1. After a certain period, settlement growth originates losses that can no longer be compensated by relief mechanisms. With the growing magnitude of fire towards the end of the simulation (see Figure 3.10), settlement growth starts to stabilize.

Once this kind of interactions is understood, the model can be tested for its sensitivity (e.g. how strong the main variables react to a change in the parameters). For example, due to a consistent projected increase in temperature across the Mediterranean basin (Giorgi, 2007) and the time delays associated with atmospheric response, climate mitigation measures (represented by parameter *emissions_rate* in Figure 3.6), have limited effect in controlling losses from forest fires. Instead, socio-economic drivers of forest land-use and settlement planning significantly contribute to the intensity of losses. Management policies should therefore focus on modifying these parameters, for example, shifting away from highly flammable pine monocultures (represented by the parameter *flam* in Figure 3.6) and providing support to mixed forests with native fire resistant species has improved natural fire prevention in the Mediterranean area and also the range of economic markets to be explored (Bassi, 2008). The model also highlights how a change in access to insurance can result both in lower and higher losses rather than the generalized assumptions that access to insurance contributes to lower economic vulnerability.

The approach followed is an attempt to evaluate how multiple actors and objects interact in the context of forest fire hazard shaping physical and economic vulnerability. The challenge of linking cross scale (both in time and space) interactions is not trivial and more assessment needs to be done mainly in the fields of risk perception and individuals decisions. On the other hand, the physics of climate, vegetation and fire are now relatively well understood. This means that simple dynamic models as the one presented can be constructed to evaluate how decisions on climate mitigation, fuel loads reduction and fire fighting capacities influence vulnerability. In this respect the model highlights that although future climate variability plays a role concerning the intensity of forest fires, losses are shaped at a large extent by settlement dynamics and vegetation flammability.