ensure	**ENSURE PROJECT** *Contract n° 212045*

WP 2: Integration and connection of vulnerabilities

Del. 2.2:

Integration of different vulnerabilities vs. Natural and Na-tech Hazards

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Short Description:

The deliverable 2.2, according to the DOW, deals with some crucial questions for an integrated vulnerability assessment. In detail, it emphasizes the growing complexity of hazards, highlighting the need for a holistic and dynamic approach both to hazard and vulnerability assessment and suggesting some tools for exploring the complex chains of hazards, vulnerabilities and damages which characterize complex events. Moreover, it deepens the concept of resilience, providing inputs for turning such a concept into operational terms and explores the relationships between vulnerability and resilience, mainly among the several facets of vulnerability and the different dimensions of resilience. Based on past disasters analyses, it highlights that mitigation measures addressed to reduce some aspect of vulnerability do not necessarily increase resilience and that measures addressed to enhance resilience do not necessary reduce vulnerability. Finally, according to the main outcomes of this task and of the previous ones, some general principles and requirements for setting up a methodological framework driving an integrated vulnerability assessment are provided.

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1 Executive summary

The deliverable report, based on the results of previous Tasks of the WP2 (2.1, 2.2, 2.3) and on further investigations on vulnerability and resilience towards natural, na-tech and other typologies of complex hazardous events, provides some general principles that have to be taken into account for an integrated vulnerability assessment.

According to the Dow, the task 2.4 (and consequently this deliverable) is aimed at providing suggestions for an integrated approach to vulnerabilities with respect to natural and na-tech hazards, whereas the Work Package 4 will be addressed to define the methodological and operative aspects related to the integration of vulnerabilities.

To achieve this aim, some relevant topics, not completely explored in the previous tasks, have been deepened.

Since the different perspectives of vulnerabilities have to be integrated taking into account both natural and na-tech hazards and according to the fact that, starting from the Nineties, many authors have clearly recognized the increasing complexity of hazards and disasters, in the chapter 3 the concept of complex hazardous events, including na-tech ones, has been deepened. Moreover, the different aspects of vulnerabilities and their relationships with respect to such events have been explored. In detail, grounding on the definition and classification of complex events, a review of current approaches to such events, especially to na-tech ones, has been provided. Besides, due to the lack in current methodologies for assessing vulnerabilities to such events, the main aspects of vulnerability to complex hazardous events and mainly to na-techs have been explored through the analysis of three case-studies: the floods occurred in England during the summer 2007 (developed by the MDX team); a comparison between the earthquake that hit the city of Kobe (Japan) in 1995 inducing fires in several areas and the Kocaeli (Turkey) earthquake (developed by the POLIMI team), occurred in 1999, which hit a large industrial area, triggering several technological accidents; the complex chain of natural and technological events which characterized the Hurricane Katrina occurred in New Orleans in 2005.

In the chapter 4, the concept of resilience has been investigated. According to the fact that the main aim of an integrated assessment of vulnerabilities is to enhance resilience and that such a concept has gained prominence in the last 15 years in most of the international reports devoted to risk reduction, the main roots of the resilience concept, its evolution and the reasons that contributed to the adoption of such a concept in the disaster field have been explored. Moreover, in order to systematize the heterogeneity of approaches due to the different disciplinary perspectives, a list of major dimensions of resilience is reported with respect to the wide literature developed over the last 30 years. Finally, due to the fact that the absence of operational approaches and tools enabling communities to effectively pursue resilience represents the main lack in current literature and that the few available studies are mainly based on quantitative approaches driving towards simplified and aggregate indexes, a framework which identifies the key-dimensions of resilience, sorting them into a circular framework according to the main phases of the disaster cycle, and highlights the mutual influences among them, has been provided. Such a framework should provide a basic operational tool for driving effective policies towards a resilience enhancement.

In the fifth chapter, the relationships between resilience and vulnerability have been explored grounding on the deepening of the resilience concept carried out in the previous chapter, on the inputs from previous tasks (namely those ones developed within the WP1), on the review of scientific literature on such a relation and, finally, on the analyses of past disasters. This chapter has been mainly addressed to answer a crucial question for the Ensure Project: do measures aimed at reducing vulnerability always lead to enhance resilience of communities and territories? Some case studies (developed with the contribution of BRGM) have been provided for answering to such a question. In detail, they show that mitigation measures addressed to reduce one or more aspects of vulnerability can increase other facets of vulnerability itself or the same one with respect to a different hazard, or can be ineffective for enhancing resilience or, even, should result in a decrease of the resilience itself. Summing up, case studies raise many doubts about the widespread assumption that vulnerability represents the flip side of resilience, highlighting that the multiple and mutual influences among the different facets of vulnerability and the key dimensions of resilience cannot be forced into simple cause-effects relationships.

The last chapter, grounding on the main outcomes of the previous WP2 tasks, on the aspects of vulnerability to complex hazardous events arising from case studies and on the investigated interactions between vulnerability and resilience, namely among their several facets, provides some general principles for building up a methodological framework for an Integrated Vulnerability Assessment. Such principles represent the basic requirements that cannot be missed in order to renew the field of vulnerability assessment in terms of approaches, methods and tools. Furthermore these principles provide a first answer to the many questions raised along the research path that has been developed up to now and pave the way for other questions to be developed in the WP3.

2 Introduction

According to the Dow, the task 2.4 has to:

- integrate the different perspectives of vulnerability with respect to Natural and Na-tech hazards to enhance resilience of communities;
- provide a wider knowledge-base approach for the implementation of mitigation measures;
- explore potentials and limits on a feasible approach for such an integration.

In order to pursue these aims, the work has been addressed both to integrate and systematize the contributions from previous tasks and to fill in some gaps in the knowledge or, better, to deepen some crucial points mentioned or partially faced in previous tasks.

First of all, the topic of Na-tech hazards has been faced, framing these events into the wider concept of "complex hazardous events". Even though in the last decades na-tech events are gaining prominence into the scientific literature, they represent only one type of complex events, an example of how hazards "are becoming an interactive mix of natural, technological and social events" (Mitchell, 1999). Even though the complex nature of hazards is currently largely recognized, very few studies focused on vulnerability to such events have been carried out and methods and procedures for understanding and measuring vulnerability to complex hazardous events are still largely missing. Therefore, trying to fill this gap, the main aspects of vulnerability to complex hazardous events and mainly to na-tech events have been deepened. In detail, grounding on the description of past events, the main aspects of vulnerability arising in case of complex hazardous events and their multiple relationships have been analyzed.

Moreover, the concept of resilience has been investigated. Such a concept became relevant in the disaster field mainly after the Hurricane Katrina in 2005 and has been largely widespread into several international reports devoted to risk reduction and to sustainability initiatives published in the last 15 years. The resilience concept had been already introduced in the previous tasks of the Ensure project, but a clear definition of such a concept was still missing within the project. The latter point is crucial since, according to some authors "resilience is in danger of becoming a vacuous buzzword from overuse and ambiguity" (Rose, 2007). Therefore, starting from the main definition of the resilience provided within the International documents focused on risk reduction, the roots and the evolution path of the concept and the reasons leading to its application into the disaster field have been explored. Finally, some tools for turning resilience into operational terms have been provided. A first one, based on the Bruneau's model, aims at quantifying resilience: although relevant, since it represents one of the first attempts to measure resilience, it takes into account only few of the multiple dimensions recognized, in current literature, as crucial for explaining resilience. Moreover, the mentioned approach grounds on the idea that Resilience represents the ability of a system to bounce back or to restore a previous state of the system itself. Thus, the possibility of achieving levels of functioning, by adapting to new circumstances and learning from the disaster experience - that is an important aspect of resilience interpreted as a dynamic and not conservative concept - is neglected. A second tool, built up according to a more conceptual and qualitative approach, has been carried out grounding on the identification of the key dimensions of the resilience stemming from current literature. The selected key dimensions have been structured into a circular scheme which follows the main phases of the disaster cycle and sorted into concentric circles that, starting from the most internal one in which resilience has been placed, drive toward a progressive specification of its dimensions. Such a framework can represent an useful tool for defining and monitoring the effectiveness of policies aimed at enhancing resilience.

According to the Dow, the task 2.4 has to provide a wider knowledge-base approach for the implementation of mitigation measures aimed at reducing vulnerabilities to natural and na-tech hazards to enhance resilience. Thus, two key questions have been faced: first of all, which kind of relation exists between vulnerability and resilience? Such a question is currently largely debated in scientific literature and is crucial for providing an answer to the second one. The latter refers to the effectiveness of mitigation measures - based on current vulnerability analyses generally focused on individual hazards - in reducing the many facets of vulnerability and, mainly, in enhancing resilience. The relation between vulnerability and resilience has been explored grounding, on the one hand, on the deepening of the resilience concept provided in this task and, on the other hand, on the inputs related to the concept of vulnerability coming out from previous tasks (WP1), Moreover, such a relation has been further deepened through the review of current scientific literature and the analysis of past disasters. Finally, based on several case studies, it has been largely demonstrated that mitigation measures aimed at reducing one aspect of vulnerability or the vulnerability to one hazard may induce an increase of other aspects of vulnerability or, even, of the same aspect with respect to other hazard factors. Moreover, since vulnerability cannot be interpreted as the flip-side of resilience, mitigation measures addressed to reduce vulnerability do not necessarily result in an enhancing of resilience and vice-versa.

Finally, since this task represents the final objective of the work package 2, a large amount of the work has been devoted to systematize the outcomes from previous tasks related to the relationships among the several facets of vulnerability. Based on the main hints stemming from them and on those ones coming out from the deepening of the topics of vulnerability to complex hazardous events and of the relation between vulnerability and resilience, some basic principles for integrating vulnerabilities to natural and na-tech events in order to enhance the resilience of communities and territories have been provided.

3 Complex hazardous events: a challenge for vulnerability analysis

3.1 Complex hazardous events: definition and classification

In the previous tasks of the Ensure Project, the topic of vulnerability to natural hazards with some references to na-tech events (technological accidents triggered by natural hazards) has been explored.

In the state of art developed in the previous WP, the many aspects of vulnerability have been faced. According to the main results of the WP1, it is possible to state that while the approaches to structural vulnerability have been historically developed with respect to, and are still mainly focused on, individual hazards, the approaches to territorial or socio-economic vulnerability, although applied to specific hazards, provide assessment methodologies that can be effectively used for and easily adapted to different typologies of hazards.

What should be underlined is that - mostly in the field of structural vulnerability that is also the most consolidated one - the strong hazard-oriented approach has led to undervalue the very complex nature of the hazardous events. It is not by chance that with respect to hazards which are intrinsically "multi-hazard", such as volcanic events, in the WP1 it is stated that:

"Although volcano hazard maps are quite common nowadays, vulnerability assessment studies and risk maps remain relatively unusual. Vulnerability assessment methodologies are clearly not as developed for volcanoes (…). The explanation mostly lies in the multiplicity of causes that might induce damages, as there are many types of volcanic activities and eruptions (…)."

Thus, since hazard analyses have been generally focused on individual events, such an approach has consequently affected the way of facing vulnerability analyses.

Nevertheless, since the Nineties, some authors have stressed the increasing complexity of hazards, underlining the fact that, namely in urban areas, hazards were shifting from individual phenomena towards "an interactive mix of natural, technological and social events" (Mitchell, 1999). Moreover, the complexity of modern disasters, characterized by diverse phenomena with a greater potential for adverse impact and due to changes of hazards, of exposure and vulnerability of territorial systems and to the interactive mix of such changes, has been stressed too (McEntire et al. 2002).

With respect to such changes, the need for a "revolution" into approaching the "disaster problem" has been recognized (McEntire et al. 2002): nevertheless, up to now the most widespread methods and tools available for analyzing hazard and vulnerability are still based on the reductionist approach that have for long driven knowledge in science. According to many scholars such a reductionist approach is incomplete and inconsistent in order to analyze complex systems or phenomena. This is particularly true for what concerns disasters and, especially, the impact of hazards on urban systems, which are both complex and fast-evolving systems.

The need for new methods aimed at providing a "reliable quantitative estimation of individual and coupled events" (Lipiatou and Peter, 2009) has been recently emphasized within some European research projects developed within the FP6, such as the Natural Hazard Risk Assessment (NaRas) one. The latter provides some examples of hazard analyses in which different kinds of hazards (natural and technological) affecting a given area are compared and ranked, taking into account the potential cascade effects. These examples represent a relevant starting point for new approaches to the disaster problem even though the challenges and opportunities that such a shift in the field of hazard analyses should induce in the one of vulnerability have still to be fully explored.

Therefore in this paragraph, according to the increasing attention paid to the changes characterizing hazardous events, the main typologies of complex hazardous events will be explored as a starting point for deepening the topic of vulnerability to such events in the following paragraphs.

As above mentioned, in the last decades the concept of complexity is more and more associated to the hazard, risk and disaster ones: such a complexity mostly depends on the interaction between hazards and territorial systems. Nevertheless, the term "complex hazardous events" aims at stressing that there is a level of complexity often associated first of all with the hazard itself. In most cases, when we refer to individual hazards we neglect or undervalue that the same hazard can occur more than once during a given temporal span or can occur in different points within a given area (multi-site event), inducing serious and sometimes dramatic consequences. When we tackle seismic events, for example, in many cases we refer to a specific and instantaneous event and assess the vulnerability of a given context to such an event. What would change, in terms of vulnerability analysis, if we considered that the stress which a given system is exposed to could be not only the instantaneous one, but the one caused by the several events taking place over time, as it happened in the Italian Abruzzo Region?

Moreover, some hydrogeological events, such as mudflows, represent not only multi-site events but they also show a high temporal variability (since they can occur in a time span ranging from few minutes to many hours).

Furthermore, many natural hazards can trigger other natural ones – such as landslides induced by earthquakes – or cause technological accidents, such as explosions or toxic releases from storage facilities.

According to the different cases mentioned above, three macro-typologies of complex hazardous events can be distinguished:

- a first one refers to hazardous events that act as a sequence of repeated events of the same typology (e.g. seismic events or floods), or even to sequences of hazardous events of the same typology (e.g. mudflows), occurring in different points of the same geographical area at different times (multi-site events);
- a second one refers to events that, with reference to a given time span, are characterized by a sequence of phenomena, different in nature and features, such as the volcanic events;
- a third one refers to chains of events, in which, a triggering hazardous one induce other natural or technological hazards.

The first category includes, for example, natural widespread, localized or multi-site events, occurring in a given area at different times in a short or medium time span (from days to months). In case of sequences of hazardous events, the same targets can be affected by successive impacts of the same hazard with a consequent progressive decrease of structural efficiency or of coping capacity of the exposed elements.

The second category includes, for example, volcanic eruptions which differs from the previous phenomena since, according to different temporal phases, different phenomena such as lava flows, ash falls, pyroclastic flows, and so on, will occur. In this case, affected areas and targets can be different according to the different phenomena.

The third category refers to hazardous events triggering other events: in these cases, the phenomena have different features and the affected areas and targets will not necessarily overlap. For example, a triggering hazardous event characterized by a wide impact area (such as an earthquake) may induce several technological accidents in areas being very far from each other, which may affect very small areas in comparison with those hit by the triggering event. Vice versa, strongly localized phenomena, such as landslides, hitting an industrial plant may induce a major accident involving a wider area or causing a complex chain of events due to a domino effect among industrial plants placed at short distance. Thus chained events can have different levels of complexity, since a natural event can trigger one or more technological accidents and, contextually, other secondary natural events, while the induced technological event can trigger, in turn, domino effects. In these cases, complexity depends not only on the peculiarities of the hazard, but even on the potential chains of events that a primary hazardous event can trigger. These chains can be articulated into different typologies too, according to the nature of the triggering hazard and the features of the induced one (natural-natural, natural-technological or technological-technological). Other elements can be relevant for classifying those chains, such as the temporal development (fast or slow chains) or the number of secondary triggered hazards (simple or multiple chains).

The last category is characterized by phenomena generally fast evolving and, according to Perrow (1999), by "tightly coupled events, (….) since one triggers the other one".

On the opposite, the first two categories include events which, according to Perrow (1999), could be defined as "loosely coupled": in the first case, the phenomena may depend, for example, on the same meteorological conditions; in the second one, ash falls or lava flows are separate phenomena, belonging to the same volcanic eruption. In both cases, the phenomena cannot be interpreted as completely separated, but it is not possible to say that one phenomenon triggers the other one.

Therefore, both the events whose complexity depends on intrinsic features of the hazard itself and the events whose complexity is due to the interactions among hazard, affected territorial context and interactions between hazards and the territory can be defined as "complex hazardous events".

The shifting from individual to complex hazardous events has relevant implications in the vulnerability assessment of exposed elements and systems. In case of complex hazardous events, vulnerability of elements or systems has to be investigated according not to their capability of facing each event, but of dealing with the synergies among the different hazards and between them and the affected areas. According to the different chains of hazardous events, not only the affected areas and the involved territorial targets, but also their vulnerability will dynamically change.

On the other side, it is widely recognized that complex systems cannot be explained and analyzed through reductionist approaches, targeted to subdivide them into elements which could be separately analyzed. A relevant input to better understand and face those phenomena issues from the *Theory of the emerging properties* (Odum, 1988), developed in the ecologic field. According to this theory, in a hierarchic system of relationships, some properties or behaviors emerge at a determined level of complexity, but they do not exist at a lower level.

An emerging behavior appears when simple entities acting in a given environment, give rise – as in the case of a community – to behaviors that cannot be inferred from the sum of the behaviors of each entity. The emerging order, in fact, does not issue from the simple coexistence among individual elements, but from their interactions.

Hence, the theory of emerging properties allows to state that the risk due to the occurrence of a complex hazardous event and to the vulnerability of the exposed elements and systems cannot be reduced to the sum of the damages due to each event and to the vulnerability to such event of each exposed element. This is a crucial aspect if we consider that up to now vulnerability has been mostly analyzed with reference to individual hazards, even when complex hazards were at stake.

For example, up to now, methodologies and parameters to assess physical vulnerability of a building to an earthquake or a landslide have been developed. Anyway, such methods do not generally consider the time sequence of the events and namely the fact that the physical vulnerability to the landslide of that building, already hit by an earthquake, will never be comparable to the one characterizing a wholly efficient building.

What above-stated can be easily applied to other "territorial targets" such as people. For example, in case of earthquake, when the phenomenon occurs - according to the emergency plan generally sized on individual hazards - people leave their houses and reach the first aid locations. In that moment a landslide due to an earthquakes may occur (unexpected event), hitting the escaping people, with consequences being totally different from those that would have been produced by the two events, the earthquake and the landslide, considered separately.

The complex hazardous events drive us to face a relevant challenge that affects, first of all, the field of hazard analyses, calling for a less sectoral approach and a larger attention to the study and prefiguration of the potential development over time and in space of the same event and/or of the potential chains of natural and technological events. Moreover, in the field of vulnerability analysis, not only the different aspects of vulnerability have to be taken into account but also their dynamics due to the spatial and temporal changes of each hazards and to the potential chains of hazards.

Provitolo (2007) clearly stresses the need for getting rid of the notion shared by the scientific community which considers the risk as a combination of hazard and vulnerability, underlying that the word "combination (…) doesn't integrate interactions between constituents". On the contrary, he defines disaster as a complex set of hazard(s) and vulnerability(ies). Summing up, disasters have to be interpreted as emergent phenomena of hazards and vulnerabilities: by neglecting the various aspects of the vulnerability itself (structural, socio-economic, etc.) and of its dynamic change according to the hazards evolution, "important aspects of the structure and the global behavior of disasters were missed out".

3.2 Na-tech events: an example of complex hazardous events

Na-Tech events are a typical example of complex hazardous events. In case of na-techs, the chain of events which generally characterizes a natural disaster (the occurrence of the hazard, its impact on different territorial targets, the multiple physical damages, the social and economic consequences at different scales, etc…) becomes even more complex. Such a complexity is due to the presence of industries or critical facilities which are, in the meanwhile, a target vulnerable to the natural hazard and a potential source of secondary hazards affecting the surrounding areas. Thus, the nature and the amount of the damages may significantly increase and the emergency management may be further complicated and, as many past events demonstrate, the time required for going back to normal life may lengthen.

Na-Tech is the English acronym of Natural-Technological. "This term denotes an accident initiated by a natural disaster which results in the release of hazardous materials. This includes releases from fixed chemical installations and spills from oil and gas pipelines" (Kraussmann and Cruz, 2008). It is still matter of discussion if this term has to be broadened to incorporate also lifelines downed by a natural disaster.

The term Na-Tech was used for the first time in the early Nineties, in the work developed by Showalter and Myers (1992), which singled out the majority of the problems characterizing such phenomena, which have been largely reviewed and investigated by the following scientific literature. In particular, the following features were underlined:

- the complex nature – synergic or chained – of Na-Techs;

- the relevance, meant as frequency of occurrence, of those events;
- the general inadequacy of studies and researches focusing on risk and of the ordinary policies for emergency preparedness and management.

A classification of Na-Tech events was provided in 1994 by Clerc and Le Claire. They stated that: "a natural event […] can directly cause a technological accident […]. The vice versa is also true, with anthropogenic influences altering natural events such as flooding and storm". Based on such statement, the authors introduced a classification of Na-Tech events in Fast, Slow and Spyraling events. The difference between Fast and Slow Na-Tech events can be found in the triggering factor of the disaster and in the time span in which it occurs. In the first ones, the natural hazard (such as an earthquake or a flood) induces, almost instantaneously, a technological accident. Generally, this type of events "happens very quickly" and requires a fast answer. In case of Slow Na-techs, on the contrary, human activities induce slow changes of the natural balances, modifying the hazardous conditions of a territory. "The classic case (…) would appear to be global warming. Which many scientists see as the natural response to an increase in so called greenhouses gases in the atmosphere. The result of such global warming may be rising sea levels, which increase risk of flooding in low lying areas (…)" (Clerc and Le Claire, 1994), with relevant consequences, even in terms of technological accidents on the affected human and natural environments. Finally, Spiraling Na-Tech can be seen as the product of Fast and Slow Na-Techs and are difficult to be prefigured, since they are produced by chains of single events potentially not dangerous. An example is the "deforestation that eventually trigger natural hazards such as floods which, in turn, cause fast Na-Techs such as the destruction of a chemical plant" (Clerc and Le Claire, 1994).

In the last twenty years many Na-Tech events occurred over the world. Generally speaking it is possible to state that the most investigated and examined Na-tech events in the scientific literature are the technological accidents due to earthquakes and floods. Nevertheless, these events are not the only potential triggering factors. As stated by Showalter and Myers (1992) "almost every natural disaster is accompanied by some sort of technological disaster". Young (2002) calculated that from 1990 to 1999 in the United States "over half of the natural events (52.0%) were associated with at least one Tech release". Nearly half (42%) of these Na-Techs were generated by wind related storms, the 30.5% by flood related storms, the 19.2% by severe winter storms and 2.2% by earthquake and aftershocks (Young, 2002). In Europe, statistics on Na-Tech events were reported in Cruz et al. (2004). According to them and to their data source, the Major Accident Reporting System Database (MARS) of the EC's Major Accidents Hazard Bureau (MAHB), an average rate of one Na-Tech accident per year occurred between 1985 and 2003. Nevertheless, those statistical data have not been recently updated; moreover, some databases, as the MARS one, are not freely accessible for private users.

Some authors (Cruz et al. 2004) state that an increase of Na-Tech events in the next decades is expected, due to the ongoing climate changes. According to that, it should be mentioned that Na-Tech events due to meteorological phenomena, such as floods, are difficult to be managed in relation to their development on wide areas, which get often over the boundaries of single states, as it occurred in the disaster of Baia Mare in January 2000 (OECD, 2006).

The potential increase of such events in Europe is very important for the institutions of the Member States appointed to the control, prevention and management of those disasters. Few years ago – and perhaps due to the perceived alarm – the European Parliament issued a Directive, the 2007/60/CE (The Flood Directive), concerning the assessment and management of flood hazards, in which technological hazards are considered as one of the elements to be taken into account in setting up the emergency plans for managing flood risk.

Although the relevance of such events has been largely recognized, methods and procedures aimed at measuring vulnerability to na-tech events are still required. In-depth studies related to the vulnerability of hazardous plants to some natural events and to the potential induced accidents (Salzano et al. 2003; Fabbrocino et al. 2005; Campedel et al. 2007; Krausmann and Mushtaq, 2008) are currently available. On the opposite, studies deepening social, economic, systemic aspects of vulnerability are still largely missing.
A review of the most recent works on na-techs can be found on the special issue of the Natural Hazard Journal "NA-TECH disasters: when natural hazards trigger technological accidents" published in 2008.

3.3 Key aspects of vulnerability/ies to complex hazardous events: case studies

To shed light on the features of the complex hazardous events, including na-tech ones, and mainly on their implications in terms of vulnerability analysis, in this paragraph some case studies will be examined.

3.3.1 The summer 2007 floods in England (MDX)

In the summer of 2007, England and Wales experienced exceptional rainfall resulting in the wettest summer since records began and extensive flooding. More than 55,000 properties (48,000 households and almost 7,300 businesses) were flooded, 13 lives were lost and around 7,000 people had to be rescued from the flood waters by emergency services. Thousands of people were left homeless. The costs of the summer floods were nationally estimated at more than £3 billion in insurance claims alone, making the floods the most expensive in the world that year.

Although many flood defences were overwhelmed by the sheer volume of water, a compounding factor was the large amount of flooding in urban areas from surface water (pluvial floods) and the lack of capacity of drainage systems to cope with the volume. Essential services, power supplies, transport links and telecommunications were disrupted and the flood resulted in the largest loss of essential services since World War II and the biggest civil emergency in British history. Around half a million people were left without mains water supply and electricity. Loss of the Mythe water treatment works lead to 350,000 people being without mains water supply for up to 17 days. The loss of water supply led to 1,000 water 'bowsers' and 2.5 million litres of bottled water being distributed by local authorities in various locations. This resulted in the potential social vulnerability of affected populations, not just for those flooded but also for those affected outside the flooded areas, many of whom had to move out of their homes until water supplies were returned. Vulnerable people and those without transport were particularly affected and had difficulties in collecting water supplies. Moreover, lack of water supply posed potential risks to public health and there were also arguments and tension within communities over the allocations of bottled water supplies.

The summer 2007 floods in England can be seen as an example of a complex hazardous event which developed over time and space. The floods were experienced in two phases: the first in June largely affected the north of England and large cities such as Hull and Sheffield while the second event in July largely affected the west-midlands and towns such as Gloucester, Tewkesbury and Oxford. The different flood events were also examples of different types of flooding, which often require different risk mitigation measures. For example the June events in Hull and Sheffield were an example of *pluvial* (surface water) flooding whereby the intense rainfall overwhelmed the capacity of local drainage systems to cope with the volume of water involved, subsequently flooding thousands of properties. The June floods happened very quickly and there were no flood warning systems available to deal with such events. However, the July floods were largely a result of *fluvial* (river) flooding, whereby the protracted rainfall had lead to saturated catchments and subsequently to rivers overtopping their banks. This flood was a slower-onset event and in many cases flood warnings were able to be issued to many properties.

The fact that two large-scale events occurred so rapidly one after the other stretched local, regional and national resources in terms of both responding to the events and during the recovery process. Moreover, the loss of essential services and critical infrastructure during the floods extended well beyond the areas that were flooded, highlighting the importance of risk assessment and mitigation preparedness of infrastructure operators and calling for a more systemic approach to understanding the vulnerability of critical infrastructure. An extensive independent review of the floods was commissioned by the Government and reported one year later in 2008, resulting in 92 recommendations for mitigating future flood risk and increasing resilience which touch upon a wide range of issues and organisations (Pitt, 2008).

3.3.2 Kobe and Kocaeli earthquakes (POLIMI)

In the recent years, earthquakes hit cities not only with seismic waves but they also trigger other hazards generally due to failures in industrial activities or in lifelines. In this paragraph, two recent and remarkable examples for both impacts are evaluated to highlight the main factors characterizing na-tech events. In the first two sections Kobe and Kocaeli earthquakes are briefly introduced. The third section focuses on the main vulnerability factors arising from the case-studies. In the last section, some concluding remarks are provided, considering which are the vulnerable points and how to increase resilience .

Kobe Earthquake

The Great Hanshin-Awaji Earthquake (Kobe Earthquake) occurred on the 17th of January 1995 with a magnitude (Mw) of 6,8 (7,2 JMA scale) on the southern part of Hyogo Prefecture, on the northern end of the Awaji Island (Japan). About 180,000 buildings were destroyed and 300.000 people lost their homes. Because of building collapses and fires, 6934 people died and 34,900 people were injured (The City of Kobe, 2008). The fires following the earthquake had devastating impacts on both buildings and human life. About 10% of the victims died because of fires (Tierney and Goltz, 1997), 6965 buildings completely burned, 80 half burned and 270 partially burned (The City of Kobe, 2008). The Kobe earthquake was defined as the Japan’s worst earthquake since the Great Kanto Earthquake in 1923.

The background of damage is lying down in structural deficits of old buildings, ground liquefaction and failure in gas pipelines. As Japan suffers from big typhoons and heavy winds, the basic structural approach in building construction has been the combination of heavy roof and weaker walls (shear walls). However, this structural aspect of traditional Japanese houses carries great inherent vulnerability against earthquakes where buildings are likely to collapse as pancake form. Despite building codes are well developed and implemented in Japan, as the older building stock does not respond to the newest building code, the damage due to the Great Hanshin-Awaji Earthquake was vast. On the other hand, liquefaction in filled up areas caused buildings to sink or to tilt (except newly installed Kansai International Airport which matches newer technology and standards). Fires following the earthquake were caused by breaks in gas pipelines which ignited and expanded due to wooden structures.

The City of Kobe has a form of linear development between Rocco Mountains and Pacific Ocean, therefore there are few alternatives of roads and railway system to connect the city to other settlements. Consequently, the collapse of the Hanshin Expressway onto the road below, damages on railways and interruption of access in several secondary roads made difficult to reach affected areas for search and rescue teams and to survivors to go out from affected areas. The failure in infrastructural system of Kobe brought secondary impacts. On the one hand, accessibility decreased in both traffic flows and communication lines; on the other hand, as Osaka Gas Company was late in shutting down the system, ignited gas caused several fires and breaks in water pipes made difficult to extinguish these fires (Menoni, 2001). The recovery process of damaged infrastructural system took 7 days for electricity and 20 months for reconstruction of Hanshin Expressway. Water, industrial activities and gas pipelines began working about 3 months after of the earthquake (The City of Kobe, 2008).

The economic structure of Kobe, and consequently Japan, suffered because of damages in both commercial and industrial facilities and in production lines and stocks. About 80% of SME factories, 1/3 of Kobe's shopping districts and half of the markets were heavily damaged. On the other hand, the interruption of expressways affected not only Kobe's economy but also Japanese economy as well. Therefore, economic losses due to material damage was officially declared as 1,5-2,0 % of GDP of Japan (The City of Kobe, 2008).

Japanese disaster management system had a very good reputation in both national and international perception until the Kobe earthquake occurred. Government and inter-governmental organizations were widely criticized due to mismanagement in response. First, Japanese system during crises is very determined with every single detail at every hierarchical level. Therefore, it excludes flexibility which may be crucial when an un-expectedly large size event happens. Consequently, in the immediate response, the rigidity of the Japanese system frustrated quick decisions and actions (Menoni, 2001). Secondly, as in the past volunteer activities were not widespread in Japan, this factor was not taken into account in governmental emergency plans. However, because of the size of the event and the intense media reporting, volunteer activities were at high levels in both national and international participation (The City of Kobe, 2008). The third deficiency was pretty much related with systemic failures. "Local officials in Kobe City and Hyogo Prefecture were initially unaware of the magnitude of the disaster because of major communications problems and traffic congestion that made movement difficult throughout the impact area and because so many emergency responders and public officials were also disaster victims themselves" (The City of Kobe, 2008).

Kocaeli Earthquake

On the 17th of August 1999, at 3:02 a.m local time, an earthquake with a magnitude (Mw) of 7,4 occurred in the Western Part of the North Anatolian Fault (Turkey). The epicenter of the earthquake was Golcuk and the affected area by this ground shaking was the most populated and industrialized region of Turkey (Eastern Marmara Region). According to the official records, the earthquake caused 17,480 deaths and 43,953 injuries and displaced more than 250,000 people (Disaster Affaires General Directorate of Turkey). About 100.000 buildings suffered heavy damage or collapsed (Sengezer and Koc, 2005) and more than 300.000 housing units destroyed (Bibbee et al., 2000). The Kocaeli Earthquake was denoted as the second biggest earthquake in Turkish seismic history after the Erzincan Earthquake in 1939.

The main reasons of vast damages in buildings due to earthquake were considered as some weaknesses such as soft-storey in buildings, irregularity, inadequate reinforcement, corrosion, poor concrete and weak infill walls (Spence et al., 2003). Besides the inherent deficiency of buildings, because of soil conditions and liquefaction, several buildings (except buildings having less than three storeys) were either sank on soil or tilted (Mollamahmutoglu et al., 2003). In the field observations after the earthquake it was noted "… that ground shaking damage was not as widely observed in areas of liquefaction. This phenomenon is sometimes referred to as a base isolation effect, whereby the overall damage due to ground shaking is reduced because once liquefaction is triggered, it limits the intensity of ground shaking" (Bird et al., 2004).

The aspect that distinguishes this earthquake from the others occurred in Turkey is that it hit large industries working on petroleum, chemistry, ammoniac and other hazardous materials. Therefore, although all attention were drawn on visible impacts of earthquake such as collapsed buildings and fire at TUPRAS Oil Refinery - which lasted for 4 days - several instantly invisible environmental damages, due to spill or leakage of hazardous materials into water, soil and air have been revealed afterword. According to some field surveys, 50.000 kg crude oil released into Izmit Bay; release of 1,2 million kg of cryongenic oxygen; spill of 100.000 kg of phosphoric acid; release of 200.000 kg of hazardous anhydrous ammonia; leakage of 6,5 million kg of toxic acrylonitrile; because of fires exposure of 350.000 m^3 of naphtha and crude oil to the atmosphere (Steinberg and Cruz, 2004; Cruz et al., 2004). Once considering traditional and well-known location theory for industrial facilities, new establishments require being near to (raw) materials, labor force and market. Furthermore, according to the type of production and goods, variety of transportation modes is desirable. Kocaeli region represents an implemented model of these theories. However, during the development process of this highly industrialized area, natural threats were underestimated; therefore, 1999 earthquake caused a large scale disaster.

In the establishment process of TUPRAS, in 1976, the seismicity of the region and the precautions which had to be adopted during the construction process were studied. According to these studies, the average return period of earthquake with magnitude 7.5 or greater was noted as 125 years; thus, considering that a life period of naphtha tanks is about 50 years, therefore the maximum earthquake expected in this period would be around 6.5-7.0 (Danis and Gorgun, 2005). However, 26 year later from the establishment of TUPRAS, the Kocaeli earthquake occurred with a magnitude of 7.4. The first fire started in a floating roof of naphtha tank and the second one started due to the collapsed of 90 meters height stack (Scawthorn et al., 2005). Because of breaks in water pipe system, fire extinguisher systems and attempts remained insufficient and help was asked from other refineries in Turkey. The equipments suffered from damages mostly because most of them were not anchored or fixed not only at TUPRAS Oil Refinery but also at other industrial facilities in Kocaeli.

Izmit earthquake is a remarkable example even for showing effects of na-techs on response organization. After the first fire initiated at TUPRAS, governorship of Kocaeli ordered to evacuate 1 km adjacent areas to the refinery (Hurriyet, 1999). In the border of this area there are residential areas affected by the earthquake and TEM (Trans European Motorway) is passing through. This declaration stopped partially search and rescue activities in those areas and made traffic flow difficult to reach the affected region.

Vulnerability and Resilience

In the literature there are several approaches to define vulnerability and resilience to natural and na-tech hazards. According to UN/ISDR (2009) vulnerability represents "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" whereas resilience is defined as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". The definitions differ once considering large urban systems. Exposure is revealed as a major element which directly affects vulnerability; on the other hand, regarding the resilience of these systems, major cities are defined as more capable to protect themselves and/or to recover devastating impacts of hazards than smaller settlements (Handmer, 1995; Parker, 1995; Cross, 2001). However, the two provided case studies show that there are some missing points in definitions. The size of natural events is crucial to assess vulnerability and resilience of a system. Large settlements have obviously diversity of resources to respond or to recover impacts of hazardous events comparing to small cities, nevertheless once facing with high scale event (which is usually noted by governors as "beyond expected"), large urban systems can be more vulnerable than smaller settlements because of na-techs and systemic vulnerability. Considering resilience of mega cities, this concept should be integrated with that ones of adaptation and learning capacity rather than to be confined in the ability of a system to turn back to its initial state (Klein et al., 2003). In the recovery processes of Kobe and Kocaeli, the main target to achieve was to organize cities in a way they would never experience such a devastating event. In Kobe, several medium to large scale restoration projects were set in and in Kocaeli case, the city of Adapazari was relocated in another place.

As far as vulnerability and resilience seem two opposite concepts, it does not mean that a decrease of vulnerability always results in an increasing of the resilience: a system maybe vulnerable and, in the meanwhile resilient or, on the opposite, it can be characterized by a low vulnerability and a low resilience.

In the following paragraphs, most of the remarkable vulnerability factors and some aspects of resilience characterizing the two case studies will be discussed, trying to highlight some aspect of the disputed relation among vulnerability and resilience

Buildings

Vulnerability to Kobe earthquake was mostly related to old building stocks which had been constructed according to earlier building codes (1960s). In newer buildings, recent building codes were implemented so that they performed well against earthquake. In the case of Kocaeli earthquake, the majority of collapsed buildings were built after 1980s which were assumed for a better performance comparing to the older ones. The main reason of this widespread failure is strongly related to un-appropriate land use decisions and mainly to the miss-implementation of building codes and. Therefore, it is worth noting that physical vulnerability was relevant in both cases, even though in the Kocaeli one, it was mainly chargeable to the corruption and to the lack of control during the construction process .

Infrastructure

Despite the magnitude and impacts of Kocaeli earthquake was higher than Kobe earthquake, the infrastructural system performed better in the former case. In both cases underground networks received great damages and furthermore in Kobe case those damages in gas pipes caused vast fires. Moreover, the main transportation roads received vast damages so that accessibility decreased. In Kocaeli case, redundancy played a crucial role by the means of road network. Despite high capacity transportation road was not functional because of the fire at TUPRAS Oil Refinery, alternative roads were available for search and rescue activities. On the other hand, the scarce usage of natural gas in Kocaeli in 1999 somehow protected the city from severe fires.

Thus, even though in both cases the vulnerability of transportation newtwork was relevant, in Kocaeli case a key role was played by "redundancy" of such network which can interpreted as a key factor for enhancing resilience.

Industrial facilities

In Kobe earthquake, despite industrial facilities received damages, these damages did not cause secondary hazards/disasters. In Kocaeli case, the situation was opposite.

Despite all industrial facilities were built according to building code for industries, low maintenance of some equipments and the lack of anchorage in cranes and other movable big devices caused collateral accidents following the seismic event. Furthermore, as it is in several building codes implemented in several countries, the regulations are designed according to probabilistic approach consistent with natural hazards. The level of damages that TUPRAS Oil Refinery in Kocaeli suffered, shows in some point to reconsider the system in hazardous facilities.

Preparedness and Response

A common point characterizing both the case studies is the size of the event: in both cases, the hazardous event was "beyond expected". In Kobe case (indeed in Osaka and Hyogo Prefecture), the un-awareness and consequently the un-preparedness of decision makers about the size of the event, combined with the low flexibility of the decision making system, made a quick response impossible.

In the Kocaeli case, it's worth noting that, according to the management system of industrial facilities, training of personnel is compulsory in each facility. However, this training is usually for expected industrial accidents, such as fire/explosion, collapse and leakage of fluid/escape of gas. Unfortunately, in some cases, as seen hereby, natural hazards turn to be disaster because of complex chains of unexpected consequences.

Hence, in face of chained events, urban systems generally show a low resilience, due to the lack of experience and knowledge related both to the intensity of primary hazards and to their consequences which results in a low level of individual and collective preparedness. Therefore, preparedness is strongly related to be ready not only for common events but also for less common and less probable, even though characterized by more destructive potential impacts, complex events.

In the both case studies, vulnerabilities are strongly related with mis-implementations, mis-leading and lack of necessary prevention/preparedness measures. Protective measures, plans and actions are certainly main components to enhance resilience against natural hazards and to help to reduce probable losses. Despite precautions taken before these devastating events were likely accurate for probabilistic point of view, however, in the real world, multi-hazardous impacts and chain reactions of these two earthquakes had not been taken into account and afterword they were called as "beyond expected".

Considering key dimensions of resilience, it is worth to note that resilience of both cases come from some initial advantages of affected areas and national scale regulations mentioned above. Once describing resilience with the average losses and the length of the recovery period to turn initial capacity of services (Bruneau et al., 2003), Kocaeli can be considered more resilient. On the other hand, if we describe resilience to become better state comparing to pre-event, which can be named as "creativity" (Maguire and Hagan, 2007), Kobe case can be considered more resilient with newly built-up areas with high-tech aftermath the earthquake. Regarding to lessons learnt from both Kobe and Kocaeli earthquakes, it is possible to draw some final remarks:

a) Location of an industrial facility may not be favorable considering natural hazards, however precautions taken would make them resistant.
b) Vulnerability of a given area depends not only on the vulnerability of buildings but even on some features of the area itself which may affect its capacity to react to a given event; for example, accessibility is crucial to allow people's evacuation and the intervention of rescue teams.
c) Some resilience factors, such as redundancy in the road network, may counterbalance the losses and failures due to the vulnerability of the roads themselves.
d) In every city there are and there will be old building stock either historic or abandoned. Rehabilitation or restoration of these areas can enhance socio-economic structure of the community and prevent some extent collateral hazards following natural phenomena.
e) Implementation of building codes and building consultancy are to be achieved for safer settlements. Furthermore, for hazardous facilities the regulations should be reconsidered in accordance with natural hazards.
f) In the response stage of disaster management system, alternative plans should be designed according to different scenarios from the most-probable one to the worst-case. Therefore training in industrial facilities can be organized accordingly. To this aim,

actions aimed at improving knowledge and preparedness to complex events may be crucial to enhance resilience of exposed communities.

3.3.3 The Hurricane Katrina

Katrina was both one of the most extensive natural disaster occured in USA - the costliest and one of the five deadliest hurricanes in U.S. history (Pine, 2006) - and the most important na-tech event in recent times. About 1.350 people were killed; about 275.000 homes were damaged or destroyed; 1.5 million people were forced to evacuate the affected area and a lot of direct and indirect damages to the productive system and to the environment were induced by Katrina. According to the American Insurance Services Group insured damage estimates due to Katrina were $40.6 billion (Pine, 2006).

Most of the damages in Louisiana and in New Orleans was related to flooding compared with the state of Mississippi where damages were largely wind-related (Bostic and Molaison, 2008). Flooding was due not just to the hurricane and consequent storm surges but also to the failure of levees built to protect the city, resulting both from the inadequacy of the design to withstand the most severe hurricanes (US Congress, 2006) and from institutional failure to maintain the required standard of protection. Moreover, hurricane and subsequent flood acted as triggering events leading to a chain of secondary hazards, such as hazmat releases, which posed serious risks to human and ecosystem health.

The complexity of the Katrina event, the many hazards which hit different targets, characterized by heterogeneous pre-disaster conditions and obviously different vulnerabilities, forced us to set up a "conceptual map" showing the chain of hazards, impacts and damages due to the hurricane. This map highlights the many involved elements and systems – represented in different colors – and the many relationships among them (fig. 3).

As concerns the triggering hazardous event - the Hurricane Katrina - it's worth underlining that the intensity of hurricanes is often expressed through categories related to the wind speed and the potential damages. According to the Saffir-Simpson Hurricane Scale, a Category 1 hurricane has lighter winds compared to storms in higher categories. Category 4 hurricane would have winds between 131 and 155 mph and would usually be expected to cause 100 times the damage of the Category 1 storm. During the main phase of the hurricane on-land fall, when it was over the Mississippi delta, Katrina was between a Category 4 to a Category 3, but major damages to buildings and industries in New Orleans account only partially to the hurricane. Most of the problems were due to the breaches in the levee network which protected the city from floods.

The complex chain of secondary hazards, impacts and damages which followed the triggering one will be presented in the next pages, focusing on each of the main exposed and vulnerable elements and systems.

Levee networks and Wetlands

All the precautionary measures against floods had been long focused on levees and floodwalls. They were developed by the USACE in the 1970s and 80s to protect the city from a 1:100 year flood (despite two near-misses from hurricanes in 1965 and 1969 which indicated that the probability of a category 3 or more severe hurricane was much higher than 1:100). Thus, "engineering solutions were privileged over all other options also at the expense of the natural defense of the ecosystem, such as coastal marshes" (Colten and De Marchi, 2009). Nevertheless, vulnerability of the levee networks, combined with the alteration of natural environment before the hurricane, was the main cause of the flood event. Storm surges destroyed the levees in four points. Data from the U.S. Army Corps of Engineers (USACE) indicate that the breaches and overtopped levees flooded approximately 80 percent of the city, with floodwaters approaching 20 feet in some places (BBC news).

Before the construction of the city of N.O., wetlands – together with cycles of renovation of soil by the Mississippi river – represented a natural barrier against storm surges and floods, because of their capability of retaining water. Due to the city development and the need for new land for urbanization, since 1930, over 19 square miles of wetlands and many natural habitats were destroyed, the Mississippi river was canalized and the artificial barrier network against floods was built up (the levee network). The 1984 decisions to fortify the levees and floodwalls underestimated the probabilities and consequences of extreme hurricanes and did not explore alternatives that provided a higher level of protection. The preferred alternative was implemented slowly and with many funding delays (Southwell and von Winterfeld, 2008). Protection of the city by the levees had also been questioned in 2003 after some simulation models had predicted that devastation could occur due to a category 4 or 5 storm hitting the city. Moreover, the record of levee maintenance quality was also spotty and did not assess geotechnical or hydrological conditions of the levees. Projects were under-funded by Congress year after year and design standards were reduced to save money without analyzing the risks created. (In hindsight, the costs for post-Katrina recovery and reconstruction significantly overshadow the costs for re-constructing the levee system). The levees and floodwalls thus became structurally deficient, with weak levee soil conditions, and presented an increased risk to public safety and to the region's economic infrastructure; the system being only as strong as its weakest link. Moreover flood hazard maps of the area were over 10 years old and outdated (Lee and Willardson, 2008).

The levels of protection thus decreased over time due to natural and man-made changes. Furthermore, the levee network had no warning system in place. "While federal regulations require that they monitor levees during periods of potential flooding, the requirement is impractical to implement during a hurricane" (US Congress, 2006). Finally, as argued by many authors, the fact that before Katrina, the levee network was able to protect the city of N.O. by withstanding various hurricanes (1985, 1997 and 1998) got to the population the idea to be safe, causing indirectly the massive urban development, especially in the Eastern part of N.O.

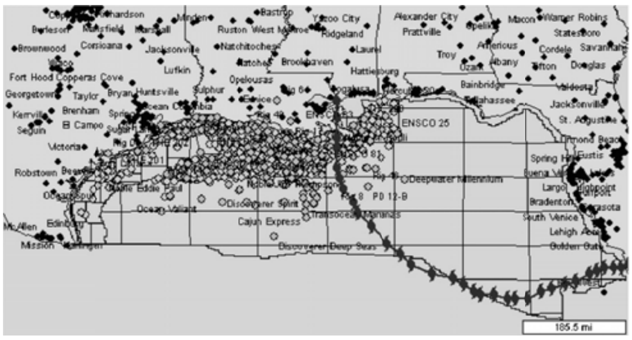

Figure 2: Platforms in the GoM (source: Cruz and Krausmann, 2008)

Dangerous industries

Due to the different natural/un-natural events described above, more than 500 hazardous material releases from in-land industries, offshore platforms and pipelines occurred (Pine, 2006; Perrow, 2007). According to Pine (2006), the industrial accidents occurred in the lower Mississippi corridor caused more than 20 million liters of chemical releases. Such releases had relevant repercussions from environmental, social and economic point of view.

Moreover, the technological accidents, combined with the natural triggering ones, represented a relevant challenge for the emergency management.

First of all, it is worth reminding that the hearth of US oil industry was damaged. Production of oil and gas from the Gulf region accounts for the 30% of US oil supply and 20% of its natural gas (Cruz and Krausmann, 2008). The offshore infrastructure of the area is one of the most extended in the world (Fig. 2) and includes about 4000 platforms and over 50,000 km of pipelines (MMS, 2006). One of the most relevant technological accident during Katrina was the Murphy Oil spill, in St. Bernard Parish (N.O.). With more than 3 million liters of oil discharged in a high populated area (about 700,000 people), it is considered the largest residential oil spill in US history. Vulnerability of such industries was due, first of all, to their location within flood hazard prone areas. This was probably caused both by decades of inadequate urban planning policies and by "the government collusion with industry against local concern" (Allen, 2003). Moreover, post disaster investigations highlighted that many oil and chemical industries in the corridor, as Murphy Oil, were not adequately prepared for the hurricane (US Congress, 2006). "A common but not legally mandated procedure for oil companies prior to hurricanes is to fill their tanks with either more crude oil or waters, thus weighing them down so that floodwaters do not trip them from their foundations. Murphy however filled its 250,000 barrels storage tanks with only 65,000 barrels of crude before Katrina struck. Predictably, the tank was dislodged by floodwaters and over 25,000 barrels of crude oil leaked out the tank. […] While no preparation can guarantee resistance to hurricanes, Murphy proximity to a residential area, combined with relatively empty storage tanks, certainty contributed not only to a massive loss of oil, but to a nightmare for homeowners who found their homes awash in filthy black crude" (Perrow, 2007).

Superfund Sites

Hurricane Katrina struck also 16 superfund[1] toxic waste sites. Three of them, in New Orleans, were flooded and one totally submerged (US Congress, 2006). The flooded Superfund sites contained contaminants, such as heavy metals and polycyclic aromatic hydrocarbons, which are well-known carcinogens substances.

Lifelines

The impacts and the damages on the lifelines' system, clearly showed both the relevant interdependencies among the individual networks and the multiple repercussions that the damages to the lifelines can induce (in short and medium terms) on other elements and systems (environmental resources, social and economic system, emergency management, etc). Most of the major roads in N.O. were damaged or collapsed. Electric power lines downed on the ground in many part of the city, contributing to the obstruction of roads which, in turn, reduced the accessibility during the emergency phase. Moreover, the lack of electricity caused interruptions in the supply of potable waters. Sewerage pipes breaks caused the pollutions of flood waters with organic components. Oil pipelines, which connected the port to oil refineries, had significant breaches in many part of the network resulting in many oil releases into the environment. According to the Mineral Management Service (MMS, 2006) over 100 pipelines were damaged. This was a great concern for emergency teams due to the lack of information related to the location of the underground networks (Perrow, 2007).

Buildings

A great number of buildings in NO experienced significant structural damages mainly due to intense winds and storm surges. It is worth mentioning that prior to Katrina, Alabama, Louisiana and Mississippi did not have statewide codes for non-state-owned buildings. According to FEMA the lack of adequate building codes greatly compounded the effect of Hurricane Katrina on building performance. As concerns flood, according to Green et al. (2007) the majority of structures, although heavily flooded, were structurally undamaged.

[1] A Superfund site is an uncontrolled or abandoned place where hazardous waste is located, potentially affecting local ecosystems or people. See also: ww.epa.org/superfund

It's worth noting that the Superdome, the main structure for sheltering people during the emergency, was built to withstand hurricanes, not flood. Hence, when the latter occurred, it began to slowly fill with water, though it remained confined to the field level.

In some urban areas, the damages were seriously increased by the hazmat releases into the flood waters and, in some cases, they were further worsened by the bureaucracy of federal laws. "After the spill the Murphy Oil hired a private contractor to begin cleaning up the spilled oil. However, because the law requires that Murphy obtain permission from individuals before cleaning their property, many homes went untouched for weeks because their owners were dispersed and could not be contacted, allowing crude oil to soak into the resident's yards" (Perrow, 2007). Hence, the recovery of buildings from oil became a great economic concern for many people, resulting in an increased poverty. Nevertheless, structural damages were not the only, or even the primary, impediment to recovery for many residents. Instead it was the outcome of pre-existing social and economic marginalization, limited resources, the widespread assumptions of non-viability and the slow pace of infrastructure recovery in certain neighborhoods that played a significant part in retarding repair and re-occupancy (e.g. the majority of lifeline service companies were out of operation) (Green et al., 2007). These conclusions were substantiated by Masozera et al. (2007) who reported that although severe flood damages occurred in the majority of the city's neighborhoods, findings suggest that pre-existing socio-economic conditions play a significant role in the ability for particular economic classes (i.e. African Americans) to respond immediately to the disaster and to cope with the aftermath.

People

Alexander (2006) stated that Katrina was a class-quake with divisions arranged along social status and ethnic origin. Katrina killed about 1,350 people: most of them were Afro-Americans, old and poor people. Even the majority of people that did not respond to the voluntary evacuation of the city were poor too. 120,000 of them lacked car; hence, some of them, were transferred to the Superdome and other shelters, while others remained in their houses waiting for the storm. For what concerns the impact of oil and other hazmat on buildings in the East part of N.O., after the hurricane authorities were vague about safety of houses and neighborhoods. Since they have not provided residents with any clear answer about cleanup processes and safety, hundreds of families have been cleaning up by themselves assuming that if it was unsafe, authorities would stop them (McKay, 2006). Only on December 9, when four months passed from the flood, CDC issued a report that concluded that most houses did not contain dangerous levels of oil-based contaminants. Environmental activists and parish officials remained wary because the report and analysis from EPA and CDC did not include samples from air inside homes and groundwater (McKay, 2006). Moreover, spills of oil and other toxic chemicals, when they dried and became airborne as invisible, breathable particulates, posed a serious threat both for the air quality and for human health.

Environmental resources

The consequences of Katrina on natural environment have already been faced in Del. 2.1. It's worth reminding that in N.O., the alteration of natural ecosystems before the hurricane largely favored the flood event. In the meanwhile, the damages due to the flood significantly affected natural resources, inducing short and long term consequences which had, in turn, repercussions on buildings, on social and economic systems. In other words, according to Clerc and Le Claire (1994), Katrina should be defined as a "spyraling" na-tech event, in which the alteration of natural ecosystems eventually favored natural hazards (namely the flood) which, in turn, caused technological accidents affecting natural resources. One of the main impacts on natural resources was due to the choice of authorities to pump the flood waters into the Lake Pontchartrain, in order to dry the city. Obviously, this probably unavoidable choice seriously compromised fishes and other organisms.

Emergency response

Many scholars highlight the lack of preparedness and the inadequate, incomplete and not updated emergency plans which drove the emergency operations during and after Katrina. Emergency response system suffered major pressures during and after the hurricane due to the many occurred unexpected events (from the flood to the hazmat releases) which, in turn, made ineffective or even wrong some of the decisions, increasing the total amount of damages.

It is worth underlining two main points related to the failure of emergency operations during Katrina. The first one is related to the adequacy of the evacuation procedures. The evacuation plan, was grounded on a spread use of private cars, using all lanes on major highways to accommodate vehicle traffic. "However, there was no effective plan to evacuate transit dependent residents. (…) This indicates that public officials were aware of and willing to accept significant risk to hundreds of thousands of residents unable to evacuate because they lacked transportation. The little effort that was made to assist non-drivers was careless and incompetent. The city established ten pickup locations where city buses were to take people to emergency shelters, but the service was unreliable. Transit dependent people were directed to the Superdome, although it had insufficient water, food, medical care and security. This lead to a medical and humanitarian crisis" (Litmann, 2006). Moreover, during the main phases of evacuation, conflicts and crimes were also reported, hence FEMA and Red Cross did not enter the city, waiting for the intervention of the National Guard troops. The second point relates to the impact of hazmat releases on natural environment, which played an important role both during emergency operations and, later, during recovery and restoration, making emergency operations a great challenge for Authorities. First of all, it is worth reminding the decision, already discussed above, to pump flood waters into the lake Pontchartrain to dry the city, which caused serious problems for ecological systems. Moreover, due to the heterogeneous impacts of primary and secondary hazards, FEMA had to coordinate – not without troubles – many federal, state and local environmental and sanitarian agencies: NOAAs Response and Restoration service, EPA, Food and Drug administration, Mineral Management Service, US Coast Guard and the State of Louisiana Department of Environmental Quality. Emergency and recovery operations were very difficult mainly in the area of the Murphy Oil, where rescue teams had to deal with sunken and grounded vessels carrying petroleum products; the transportation and movement of cleanup crews and materials in the urban areas around the Murphy Oil C. dealt with reduced accessibility due to the downed power lines and flooded roads. Hence, often, cleanup crews had access to those site through the use of boats (Pine, 2006).

Economic losses

The total amount of economic losses have been estimated to range from $150 to $200 billion (Kunreuther and Michel-Kerjan, 2008). Moreover, it has to be noticed that the damages suffered by industries caused temporary closing of many industries and the interruption of the oil production. In short term, such events had repercussions both on the employment at local scale and on the national oil need at large scale.

Most of the damages were registered in and near the Metropolitan area of New Orleans and all around the southeast cost of Louisiana, in the Gulf of Mexico (GoM) which represents, as mentioned above, the hearth of US oil industry. Moreover, the port of South Louisiana and the port of New Orleans represented respectively the first and fifth largest ports in the U.S. and they account for $150 billion and 20 percent of U.S. import/export cargo traffic annually. Hence disruptions to such industries and major infrastructures had repercussions on all the national economy and reverberated in the whole world (Cruz and Krausmann, 2008).

Conclusions

Summing up, what lessons can we learn from Katrina? It was a major natural disaster, whose impacts were exacerbated by a poorly performing flood protection system due to engineering and institutional failures, questionable judgments, and errors involved in the design, construction, operation and maintenance of the system (Southwell and von Winterfeld, 2008). Hurricane Katrina has been referred to as the "mother of all multidisciplinary problems" (Walker and Warren, 2007): biological, physical, ecological as well as social, political and economic factors contributed to risks to human life and health. According to many authors Katrina was both a natural and an un-natural disaster and it "exemplifies the inability of human artifice to exclude nature from cities" (Colten, 2006).

The triggering natural event, the Hurricane Katrina, has undoubtedly played a role in determining the catastrophe. Nevertheless, such a meteorological "Big One" (US Congress, 2006) was largely expected and many scientists predicted the effects of a hurricane such as Katrina, even though they were not in positions of power to enable them to act on their knowledge (Clarke, 2008). As stated by Alexander (2006) "the heart of the failure in New Orleans lays in the evaluation and translation of scientific information into public action". Nevertheless, as clearly stated by the investigation bipartisan Committee of the Congress (US,2006), "it remains difficult to understand how government could respond so ineffectively to a disaster that was anticipated for years, and for which specific dire warnings had been issued for days. This crisis was not only predictable, it was predicted. If this is what happens when we have advance warning, we shudder to imagine the consequences when we do not". The Hurricane demonstrated a major failure in the country's preparedness to deal with large-scale disasters: lack of emergency preparedness, lack of adequate loss reduction measures, and many uninsured people requiring historical levels of federal aid (over $110 billion). "Katrina was a national failure, an abdication of the most solemn obligation to provide for the common welfare. At every level – individual, corporate, philanthropic, and governmental – we failed to meet the challenge that was Katrina. [...] In many respects, our report is a litany of mistakes, misjudgments, lapses, and absurdities all cascading together, blinding us to what was coming and hobbling any collective effort to respond. (....) Government failed because it did not learn from past experiences, or because lessons thought to be learned were somehow not implemented" (US Congress 2006).

Therefore, Katrina highlights the close network of relationships among different types of vulnerability (physical, social, economic, institutional, etc.) that, starting from a triggering hazardous event, lead to a catastrophe. Moreover, it provides a clear example of the consequences – at different temporal and geographical scales – due to complex hazardous event hitting a large urban system. Finally, Katrina highlights the need for a dynamic and flexible risk assessment and disaster preparedness plans involving all the key components of society as well as the linkages and relations between hazards and vulnerabilities of exposed elements and systems. Another need is for better advance planning, better communications, more rapid deployment of resources and better coordination. Recovery plans should also consider the relationship that a neighborhood has to the larger urban area and the need for neighborhoods to support a diverse range of residents. Finally, there is also the need for improving socio-economic conditions that make certain groups more vulnerable, e.g. by addressing low wages, facilitating access to loans and financial incentives, improving access to transport.

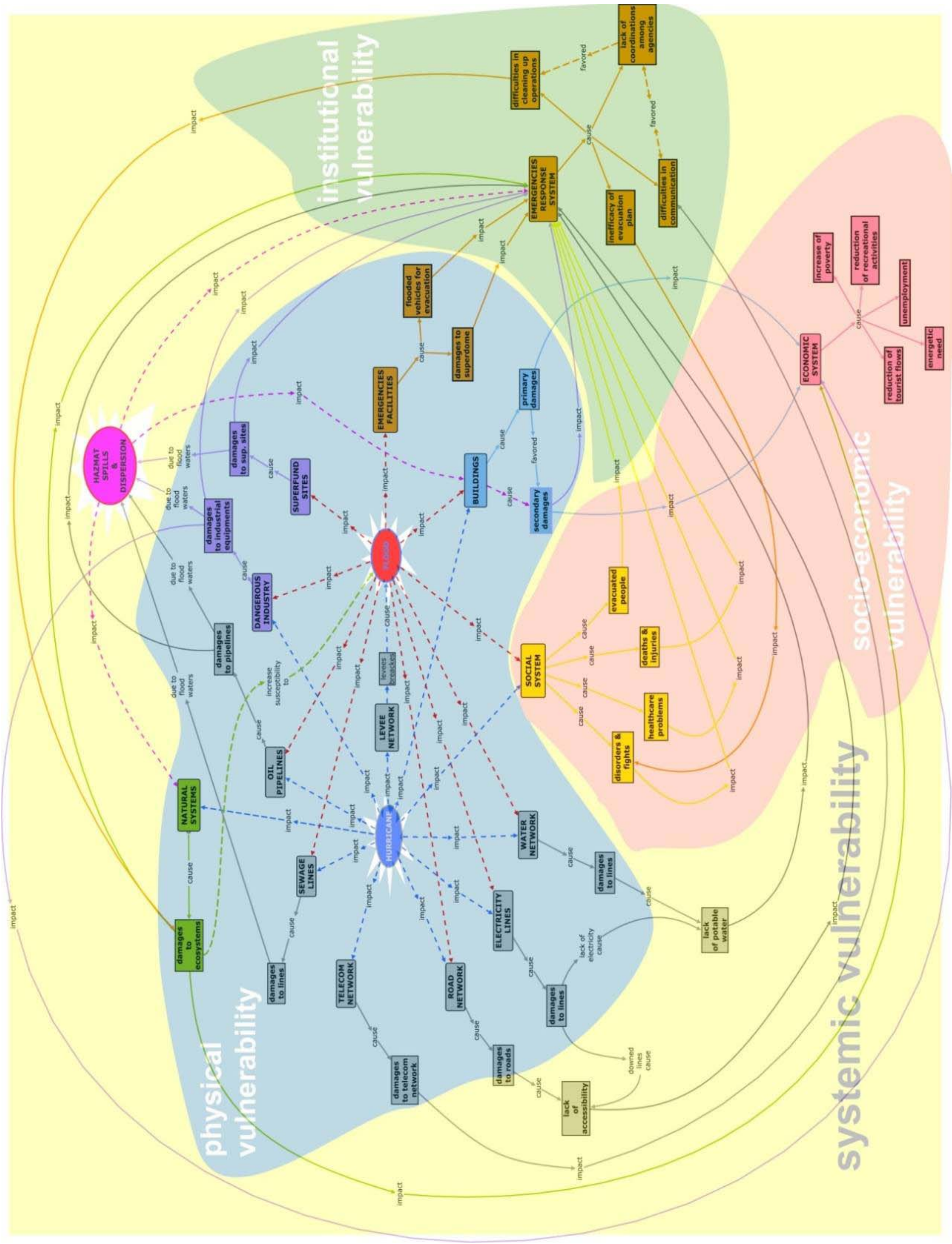

Figure 3: The conceptual map showing the chain of hazards, exposed vulnerable elements and targets during the Hurricane Katrina

4 The resilience concept

4.1 Resilience in the international risk reduction initiatives

The resilience concept, although investigated since 1970s, has gained prominence in the disaster field after the Hurricane Katrina occurred in August 2005, when a lack of resilience was largely complained. Nevertheless, the term is mentioned in many of international reports devoted to risk reduction and sustainability initiatives published in the last 15 years.

In the guidelines prepared for the World Conference on Natural Disaster reduction (UN, 1994), held in Yokohama, the following declaration is reported: "There is a strong need to strengthen the resilience and self-confidence of local communities to cope with natural disasters through recognition and propagation of their traditional knowledge, practises and values as a part of development activities".

Five years later, within the IDNDR Programme Forum (IDNDR, 1999), the participants promoted the adoption of "policy measures at the international, regional, sub-regional, national and local levels aimed at reducing the vulnerability of societies to both natural and technological hazards through proactive rather than reactive approaches". Such measures had to be addressed to "the establishment of hazard-resilient communities and the protection of people from the threat of disasters". It is worth noting how, within this line of thought, the spread of a new awareness addressing something that was different from the traditional concept of "resistance" can be observed and how a proactive approach, especially for what concerns governments actions, is invoked to achieve resilience.

Referring to climate change, the IPCC Third Assessment (2001) report provides a first "institutional" definition of resilience, expressed in comparative terms with vulnerability. According to IPCC, a resilient system or population is not sensitive to climate variability and change and has the capacity to adapt. In such a way, resilience represents the flip side of vulnerability.

In line with IPCC, but by a mirror perspective, ISDR[2] (UN/ISDR, 2002) defines vulnerability as a function of the susceptibility or resilience showed by socio-economic systems and physical assets to the impact of natural hazards.

The same ISDR (2004), a couple of years later, officially introduces the concept within the field of disasters, including resilience into its glossary devoted to the basic terms of disaster risk reduction. Resilience is defined as "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure"[3]. It is worth noting that the components of the traditional and pragmatic formulation of risk are pointed out in this definition: hazard and exposure in an explicit manner, vulnerability through some concepts closely related to, namely adaptation and resistance in face of likely damages.

OECD (2004) focuses the attention on the relationship between adaptive capacity and natural disasters. In this respect, it is stated that "adaptive capacity can be defined as the vulnerability of a society before a disaster strikes and resilience after the fact".[4] Hence,

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[2] ISDR was launched in 2000 by UN General Assembly Resolution A/54/219 as successor of IDNDR.

[3] Further, according to ISDR (2002), such capacity is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures. The same meaning will be adopted later by IRIN/OCHA(2005), quoted by UNU/EHS(2006).

[4] By collocating the adaptive capacity into different temporal span with respect to the disaster occurrence, this definition explains the fact that adaptive capacity is considered as part of vulnerability by some authors and as part of resilience by others.

resilience is related to adaptive capacity rather than directly to vulnerability. In the report, it is suggested that an enhancement in resilience "can be achieved by implementing a series of precautionary measures that would lower the cost of relief (e.g. social safety nets, improved communications), and preparing adequate contingency plans for rapid medical and humanitarian responses".

The humanitarian organization IFRC (2004) proposes a "shift in thinking" in the field of disaster, concerning the need for putting resilience – in terms of strengths, skills, and resources – at the heart of the aid debate rather than just vulnerability. As a consequence, the emphasis on identifying and building strengths represents a paradigm shift in approaching risk. Resilience is adopted in the understanding of "the capacity to survive, adapt and recover from a natural disaster. Resilience relies on understanding the nature of possible natural disasters and taking steps to reduce risk before an event as well as providing for quick recovery when a natural disaster occurs".

After the World Conference on Disaster Reduction, held in Kobe in January 2005, the Member States of United Nations adopted the Hyogo Framework for Action 2005-2015 (UN/ISDR, 2005), with the overarching goal to build resilience of nations and communities to disaster, by achieving substantive reduction of disaster losses by 2015. HFA defines five areas of priorities for action, guiding principles and practical means for achieving disaster resilience for vulnerable communities in the context of sustainable development. With respect to resilience the following priorities for action are identified:

- knowledge, innovation and education represent a need for building a culture of safety and resilience at all level;
- the development and strengthening of institutions, mechanisms and capacities is a strategic goal for building resilience to hazard.

According to OECD (2008), interested in investigating the conditions determining fragility for a state, resilience consists in the ability to cope with change driven by sudden shocks or long-term changes. It derives from a combination of capacity and resources, effective institutions and legitimacy, all of which are underpinned by political processes that mediate state-society relations and expectations.

The last ISDR's updating of disaster risk terminology (UN/ISDR, 2009) provides the following definition of resilience: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". The major innovative element in such definition is represented by the inclusion of "time" as a parameter for evaluating resilience. Finally, it is worth mentioning that the resilience concept has widely permeated the last session of the Global Platform for risk reduction, organized by UNISDR and held in Geneva in June 2009.

The presented overview shows how resilience is often referred to as a "panacea" within the disaster field. Apart from some definitions, potentially embodying a wide spectrum of evaluation parameters and some general hints (e.g. precautionary measure, developing and strengthening of institutions, etc..), how pursuit an effective enhancement of resilience as overarching goal of disaster risk reduction is still a nebulous matter. As a consequence, this chapter is addressed to draw an outline of resilience by an operational perspective, starting from a deepening of both the roots of the concept in the ecological field and the influences that it received from the Complexity and Sustainability theories.

4.2 Resilience theory: roots and evolution

The term resilience, from Latin *resilio*, means "to jump back" (Klein et al., 2003). From a scientific point of view, it has been used, at first, in physics where it was assumed to refer to the resistance of a material to shocks, namely the quality of being able to store strain energy and deflect elastically under a load without breaking or being deformed (Gordon, 1978). Nevertheless, the application of the term in a technical meaning - in that some attempts aimed at providing related quantitative measures have been carried out - grounds on the field of Ecology (Carpenter et al., 2001).

In this paragraph, wide room is devoted to this perspective due to the strong influence that it has had on the resilience thinking and due to the transfer of its meaning from ecological to disaster field. Hence, Ecology represents an adequate entry point for any discussion related to resilience.

The concept of resilience was being studied by ecologists since Seventies to know why some species survived in environments with high uncertainties and/or affected by catastrophic events. They initially adopted the term in the same sense as in physics. In 1973, Holling assumed resilience for referring to one of the property through which the behaviour of ecological systems could be described. He defined resilience as "a measure of the ability of a system to absorb changes of state variables, driving variables, and parameters, and still persist and by doing so, it is responsible for the persistence of relationships within a system" (Holling, 1973). The most innovative aspect of such meaning is given by its separation from the concept of stability whereas, according to Holling (1973), stability represents "the ability of a system to return to an equilibrium state after a temporary disturbance". He added that "the more rapidly the systems returns, and with the least fluctuation, the more stable it is". With the aim of underlining this difference in meaning, he stated that a system can be very resilient and still fluctuate greatly (low stability). Hence, "stability" is representative of a system perspective in terms of equilibrium states. In this respect, already in 1973, Holling came to the conclusion that "an equilibrium centered view is essentially static and provides little insight into the transient behaviour of systems that are not near the equilibrium". For this reason, an equilibrium view doesn't fit to deal with the ecological systems that are likely to be continually in a transient state, even in absence of disturbance agents.

The admission of the existence of one or more equilibrium states has entailed a twofold characterization of the resilience concept. Some years later, Holling (1996) himself breaks down resilience into two typologies:

- engineering resilience;
- ecological resilience.

In fact, Holling stigmatizes the "ability to return to a stable steady-state following a perturbation", as defined by Pimm (1984), as engineering resilience, putting it in opposition to an ecological resilience. The last one better fits with "designing with ecosystems" since it describes "conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behaviour". As a consequence, whereas the engineering resilience emphasizes the efficiency, constancy and predictability aspects, the ecological resilience emphasizes the persistence (maintaining existence of function) and robustness (preservation of the structure of the system in the face of perturbations) aspects (table 1).

Resilience concepts	**Characteristics**	**Focus on**	**Context**
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibrium states, stability landscapes

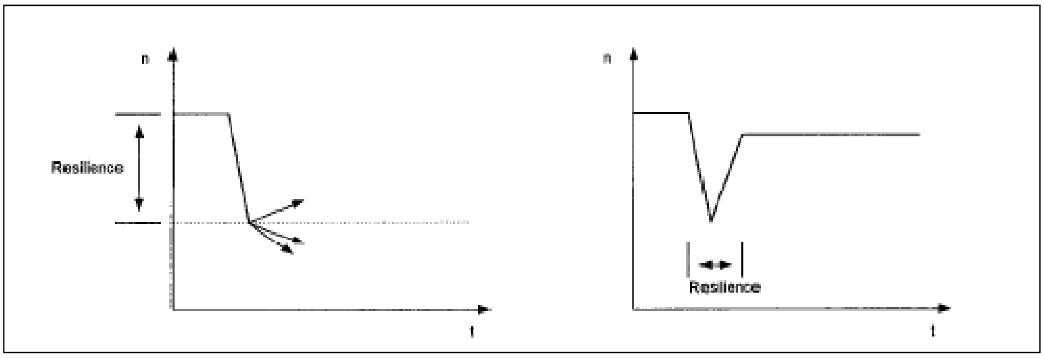
Table 1: Engineering and ecological resilience (extracted by Folke, 2006)

The "engineering" attribute is chosen by Holling according to the common approach of engineers aimed at designing systems with a single operating objective. Engineering resilience is permeated by "an implicit assumption of global stability, that is, that only one equilibrium steady state exists, or, if other operating states exist, they should be avoided by applying safeguards" (Holling, 1973).

According to their definitions, the two types of resilience are measured in a different manner (fig. 4): ecological resilience (left side) is measured by the magnitude of disturbance that can be absorbed before the system changes its structure by modifying variables and processes that control its behavior. In Adger's representation (fig. 4) this magnitude is given by the distance between a pre-disaster level and a threshold (dotted line) beyond which the system flips into another regime of behavior[5]. On the other hand, engineering resilience is measured "by a return time, the amount of time taken for the displacement to decay to some specified fraction of its initial value"[6] (Pimm, 1991). The concept of rapidity needed by a given system to return to equilibrium following a perturbation, has been embodied in common dictionary definitions of resilience, for example as ability of people to feel better quickly after something unpleasant, such as shocks and injury[7], as well as in the updated ISDR's definition of resilience included in its report on disaster risk terminology (see § 4.1).

Walker et al. (2004) expand the definition of resilience as follows: "resilience is the capacity of a system to absorb disturbance and reorganize[8] while undergoing change as so still retain essentially the same function, structure, identity and feedbacks" [9].

The aspect of resilience concerning the resistance and the absorption of disturbance is more properly called "stability" by Berkes and Folke (1998) even though resilience includes something else, for example, the capacity to "conserve opportunity for renewal of the system and emergence of new trajectories" and opportunity for recombination of evolved structures and processes after a disturbance (Folke, 2006; Berkes and Folke, 1998). These capacities become preeminent when discussion on resilience moves, on behalf of Resilience Alliance[10], from the ecological field to another one, namely the socio-ecological field (SES).



[5] The different arrows are representative of the plurality of equilibrium states that a system can assume after a disturbance.

[6] With reference to some considerations afterwards developed, it is worth underlining the effectiveness range of Pimm' s definition. According to Ludwig et al., (1997) it "applies only to behaviour of a linear system, or behaviour of a non-linear system in the immediate vicinity of a stable equilibrium where a linear approximation is valid".

[7] Adapted from Oxford Advanced Learner's Dictionary (2005).

[8] A similar definition was already provided by Louis Lebel (2001) quoted in USAID/ASIA (2007): the potential of a particular configuration of a system to maintain its structure/function in the face of disturbance, and the ability of the system to reorganize following disturbance-driven change and measured by size of stability domain".

[9] This meaning for resilience is well represented by the model of "basins of attraction" .

[10] Resilience Alliance is a network of scientists which aims to stimulate academic research on resilience and inform the global policy process in sustainable development. Nowadays, it represents the main authority in the field of resilience.

Figure 4: Ecological (left side) and engineering resilience (right side) measures (Adger, 2000).

An earlier definition of SES is that provided by Gallopin et al. (1989): "any system composed of a societal (or human) component (subsystem) in interaction with an ecological (or biophysical) component". The hierarchical structure in which SES are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring and renewal, is described by Gunderson and Holling (2001) by the term Panarchy (see annex 1) that is a key concept to understand the evolving nature of complex adaptive systems.

Carpenter et al. (2001) single out three essential properties of Resilience that will be later adopted as a sort of manifest of resilience by the Resilience Alliance:

- the amount of disturbance a system can absorb and still remain within the same state or domain of attraction;
- the degree to which the system is capable of self-organisation;
- the degree to which the system can build and increase the capacity for learning and adaptation.

These properties, even if related to different aspects, find a common source in the Theory of Systems and in its evolution into the Complexity theory. In detail, the concept of self-organization, initially meant as a property of systems resulting from the interaction with external factors, is expanded when it is applied to the complex adaptive systems that have the potential to learn by experience, specifically to process information and adapt accordingly (Bankoff et al., 2004).

The other prominent cultural source which has strongly contributed to the evolution of the resilience thinking is represented by the theory of Sustainability.

Both Complexity and Sustainability theories assume as starting point a vision grounded on a systemic approach and both recognize the existence of factors, within systems, that are responsible for change and that represent a source of uncertainty due to the fact they act in a not predictable manner.

According to Waldrop (1992), the Complexity theory deals "with stability and change in systems that are complex in the sense that they consist of a great many independent agents that interact with each other in many ways". The many ways through which the different components of the systems can interact with each other define the main character of a complex system that is the non-linearity of its relationships and, as a consequence, the possibility of having more than one solution.

Within the Complexity theory, Prigogine (1967) developed his theoretical construct of "dissipative structures"[11] through which he referred to those open systems that stay in condition far from equilibrium and, as a consequence, have to be described by non-linear equations[12]. In many non-linear systems, significant modifications could be observed following to small changes of parameters: such systems are defined "structurally unstable". In detail, the critical points of instability are called points of bifurcations[13] in that, in their correspondence, the system can evolve according to different directions compared with the previous one. By a physical perspective, new forms of order emerge as a result of the growing comprehensive disorder transfer towards outside[14]. This happens in correspondence

11 The term was coined by himself to stress the coexistence of both change and stability.

12 Moving from Math to Physic, this same process is expressed by the "feedback loop" concept (Capra, 2001).

13 The points of bifurcations, and more specifically, their topology, will be later taken into account by the mathematician Thom (1972), author of the "Theory of Catastrophes" where catastrophe is used in place of point of bifurcations.

14 Hence, whereas the energy dissipation was linked to an idea of "loss" by the perspective of the classic thermodynamic, the introduction of the "dissipative structures" has allowed to interpret this same dissipation as a source of order.

to bifurcations and is mirrored by sudden changes of direction. As shown by Prigogine, such instabilities occur only in open systems that act in condition far from equilibrium, or in other words, only within the "dissipative structures". What happens after these critical points in terms of evolution in direction strongly depends on the previous history of the system, or in other words, on the path followed to reach the point of instability (Capra, 2001). Further, the dissipative structures show a great susceptibility even to small fluctuations occurring in correspondence to bifurcations. Since such fluctuations are not known a priori and occur by chance, it is not possible to foresee the path followed by the system (Capra, 2001). The emergence of new structures and new forms of behaviour, resulting by synergic effects of non-equilibrium, irreversibility, feedback loop and instability, represents the higher expression of what is called self-organization within the Complexity theory (Capra, 2001).

With respect to complex adaptive systems, the term self-organization refers to "agents interacting locally according to their own principles or intentions in the absence of an overall blueprint of the system" (Stacey et al., 2000). Adaptive systems do not just passively respond to events; they actively try to turn whatever happens to their advantage (Waldrop, 1992). Such an interaction becomes source of further unpredictability and uncertainty. The importance of the uncertainty component has been highlighted in many other typologies of systems as well.

In the socio-institutional field, the political scientist Wildavsky (1985) takes into account two different ways of coping with uncertainty: anticipation and resilience. Whereas "anticipation relies on detecting problems and trying to avoid them[15]" (Handmer and Dovers, 1996) and seeks to preserve stability, "resilience accommodates variability" (Wildavsky, 1988). Extending this line of thought, Dovers and Handmer (1992) adopt resilience as a useful concept for defining responses to ignorance/uncertainty and risk. In detail, the authors single out two typologies of strategies:

- reactive resilience as that one approaching the future by strengthening the status quo and making the present system resistant to change[16];
- proactive resilience as that one accepting the inevitability of change and trying to create a system that is capable of adapting to new conditions and imperatives (Handmer and Dovers, 1996).

As referred by the authors, this meaning for proactive resilience, is quite similar to the resilience advocated by Holling (1973), Wildavsky (1988) and to Conway's (1987) sustainability concept[17] as the ability of the system to maintain productivity following large disturbance. Even Dovers and Handmer (1992) provide their own definition for sustainability in terms of responses to change: "sustainability is the ability of a human, natural or mixed system to withstand or adapt to endogenous or exogenous change indefinitely". Hence following a comparison of their definitions, a tight connection emerges between the concept of sustainability and the proactive resilience one.

As observed by Common and Perrings (1992), the relevance of the concept resilience for sustainable development was on the table in the economic field since the late 1970s. Moreover, these authors state that a necessary condition for sustainability is that current economic activities should not result in the loss of system resilience; in such a way, they strongly link resilience and sustainability. Levin et al. (1998), quoted by Perrings (2006), refer to resilience as the preferred way to think about sustainability in social as well as in natural systems. Folke et al., (2005) state that the major challenges for research on

[15] The anticipation approach implies a deterministic vision; in fact as referred by Handmer and Dovers (1996), "implicit in this approach is the belief that a very low level of ignorance is achievable: Ignorance can be identified, then reduced or eliminated".

[16] In such terms, reactive resilience can be seen as a quest for constancy and stability.

[17] Conway's definition has been developed in the context of agricultural system.

sustainability is how to stimulate the emergence of multilevel and adaptive management systems that can secure the capacity to sustain the ecosystem services[18]. Hence, as resilience represents also the degree to which the system can build and increase the capacity for adaptation (Carpenter, 2001) it is not surprising that Folke et al. (1998) pinpoint ecologically adapted management practices and social mechanisms for both resilience and sustainability.

Many of the mentioned authors (Perrings, Folke, Hanna and Levin), devoted to interdisciplinary studies grounding on sustainability, in collaboration with the Beijer Institute and University of Florida[19], give life to the Resilience Network. It was a research program that later developed into the Resilience Alliance, a consortium of research groups and research institutes from many disciplines who collaborate to explore the dynamics of social-ecological systems. The most important insights of resilience and sustainability in SES have been synthesized by Resilience Alliance in a report entitled "Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformation[20]" (Folke et al., 2002), in which resilience and adaptive capacity are described as key properties for sustainability. Moreover, some policy recommendations based on the role of resilience in the context of sustainable development are suggested in the report. These recommendations are essentially targeted to:

- the implementation of frameworks addressing building adaptive capacity;
- the creation of action platforms for adaptive management processes and flexible multi-level governance;
- the generation of knowledge and cope with change in such a way to create a diversity for management options of significance for responding to uncertainty and surprise;
- the development of indicators of gradual change and early warning signals of loss of resilience and possible threshold effects;
- the management of diversity for insurance to cope with uncertainties and the implementation of structured scenarios and active adaptive management processes[21].

In such a way, the policies recommended by Resilience Alliance greatly emphasize, through Resilience thinking, concepts as ecological thresholds, uncertainties and surprise. Even the sustainability debate is permeated by uncertainty, so that the precautionary principle appears as an official recognition of pervasive uncertainty in some statutory law and is the reason for many major sustainability policies although it is vague, inoperative by itself and open to wide interpretation (Handmer and Dovers, 1996). In line with the above comments, Adger (2003) asserts that "the unfocussed aspirations for sustainability are captured in the notion of resilience" and recognizes that "the message of resilience is more radical for policy-makers than that of sustainability". In such a way he attributes a more operational and pragmatic meaning to resilience with respect to sustainability.

In the field of sustainability some attempts have been devoted to define operational indicators as well. By this perspective it is worth noting how they often match with resilience

[18] Ecosystems are seen essentially as ecological services providers.

[19] Holling was directly involved in this initiative as Professor of University of Florida.

[20] The report is sustainability-oriented in that it has been ordered by the Environmental Advisory Council of the Swedish Government for the forthcoming World Summit on Sustainable Development (WSSD) and published in ICSU series on Sustainable Development.

[21] It is worth noting that in the above mentioned report, Folke et al.(2002) present resilience exclusively in its positive acceptation by neglecting to consider that a system showing resilience is not always representative of desirable conditions (The concept is more precisely expressed through the model of basin of attractions). By this perspective, one year before the report, Carpenter (2001) stated: “Unlike sustainability, resilience can be desirable or undesirable. For example, system states that decrease social welfare, such as polluted water supplies or dictatorships, can be highly resilient. In contrast, sustainability is an overarching goal that includes assumptions or preferences about which system states are desirable.

indicators. As an example, Dalsgaard et al. (1995) recognize "diversity, cycling, stability and capacity[22] as crucial system properties with respect to sustainability assessment of local agro-ecosystems.

Finally, it is useful to give a glance to the objectives of sustainable development[23] according to Gallopin (2003): "sustainable development must aim not only to preserve and maintain the ecological base for development and habitability, but also to increase the social and ecological capacity to cope with change, and the ability to retain and enlarge the available options to face a natural and social word in permanent transformation". If one replaces "ecological base" with "structure/state" and bears in mind that capacity to cope with change is an intrinsic aspect of resilience, the achieved conclusion is that getting resilience is a main goal of the sustainable development policies. Such consideration appears as fully complementary to Resilience Alliance point of view, according to which building resilience is a medium towards sustainability. Fiksel (2006), in a paper devoted to the two issues, supports the last thesis and states that "the sustainability of living systems, including humans, within the changing Earth system will depend on their resilience" and that "achieving sustainability will arguably require the development of resilient, adaptive industrial and societal systems that mirror the dynamic attributes of ecological systems".

To sum up, there is no doubt that the two concepts are closely related so that one becomes premise for the other with roles appearing often as interchangeable.

4.3 Resilience into the disaster field

This paragraph explains the main reasons leading to the adoption of the Resilience concept into the disaster field and broadly justified by the opportunities that resilience provides for dealing with concepts like non-linearity, change, surprise and cross-scale effects which are very relevant within the disaster field.

As previously highlighted, the main cultural source from which a technical meaning of the concept stems has been Ecology. The ecological and the disaster field have been put in parallel by some authors interested in the wide discussion on sustainability. Within this discussion, the need for integration of issues concerning all aspects of both natural and human systems was a main topic. First among them, Handmer e Dovers (1996) state that "it would make sense to look at ecology and disasters research" due to the fact that they represent "two areas of human experience where change and the interaction of human and natural systems have been addressed before". The authors argue that "it is proposed as axiomatic that managing ecological change (pursuing sustainability) and coping with hazards and disasters should share some common problems and features. Fundamental to both is the need to cope with pervasive risk and uncertainty" and, in this respect, the attribute of resilience, understood as "ability to operate in the face of this uncertainty", is required. According to the authors, the disaster field and the ecological one are similar also due to the fact that they share the "attention paid to systems approach[24] to the problems". In such a way they can further take into account the complexity of systems.

As previously shown, one of the findings of the complexity theory has been the recognition of self-organization as a characteristic of complex dynamic networks[25] (Kauffmann, 1993).

[22] In this context, capacity refers to the quality of soil and water resource base and its ability to produce and sustain biomass (Dalsgaard et al., 1995)

[23] Gallopin (2003) stresses also the difference between sustainability and sustainable development "The concept of sustainable development is quite different from that of sustainability in that the word "development" clearly points to the idea of change, of directional and progressive change.

[24] The system approach implies recognising that "any defined system will also be a subsystem" and that "dynamic interdependency" exists among the elements of the systems. (Handmer and Dovers, 1996).

[25] Complex networks are referred to as "adaptive" or "dynamic", because they are constantly changing their interrelationships based upon the needs of individual agents and environmental impacts.

The first application of the Complexity theory in the field of disaster has just focussed on this topic. In fact, Comfort (1994) assumes self-organization as a fundamental aspect of investigation within the analysis of a disaster response system: "disaster serves as a mechanism of transition in complex, social systems that can be either be used to redesign the system's structure and performance to fit more appropriately the vulnerabilities of its environment, or unattended, creates the conditions for more serious or costly disruption at a later time". Comfort (1994) defines the self-organization as "a spontaneous reallocation of energy and action in response to changes in the operating environment". Such definition is quite similar to the "capacity to adapt existing resources and skills to new situations and operating conditions" to which Wildavsky (1988) has referred to as resilience. Hence, resilience can be interpreted as a sort of indicator for the self-organization level of the social system. In line with this conclusion, even if starting from different premises, the Resilience Alliance put "the degree to which the system is capable of self-organisation" as a dimension of resilience. The self-organization property emerges at the occurrence of a disturbance. According to Gallopin (2003), "all living systems are exposed to unavoidable stresses and disturbances as a consequence of their being an open system". Such disturbances can push the system across given thresholds and shift the system from one stable state to another, that is in line with Holling's school of thought. As resilience declines, the amount of disturbance needed to cross the threshold declines (Walker and Meyers, 2004).

With reference to the disaster field, natural and technological hazards can be considered particular typologies of disturbances (or perturbations) and as consequence, they can affect the system, causing shifts from one equilibrium state to another one. They can induce non-linear response in that responses are not linked to the typology of the disturbance by a cause-effect relationship. The non-linearity of these relationships is also the most characteristic aspect of their complexity. Non-linearity entails the coexistence of more than one outcome and a related significant susceptibility depending on the initial conditions of the system. Shifting on the disaster field, Comfort (1999) refers that "vulnerable communities demonstrates a sensitive dependency upon initial conditions. That is, the capacity of a community to mobilize collective action in response to perceived risk depends directly upon the degree of awareness, level of skills, access to resources, and commitment to informed action among its members prior to the occurrence of a damaging event". "Reconstruction" is not even sufficient in terms of response to an event as reported by one of the axioms of resilience presented by Vale and Campanella (2005). In fact, the authors affirm that "the process of building is a necessary but, by itself, insufficient condition for enabling recovery and resilience" as "cities are more than the sum of their buildings. They are also thick concatenations of social and cultural matter, and it is often this that endows a place with its defining essence and identity" (Campanella, 2006).

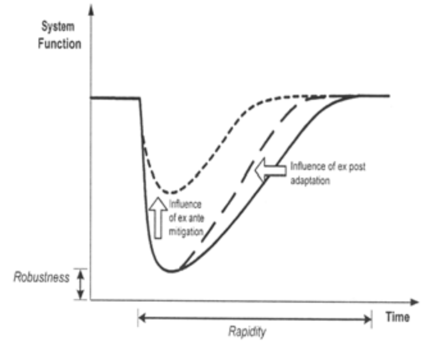


Figure 5: Influence of ex-ante mitigation on the performance of a system after a disaster (McDaniels et al., 2008)

With respect to a disaster, even mitigation actions have to be taken into account as part of the initial conditions framework. As shown in fig. 5, by a performance perspective[26], the extent of robustness, adopted as a performance dimension, which is lost by a system following a given event, strongly depends on the ex-ante mitigation programme[27].

A hazard, seen as a perturbation inducing change, represents a point of bifurcation in correspondence of which, different trajectories of the system can result. The scarce forecasting capacity for such trajectories represents an important source of uncertainty because it doesn't allow to apply actions of control on the post-event conditions of the system due to the fact that they are not known. In this respect, as suggested by Pelanda (1981), what makes "abnormal" an event or, in other words, what places an event out of its range of normal variability, is not only its rarity in terms of frequency but, overall, the lack of control, by both a cultural and technological perspective, on its effects. By this point of view, the resilience perspective appears as a strategy for a shift from those policies that aspire to control change in systems assumed to be stable, to those managing the capacity of (socio-ecological) systems to cope with, adapt to, and shape change (Folke, 2006). Hence, it can be deduced that even if "the last goal of a system remains control" as stated by Comfort (1999), a strategy based on such aim is not adequate to cope with uncertainty; on the contrary the resilience approach fits in this purpose as it assumes uncertainty as one of its main premises (Folke, 2006; Berkes, 2007).

Another useful concept that can be permutated from the ecological to the disaster field, refers to the cross-scale effects embodied in the concept of panarchy (see annex 1). In this respect, Walker et al. (2004) argue that some loss of resilience, at some scales, is an inevitable feature of the cross-scale dynamics in complex adaptive systems. Transferred to disasters, this concept reminds to the fact that an event occurring in a given place can have consequences that spread over areas even quite far from the place of the occurrence. This fact entails the need for thinking in terms of interactions within systems at both spatial and temporal different scales. The concept of panarchy includes also another idea allowing a further analogy with the field of disasters, that is "the creative destruction". The term was coined in 1942 by the economist Shumpter to refer to a phenomenon in which bankruptcies eliminates inefficient enterprises, freeing up resources for a more efficient use. Holling (2001) uses the term with regard to "a phase of rapid reorganization during which novel recombinations can unexpectedly seed experiments that lead to innovations in the next cycle"[28]. Such rapid reorganization is requested also in the immediate aftermath of a large disaster and can be coupled with what is better known as the "window of opportunity" period. In fact, in this phase, the political attention and social pressure tend to reach their maxima and the greatest investments are made (Bosher, 2008). This period is also recognized as the time in which something like three quarters of all legislation relevant to disasters is passed. In this respect, for example, just few months after the Sarno mudflows in which more than 150 people were killed, a law decree (180/98 turn into law with L. 267/98) passed to ensure the assessment of landslide risk of all the country's 20 regions; furthermore, investments in landslide risk investigation followed the legislation[29]. Christoplos (2006) carried out a detailed analysis on factors both contributing and contrasting the effectiveness of this "window of opportunity".

Shifting on a practical ground, an example about a bad management of a disaster aftermath

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[26] This approach is widely developed in next paragraph.

[27] By this perspective, del. 2.1.2 has highlighted how planning activities serving risk mitigation objectives are the main drivers of change into the structures of vulnerability relationships, hierarchies and distribution in pre-disaster terms.

[28] Such aspect is in line with what stated as a conclusion of Del. 2.1.2: "Resilience, especially in the relief/recovery period, is a catalyst for vulnerability change, transfer and transformation".

[29] Bosher (2008) by arguing that "this is one example of a more or less universal process in which change is achieved largely after the event, rather than before it", denounce the lack of policies grounded on prevention actions.

is represented by the Mexico city earthquake case (del. 2.1.2). In fact, administration and decision makers managed the recovery phase in such a way to lead to an unfair distribution and redistribution of means and hence, to interpret resilience according to a "speculative" perspective that is clearly in contrast with the positive meaning generally associated with the term. It is worth reporting also what happened after the 1998 earthquake Mitch. The "temporary housing built after hurricane Mitch in 1998 had become permanent by 2001, simply because no other housing alternatives had been offered. Because these houses had been built as temporary shelter, they were not adapted to the seismic conditions in Central America, and collapsed during the 2001 earthquake" (Wisner, 2001). Within this experience, a clear waste of the "window of opportunity" emerges due to:

- a lack of integration of measures towards different typologies of disturbance/hazards;
- a disregarding of temporal scale effects.

Indeed, adopting a resilience thinking to face the emergency phase should have provided a contribution in this regard, since, at least as it is conceived in Ecology, it emphasizes the cross-scale relationships and suggests to examine the effects of a given measure, implemented with respect to a specific perturbation, in the light of other typologies of perturbations.

To sum up, the presented remarks corroborate the assumption according to which thinking in terms of resilience can be advantageous in the field of disasters due to the following aspects:

- resilience is conceived as a conceptual approach to deal with uncertainty and future change with respect to traditional approaches mainly focused on system's control;
- resilience represents a premise for a proactive response to disasters as it embodies the concept of adaptive and learning capacity, that is typical of living systems;
- resilience gives room to the emergence of new configurations of the system (even more desirable than the previous ones) after a disturbance, as a result of the self-organization capacity that is typical of complex systems;
- resilience paves the way to recognize the role of the initial condition of a system in its evolution pattern following the occurrence of a given event. In such a way, there is an implicit assumption of the importance of effective mitigation measures towards more or less likely hazards;
- resilience exalts the cross scale effects related to a given event. Such aspect assumes particular relevance with respect to chained events such as the na-tech disasters that probably represent the most significant example of events whose evolution is characterized by non-linear dynamics.

4.4 The dimensions of Resilience

The previous insights on resilience have highlighted as the concept is largely oriented to implement policies of coping with a wide spectrum of shocks as sources of change and uncertainty, and to provide useful suggestions for increasing capabilities of self-organization, and preserving and improving capacity for learning and adaptation.

Nevertheless, up to now due to the heterogeneity of approaches and aims and to the different disciplinary perspectives, both the definitions of resilience and of its main components or dimensions are very heterogeneous so that Rose (2007) stated that "resilience is in danger of becoming a vacuous buzzword from overuse and ambiguity". Therefore, in this paragraph, the main studies focused on resilience have been analyzed, in order to provide an overview of the main research findings on this topic.

In detail, the main performance dimensions having a reverberating effect on resilience, as reported by current scientific literature, have been collected in table 2 according to different typologies of systems. Once again, the ecological field and its extension into the socio-ecological domain offer fundamental remarks for singling out such characteristics. The researches related to this field are namely the one of Folke et al.(2002) that represents a synthesis of Resilience Alliance thinking and the one of Walker et al.(2004). Fiksel (2003) faces the problem by a clear system perspective grounding on the opportunity of designing industrial product and service systems; in detail he couples the aspects of resilience with those referring to sustainable development. Godshalk (2003) deepens the problem by a planning perspective, stating that "since hazard planners must cope with uncertainties, it is necessary to design cities that can cope effectively with contingencies". The author, starting from previous researches on the topic, gathers some resilience principles fitting cities systems with respect to the threat of natural hazards and terrorism. Another contribution developed with reference to urban system is provided by Chuvarajan et al. (2006) that investigate how improving municipal resilience can be a strategy to reach sustainability and proposes implementable measures to improve both resilience and sustainability. Some diagrams for barriers and supporting factors of resilience are reported in the appendix of the work. Maguire and Hagan (2007) recognized resistance, recovery and resilience as the three properties characterizing a resilient community. In fact, in an ongoing process, a resilient community predicts and anticipates disasters; absorbs, responds and recovers from the shock; and improvises and innovates in response to disasters. The economic perspective is represented by the contributions of Van der Veen (2005) and Briguglio et al. (2008). Van der Veen introduces redundancy, with respect to an analysis of vulnerability to flooding, in terms of "ability to respond to a disruption" and, as a consequence, with a clear reference to resilience. Briguglio et al. (2008) propose a generic economic resilience index built on four variables: macroeconomic stability, microeconomic market efficiency, good governance and social development. The concepts of efficiency, rapidity and flexibility act as background to all the dissertation.

Some researchers of MCEER[30] provide a relevant contribution, presented in Bruneau et al. (2003), on the dimensions of resilience. In detail, they carried out the R4 model (robustness, rapidity, redundancy, resourcefulness) which refers to the resilience of social system in face to earthquakes. The authors define community seismic resilience as the ability of social units (e.g. organizations, communities) to mitigate hazards, to contain the effects of disasters when they occur, and to carry out recovery activities in ways that minimize social disruptions and mitigate the effects of future earthquakes. Seismic resilience can be achieved by enhancing the ability of a community's infrastructures to perform during and after an earthquake (lifelines, structures) as well as through emergency response that effectively cope with and contains losses and recovery strategies that enable communities to return to levels of predisaster functioning (or other acceptable level) as rapidly as possible. In addition to the aforementioned properties of resilience, the framework of Bruneau et al. (2003) includes the following "dimensions" (but according to our perspective, it should be better defining them as "domains") of community resilience: technical, organizational, social and economic.

These domains constitute the TOSE framework whereas:
- the Technical one refers primarily to the physical properties of systems, including the ability to resist damage and loss of function and to fail gracefully. The technical domain also includes the physical components that add redundancy (Tierney and Bruneau, 2007);
- the Organizational one refers to the capacity of organizations that manage critical facilities and have the responsibility for carrying out critical disaster-related functions to make

[30] Multidisciplinary Center for Earthquake Engineering Research.

decisions and take actions that contribute to achieve the properties of resilience, namely robustness, redundancy, resourcefulness and rapidity (Bruneau et al., 2003);

- the Social one encompasses population and community characteristics that render social groups either more vulnerable or more adaptable to hazards and disasters. Social vulnerability indicators include poverty, low levels of education, linguistic isolation, and a lack of access to resources for protective action, such as evacuation (Tierney and Bruneau, 2007);
- the Economic one refers to the capacity to reduce both direct and indirect economic losses resulting from earthquakes (Bruneau et al., 2003).

According to Tierney and Bruneau (2007), the TOSE framework emphasizes a holistic approach to community and societal resilience, looking beyond physical and organizational systems to the impact of the disruptions on social and economic systems. The MCEER's research has been used as a benchmark for practitioners more than once. Chang and Shinozuka (2004) refine Bruneau's approach by reframing the measure in a probabilistic context. Davis (2005) explores the concept of resilience before, during and after disaster impact and presents various case studies to indicate how resilience operates or fails to occur and why. Tierney and Bruneau (2007) reaffirm the validity of the R4 approach for highlighting the multiple path to resilience. Within the MCEER's framework, UNESCAP[31] (2008) takes into account only the robustness, redundancy and resourcefulness dimensions. In fact, rapidity is excluded due to the fact it depends also on the degree of shocks experienced. The UNESCAP report examines resilience coupled with resource efficiency as key factors for strengthening efforts to improve the sustainability of economic growth, with a specific focus on Asia and the Pacific in a risky development context.

[31] United Nations Economic and Social Commission for Asia and the Pacific

AUTHOR	YEAR	DIMENSIONS/PROPERTIES/CHARACTERISTIS/ATTRIBUTES	TARGET
Folke et al. (Resilience Alliance)	2002	Diversity Redundancy Adaptability Self-organization Innovation Memory Experience & knowldge Learning capacity Transformability	Complex Adaptive Systems
Fiksel	2003	Diversity Adaptability Cohesion Efficiency	Systems
Godshalk	2003	Diversity Redundancy Strenghts (Resistance) Adaptability/Flexibility Collaboration Interdependence Autonomy Efficiency	Cities
Bruneau et. al **Chang et al.** **Davis** **Tierney & Bruneau**	2003 2004 2005 2007	Redundancy Robustness Resourcefulness Rapidity	Communities
Walker et al.	2004	Resistance Latitude Precariousness Panarchy	Socio-ecological systems
Adger et al.	2005	Diversity Redundancy Spatial pattern	Ecosystems
Van der Veen et al.	2005	Redundancy (including substituability and transferability)	Economic systems
Chuvarajan	2006	Diversity Redundancy Self-organization Memory Networks Innovation Individual capacity Spatial scale interaction Temporal scale interactions Self-reliance Feedback	Municipal communities
Maguire and Hagan	2007	Resistance Recovery Creativity	Social systems
UNESCAP	2008	Redundancy Robustness Resourcefulness	Socio-ecological & economic systems
Briguglio et al.	2008	Efficiency Rapidity Flexibility	Economic systems
McDaniels et al.	2008	Robustness Rapidity	Infrastructure systems

Table 2: Main research findings on resilience dimensions

	Robustness	Redundancy	Resourcefulness

Economic resilience			
Ecological resilience			
Social resilience			

Table 3: Potential framework for a Resilience index (UNESCAP, 2008)

A potential framework (table 3) for a resilience index is suggested in the report with respect to different domains. (economic, ecological and social).

Finally, McDaniels et al. (2008), with a specific reference to infrastructures systems, develop a conceptual framework for understanding the factors that influence resilience with respect exclusively to robustness and rapidity. Furthermore, the author presents some flow diagrams for understanding kinds of decisions that can be pursued within infrastructure systems to foster these two dimensions of resilience.

Following the appearance order of resilience dimensions in table 2, a definition, coupled with some specific examples grounded into different field of applications (ecological, social, economic, disaster), is provided below. Only some of the dimensions suggested by Walker et al. (2004) have been neglected due to their specific reference to the basins of attractions for representing the dynamics of socio-ecological systems.

Diversity

"Diversity is the variety within a system, and is a characteristic of all complex systems" (Robèrt et al., 2005). Not surprisingly, the importance of diversity and, in detail, of functional diversity as a prerequisite for resilience, has been firstly recognised in the ecological field in that it plays a significant role in the production and maintenance of ecological services that underpin human societies. In detail, Folke et al. (1996) look at diversity maintenance as a manner that assures that the ecological functions underpinning ecosystem productivity are preserved, over a range of climatic conditions. This range of climatic conditions can be viewed as a source of variability and potential changes. Expanding this line of thought, Berkes et al. (2002) state that diversity of species performing critical functions, diversity of knowledge, institutions and human opportunity and diversity of economic supports all have the potential to contribute to sustainability and adaptive opportunity.

Diversity is recognized as a resilience contributor in socio-institutional and economic field as well. In the latter respect, a diverse economy ensures that there is overall economic viability if one industry fails due to market conditions or resource scarcity whereas, by a socio-institutional perspective, for example, the variety of stakeholders (institutions, ordinary citizens, NGOs, etc) is beneficial in the sense that they provide diversity of experience and knowledge (Chuvarajan et al., 2006). According to Adger (2000), some areas, like coastal regions due to their "diverse" resources are more resilient compared to areas dependent on a single resource. With respect to the disaster field, Twigg (2007), referring about indicators of communities resilience suggested by PLAN International[32], reports the "extent of diversity of livelihood options" as indicator of communities resilience in the face of the risk management and vulnerability reduction and the "extent of diversity of physical and communications infrastructure and assets" (e.g roads, boats, mobile phones etc) as indicator in terms of disaster preparedness and response[33].

[32] PLAN International is an international development agency.

[33] "Risk management and vulnerability reduction" and "Disaster preparedness and response" are two of five thematic areas relating to resilience and Disaster Risk Reduction (DRR).

Redundancy
Redundancy is defined by the Oxford English Dictionary as "the state or quality of being redundant; superfluity; superabundance" and further as "excessive, abounding too much". In such a way, the word seems to carry a negative connotation. On the contrary, it is considered a key-factor enhancing resilience. By a functionality perspective, redundancy, as presence within a system of several actors which perform the same function, assures the function to continue if one actor fails (Chuvarajan et al., 2006). Within the economic field, Van der Veen et al. (2005) identify redundancy with transferability as the ability of an activity (or system) to respond to a disruption by overcoming dependence by deferring, using substitutes or even relocating. More specifically, substitutability refers to the degree to which a good or service can be replaced by another good or service when the need arises. In the disaster field, and in detail, referring to earthquake, Bruneau et al. (2003) define redundancy as the availability of substitutable elements or systems that can be activated when earthquake-related disruptions occur. In such a way, redundancy contributes to ensure the continuity of lifelines and business during the emergency stage. A special case of redundancy can be considered adopting "fall-back arrangements", (for example developing several lines of defence against flooding) in terms of pre-prepared back up strategy. This is a very relevant concept due to the uncertainty of what can happen and of the surprise factor.

Adaptability
Adaptability is the capacity of actors in the system to influence resilience (Walker et al., 2004) or similarly, the capacity of actors in a system to manage resilience in the face of uncertainty and surprise (Gunderson and Holling, 2001). It is used as a synonymous of adaptive capacity (Smith and Wandel, 2006). According to Folke et al. (2002), adaptability is closely related to learning in that the latter is a premise for the former. In line with the Resilience Alliance perspective, Godshalk (2003) defines adaptability as related to capacity to learn from experience and to flexibility to change.

Self-organization
It is one of the defining properties of complex systems. The basic idea is that open systems will reorganize at critical points of instability (Berkes et al., 2002). Such a reorganization includes the ability of humans to meet their needs through creative interactions between each other as stressed by Chuvarajan (2006) referring to social systems. This aspect has been previously investigated by Kimhi and Shamai (2004), quoted by Maguire and Hagan (2007), and named expressly "creativity" to refer to a gain of resilience achieved as a part of the recovery process following a disturbance.

Innovation
It is the reorganization of variables within a system in response to change (Chuvarajan, 2006). In ecosystems, innovation is termed novelty and corresponds to reorganization following a disturbance. Innovation is part of the Holling's model of panarchy (see annex 1).

Memory
Memory is the ability of a system to preserve knowledge and information (Chuvarajan, 2006). Even if an ecological memory is recognized, memory becomes prominent within the social field. Social memory is defined as "the accumulation of experiences concerning management practices and rules-in-use that ensure the capacity of social systems to monitor change and to build institutions (formal and informal norms and rules) that enable appropriate responses to signals from the environment" (McIntosh, 2000). It embeds long-term historical and cultural observations of which cultural diversity and a diversity of worldviews linked to cultural evolution may play an essential role in nurturing resilience and capacity to adapt to change (Chuvarajan, 2006). According to Adger et al. (2005), social memory comes from the diversity of individuals and institutions that draw on reservoirs of practices, knowledge, values, and worldviews and is crucial for preparing the system to change, building resilience, and for coping with surprise. Jacobs (2000) includes memory

within the "human capital" but according to Berkes's point of view (Berkes et al., 2002), social memory represents the accumulation of experience with practices and rules in use at the collective level; as a consequence, it should be more correctly classified as a form of "social capital". Social memory is explicitly recognized as a source of resilience by Folke et al. (2005). In detail, the mobilization of social memory is seen as a strategy for adaptive governance during period of rapid change in so far it allows for novelty, innovation, and experimentation within the framework of accumulated experience. With respect to SES, the Holling's model of panarchy (see annex 1) includes memory as well.

Experience

The accumulated experience represents an essential source of resilience in the light of both the re-organization after a disturbance (Folke et al., 2002) and the ability to anticipate a disaster (Gunderson, 2009). The meaning of experience is very close to the memory one in that there is no memory without experience. By a social perspective, experience is one important factor constituting the human capital and, coupled with knowledge, represents a starting point for warning and other preparedness activities.

Learning capacity

The capacity of learning from past event in order to foresee and cope with the future is recognised as part of the resilience concept by Resilience Alliance (Folke et al., 2002). It can be supported by the preservation of diversity.

Transformability

With respect to SES, transformability is the capacity of people to create a fundamentally new social-ecological system when ecological, political, social or economic conditions make the existing system untenable (Walker et al., 2004).

Cohesion

Cohesion requires the existence of unifying forces or linkages (Fiksel, 2003). In the social field, cohesion represents an essential property to express what is defined "sense of community".

Efficiency

In the words of Fiksel (2003), efficiency represents a fundamental property for service system and entails that performance are realized with modest resource consumption. According to Godshalk (2003), resilient systems tend to be efficient. Nevertheless, efficiency is not widely recognized as a desirable dimension. For example, Walker et al. (2002) report that a loss of resilience can result as a consequence of an increased efficiency of resource use. In line with Walker, Folke et al. (2002) clearly state that keystone processes in ecosystems should not be evaluated by the efficiency with which each process functions. Within the UNESCAP (2008) report, efficiency is seen as something different from resilience, both important aspects of sustainability.

Resistance

When the researches on resilience were at the beginning, resistance has been adopted as a mere synonymous of resilience. Using the models of basins of attraction to explain the existence of different forms of stability, a lack in equivalence has been stressed by some members of Resilience Alliance. In this respect, Carpenter et al. (2001) state that two systems may have the same resilience but differ in their resistance, as measured in terms of how much they are displaced (or disturbed) by a given physical force or pressure. As a consequence, how great an external force the system can withstand before it crosses the boundary of its basin of attraction depends on both resilience and resistance (Carpenter et al., 2001). Walker et al. (2002), expanding the relationship between resistance and resilience, state that "some (social) systems may be resistant, yet not resilient" and mention systems that "do not allow for self-organization and learning" as examples of the last one. Anyway, Walker et al. (2004) themselves choose resistance as an important aspect to measure SES's resilience with the following meaning: "the ease or difficulty of changing the system". Resistance is recognized as different from resilience within the disaster field as well and even referring to mitigation measures. With respect to the Flood Hazard (Bowker, 2007), resistance measures are about constructing a building in such a way to prevent floodwater entering the building and damaging its fabric whereas resilience measures are about constructing a building in such a way that although flood water may enter the building its impact is reduced (i.e. no permanent damage is caused, structural integrity is maintained and drying and cleaning are facilitated). A fundamental aspect seems to emerge from such definitions: resistance measures have a passive character in that they tend to avoid that the hazard can affect the structures whereas resilience measures admit the occurrence of the effect/damage of a hazard according to a "pro-active" response.

Collaboration

Collaboration refers to the existence of multiple opportunities and incentives for broad stakeholder participation, as in public private partnerships (Godshalk, 2003). A synonymous of collaboration, especially from an institutional perspective, is cooperation.

Interdependency

Interdependency occurs when system components are connected in such a way that they support each other, as in engineered structures (Godshalk, 2003).

Autonomy

Autonomy represents the capability to operate independently of outside control, as in self-government (Godshalk, 2003). Autonomy can be considered as the antonym of "dependence" or a synonymous of independence. Adger (2000), with the aim of showing the linkages between social and ecological resilience, refers to resource dependence as a general indicator for a lack of resilience. Nevertheless, by this perspective, a distinction between dependence on a single resource and dependence on diverse resource is made (see diversity dimension). From a social perspective, independence has also to be linked to welfare and assistance issues that are usually provided by formal institutions. If the last ones are not able to guarantee services related to welfare and aimed to assure assistance at a community level, only individual's initiatives (e.g. personal insurance or mitigation measures, with respect to a given likely hazard) taken on one's own, can determine an increase of resilience. As shown within this project, by the analyses carried out following the Four Quadrant's approach (ENSURE project, Deliverable 1.3), such initiatives depend, in turn, on other social factors like the education level, the religious beliefs, the level of trust in local authorities and risk managers and the economic conditions. From an institutional perspective, independence/autonomy can refer to the existence of devolved structures at local levels.

Robustness

"The maintenance of some desired system characteristics despite fluctuations in the behavior of its component part or its environment" can be defined as robustness (Carlson and Doyle, 2002). As a consequence, a need for defining *a priori* which characteristics of the system are the desirable ones arises. Many deepening have been carried out on the topic, especially in the socio-ecologic field. As an example, Anderies (2004) wonders if a system can be considered robust when a particular ecological system collapses, but the social system continues to function due to its ability to adapt and use alternative resources. Robustness should not be identified with a "static" concept of stability. Anderies (2004), paraphrasing Ostrom (1990), states that to enhance the robustness of SESs, it might be desirable to have institutions that are not persistent but may change as social and ecological variables change. Another definition of robustness, as synonymous of structurally stable, is provided by Tu (1994) as "the ability of a system to preserve its structure in the face of perturbations". In such a way the term is used as the flip side of vulnerability (Gallopin, 2006). Another term used as converse of robustness is fragility. Robustness is strongly linked to the concept of a performing system as underlined by UKCIP[34] definition (UKCIP, 2003) referring to climate change as "the ability of a system to continue to perform satisfactorily under load". In the disaster field, according to Bruneau et al. (2003), robustness refers to strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function". Robustness is seen as a desired end state of resilience-enhancing measures.

Resourcefulness
Such a property has been implemented with respect to earthquakes in MCEER's model (Bruneau et al., 2003), and represents the capacity to mobilize and apply material and human resources to achieve goals in the events of disruptions. The local availability of resources and skills may be directly relevant to emergency management, planning, preparedness and for community support if an emergency does occur (Buckle et al., 2000).

Rapidity
Rapidity is a controversial property according to some aspects. It cross-refers to time that can be considered a final indicator to measure resilience to all intents and purposes. Time appears as an explicit indicator of resilience as the "speed of return to equilibrium" according to the definition of engineer resilience. On the other hand, the ecological resilience concept excludes the use of such an indicator due to the existence of multiple stable states. Nevertheless, in the disaster field terminologies, time is a recurrent concept (e.g. ISDR, 2009). In the disaster field, according to Bruneau et al. (2003), rapidity is the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruptions.

Spatial pattern
Spatial pattern is a terminology used by Adger et al. (2005) to highlight the importance of distribution (e.g. resources) over the space. Tobin (1999) adopts the term to refer to the sprawl of communities, essentially constituted by immigrants, along the coastline in Florida that are hurricanes and flooding prone-areas. The characteristics of spatial pattern can affect also the sense of cohesion, solidarity and cooperation, and as a consequence, the social capital of communities. By this perspective, the Northern Negev case study (del. 2.1.1 and del 2.1.3) has shown how cooperation within the Bedouin people is relatively low, if compared to the Jewish groups one, due also to the fragmented spatial distribution of their settlements. Another example of the importance of spatial patterns, in terms of both vulnerability and resilience is provided by the Mexico city case (Del. 2.1.2) that shows how the mono-centric urban spatial pattern of the capital city and the mono-centric structure of all the settlements within the affected area caused damages and limited possibility to restore the services of communications and electricity in an area that was wider than the one directly hit.

Networks
Networks are formed by the relationships between interdependent actors within systems. Due to its implications within the disaster field, it is worth reporting the description for networks provided by Chuvarajan (2006):

Network consist of non-identical elements, or actors, called "nodes". These nodes are connected by diverse interactions or links. There are two main types of networks: random and scale-free networks. Random networks are those in which all nodes have a similar number of links. Scale free networks, on the other hand, are those where some nodes have a high number of links that are called hubs. A random network has no more important or less important nodes and it is rather resistant against a direct attack, on the other hand, a direct attack against its major hubs can cause collapse of the whole scale free network. Hence, scale-free networks might be less resilient if major hubs disappear and vice versa.

[34] UK Climate Impact Programme

Indeed, a certain level of redundancy among hubs should be preserved in order to maintain resilience, in case one or two major community hubs fails or falls apart.[35]

By a social perspective, networks can be key mechanisms for drawing on social memory at critical times and enhance information flow and collaboration across scales (Chuvarajan, 2006). Established networks are recognized as elements supporting resilience by Buckle et al. (2000) as well. In fact, stable links between people and groups facilitate the exchange of information as well as the sharing of resources and the commitment of skills, time and effort to planning and preparedness. The value of social networks which affects the productivity of individuals and groups represents a core part of what has been named social capital (Parker and Tapsell, 2009; Sapountzaki, 2009). Social capital, as a component of the broader concept of territorial capital, contributes to cope with, and successfully counter, adversities generated by external shocks (Sapountzaki, 2009). Quickly, the concept of resilience is again called to mind through such a definition. Just as an example, as highlighted in the Monserrat case study (Del. 2.1), the loss of social capital has had negative impacts upon the coping capacity with respect to the eruption event, especially in economic terms. Hence, social capital plays a central role in the process finalized to enhance resilience.[36]

Furthermore, according to Matthiesen (2005), it is worth making a distinction between formal and informal networks:

- formal networks are "strategic cooperation structures within formal-institutional structures and systemic functions, with clearly defined strategic goals;
- informal networks consist of family-members, friends, neighbours and colleagues. They are defined, above all, by "intensified communication processes and shared tacit/explicit components of knowledge".

Informal networks represent a "suspected" source of resilience especially in:

- small communities that appear more inclined to "use" them in an emergency context, when formal structures (institutions, fire service, police forces) fail (Lavanco, 2003);
- people with scarce accessibility to resources and means during the recovery phase (Del. 2.1.2).

An example of informal networks and cooperation is mentioned in the case of the Northern Negev (del.2.1), in which the existence of a social solidarity between the Jewish groups has represented a precursor for pre-adaptation measures in face of the continuous threat of drought and have affected also positively the ability to use institutional assistance. Hence, a networking capacity is a premise for cooperation activities. From a technical and organizational perspective, cooperation can take advantage from interoperability agreements that allow a synergic work in terms of information exchange, among different types of networks. This aspect shows its importance especially during the emergencies phases following a disasters.

Individual capacity

Individual capacity refers to strengthening the individual actors within the system. From a social perspective, individuals will be more likely to contribute positively to their community if they are healthy and have good individual resources. Learning can be viewed as a part of building individuals capacity for social resilience (Chuvarajan, 2006).

Spatial scale interactions

Interactions take place between different spatial scales and hierarchical levels on socio-ecological systems. It is important to maintain these interactions in order to influence and respond locally to regional and global effects (Folke et al., 2005). In a social system,

35 The consequence of having no redundancy in the lifelines networks (electricity, medical centers and so on) is accurately described within the Mexico case study (del 2.1).

36 Within this paper the concept of social capital has been "unpacked" according to some of its factors with the aim of focussing more easily on specific aspects and suggesting action that can influence them.

members will advantageously be aware of their interdependence with communities. In fact, members can respond to feedback and consequently influence the results that might have an impact on their community. (Chuvarajan, 2006).

Temporal scale interactions

Temporal interactions are interconnected with spatial scale interaction and both included in the Holling's model of panarchy. The concept of time contributes to define resilience. By an ecological perspective, in the short run, a system may seem resilient, but a cycle may last over hundreds of years. Moreover, feedback can be delayed over a long period of time. Hence the necessity to have long-term perspective and to recognize these system cycle variations arise. Broadly speaking, an important way through which temporal interaction contributes to resilience is by framing short-terms plans, projects and actions within long-term objectives (Chuvarajan, 2006).

Self - reliance

Self-reliance means satisfaction of basic needs locally with the aim to eliminate dependence on imported resources (Chuvarajan, 2006). In economy, self-reliance has the advantage of strengthening the local economy, decreasing energy consumption for transportation (Ekins, 1986), and makes local economy stronger and less vulnerable to global economy fluctuations (James and Torbjorn, 2004).

Feedback

Feedback represents the propagation of a response across the system due to the fact that the different parts of which it is constituted are connected and interdependent in such a way that when one part changes, it affects another part. Due to the fact that feedback happens at different time scales, some responses may be immediate whereas other may occur at a much longer temporal scale. Referring to social system, a participatory process of citizens into the disaster management can provide feedback that local administrations should take into account to enhance resilience (Chuvarajan, 2006).

Recovery

Recovery relates to a community's ability to 'pull through' the disaster (Kimhi & Shamai, 2004). It is this property that refers directly to the idea of a community 'bouncing back' to its pre-disaster level of functioning. Recovery can be understood in terms of the time taken for a community to recover from a disruption. A more resilient community returns to its pre-disaster state quickly and efficiently whereas a less resilient community recovers more slowly, or will fail to recover at all (Maguire and Hagan, 2007). Nevertheless, according to ENSURE project approaches, recovery should refer to a phase of the disaster cycle whereas the effective dimensions can be represented by the efficiency and rapidity ones that are included within the concept.

Creativity

Creativity represents the achievement of higher level of functioning by adapting to new circumstances and learning from the disaster experience. (Maguire and Hagan, 2007). Creativity is key to cope with surprise or, in other words, with hazards events that can't be foreseen or that have a magnitude higher than the expected one. By this perspective, creativity is extremely important also in respect to the development of scenarios that take into account less likely events and the definition of mitigation measures that are activities closely linked to the preparedness phase.

Flexibility

Flexibility enables an economy to bounce back after being adversely affected by a shock (Briguglio et al., 2008). Flexibility to change is further recognized as an aspect of adaptive capacity by Godshalk (2003).

4.5 Turning resilience into operational terms

Resilience is often invoked in concomitance of sudden shocks without considering that an erosion of resilience across time and space is a gradual and probably unconscious process. This threat has been underscored by Folke et al. (1996) with respect to ecosystems that "fails to signal" the long-term consequences of loss of resilience, continuing to function in the short term even though resilience declines. Hence, the need for the availability of a set of parameters emerges in order to monitor resilience across time and different spatial scales and also to control the effectiveness of risk reduction efforts (Chang and Shinozuka, 2004). On the opposite, what is currently missing are operational tools to assess resilience.

Hence, in this paragraph two different approaches for turning resilience into operational terms will be provided. A first one, refers to the Bruneau's model which represents a first attempt for measuring quantitatively some of the resilience dimensions sketched above. A second one, based on the main dimensions of resilience reported in table 2, is addressed to identify a framework of the key performance dimensions of resilience. Such a framework should be useful for both driving suitable policies towards an increase of resilience and providing insights on the extent to which current mitigation measures - generally aimed at reducing hazards, exposure and vulnerabilities - effectively contribute to enhancing resilience.

4.5.1 Bruneau's model for a quantification of Resilience

An important aspect of turning resilience into operational terms is the possibility of quantifying the resilience of a system. Bruneau proposes to quantify the resilience of a structure by the evolution of the "quality of the structure" Q(t) with time t, (e.g. the capacity of a hospital or the number of households provided with electricity). According to the author and in order to simplify the problem on the following scheme, the quality of the structure is supposed to remain constant (Q(t)=100%), before the occurrence of the event ($t=t_0$) and at the end of the recovery ($t=t_1$), the system is supposed to go back to the initial state. In practice, after t_1, the quality of the system can be improved (Q(t)>100%, e.g. the building may be repaired with more advanced seismic performance) or depreciated (Q(t)<100% some structural cracks may never be repaired) and this point will be integrated later in the quantification thanks to the parameter α_R (so-called the recovery factor).

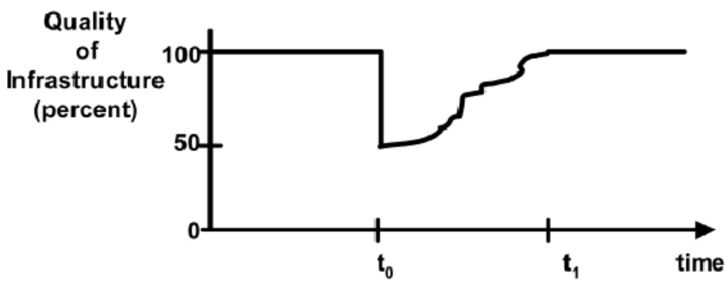

Figure 6: Evolution of the "quality of the infrastructure" among time

The resilience (for one structure and one event) is quantified by the integral: $R = \int_t (100 - Q(t))dt$, and the system is as much resilient as the area R is small. In order to take into consideration several events of different intensities, Bruneau (2006) introduces an average on both the number of events and their intensity:

$$\overline{R} = \frac{1}{N_I}\sum_{I=1}^{N_I}\left\{\frac{1}{N_E}\sum_{E=1}^{N_E}\frac{1}{T_{RE}}\int_{t_{0E}}^{t_{0E}+T_{RE}}\left[1 - L(I,T_{RE})\cdot\alpha_R\cdot f_{\mathrm{Rec}}(t,t_{0E},T_{RE})\right]\cdot dt\cdot p_E(0,T_{LC})\right\}\cdot P(I)$$

Bruneau's quantitative approach takes only into consideration two of the four dimensions of resilience (Bruneau and al., 2003): robustness and rapidity (which are ends by themselves). Hence, redundancy and resourcefulness dimensions (which are means to enhance resilience) are not taken into account in this formula. Integrating redundancy and resourcefulness in the quantification of resilience would be very complex and studies on this subject are still in their early stages.

To take redundancy into consideration, quantification of the linkages between the structures' activities and networks' quality and precise information on the fragility of networks will be necessary.

$\mathbf{N_E}$	Number of extreme events expected during the lifespan T_{LC} of the system
$\mathbf{N_I}$	Number of different extreme event intensities expected during the lifespan T_{LC} of the system
$\mathbf{T_{RE}}$	Recovery time from event E
$\mathbf{T_{0E}}$	Time of occurrence of the event E
$\mathbf{F_{REC}(T,T_{0E},T_{RE})}$	Recovery function
$\mathbf{A_R}$	Recovery factor=1 for full recovery
$\mathbf{L_I(I,T_{RE})}$	Normalized loss function
P(I)	Probability that an event of given intensity "I" happens in a given time interval T_{LC}
$\mathbf{P_E(0,T_{LC})}$	Probability that an event happens E times in a given time interval T_{LC}

Therefore, in his work Bruneau assimilates redundancy to a simple aggregation, which, of course, does not reflect practical situations. Besides this, the above quantitative approach presents other weak points such as the definition of the quality of the infrastructure or the non-linearity. Defining the quality of an infrastructure is a very difficult matter. For some infrastructures like power networks, the quality is directly quantifiable in terms of performance (kilowatts, households supplied…) but in many cases, quantification of the quality of the infrastructure is a difficult task. Bruneau develops the example of accurate care system (Bruneau and Reinhorn, 2007): the quality of hospitals can be defined for instance either by the healthy population proportion, or the patients per day capacity. The two descriptions will not lead to the same result and the second one better corresponds to "engineering terms" and gives a better idea of the hospital state. As mentioned above, the system is as much resilient as the area R is small. But, as emphasized by Bruneau (2006), two equal surfaces do not necessarily mean that the considered situations are equivalent.

For example, considering the following situation:

- Structure S1 loses 50% of quality and reaches a normal state in 100 days;
- Structure S2 suffers total loss and is re-built in 50 days;

the areas are equal, but resiliences are not the same. Bruneau puts forward that "greater loss likely" is linked to "less rapid recovery", but it seems that building a new structure to replace the collapsed one may be much faster than repairing a structure heavily damaged.

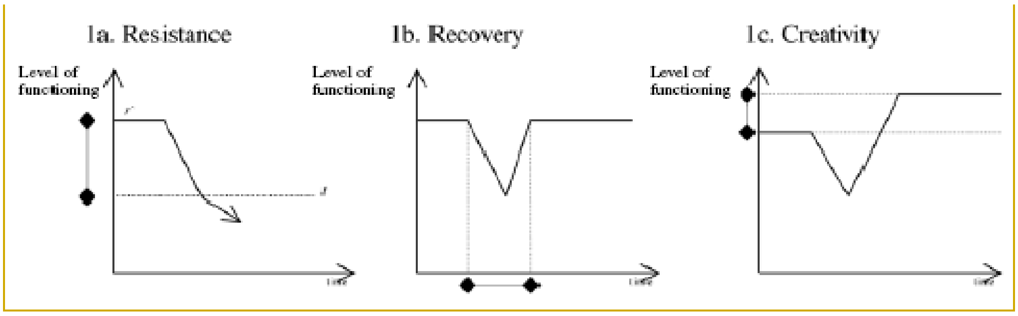

Figure 7: Properties of resilience adapted from Adger, 2000 (Maguire and Hagan, 2007)

However in any case, it appears preferable (from the community point of view) to try to reduce the initial loss.

The quantitative model of Bruneau provides spurs for further insights. As shown, from a mathematical point of view, resilience is represented by the complementary area of the function Q(t)=100 with respect to that subtended by the Q(t) function in the same span of time. In such a way, the quantitative definition of resilience is not expressed through "absolute" terms but only with respect to a previous level of functioning. For admission of the same authors (Bruneau et al., 2003) " return to 100% pre-event levels may not be sufficient in many instances, particularly in communities where the existing seismic resiliency is low, and post-event recovery to more than 100% pre-earthquake levels are often desirable". Moreover, the possibility of an attainment of higher levels of functioning by adapting to new circumstances and learning from the disaster experience (Maguire and Hagan, 2007) which is an important aspect of resilience as a dynamic and not conservative concept, is completely excluded by defining resilience with respect to a pre-event level.

Such possibility is named "creativity" (fig. 7) by Kimhi and Shamai (2004) and it is quite similar to the definition of resilience provided by Resilience Alliance as the degree to which the system can build and increase the capacity for learning and adaptation (Folke et al., 2002).

In the plot, apart from creativity, resilience is represented by the resistance[37] and the recovery[38] properties, both expressed by linear measures. Bruneau's model combines these two aspects, giving in such a way a bi-dimensional representation of resilience. Being resilience expressed as a "complementary" area, as already mentioned, the system should be as much resilient as the area R is small. As shown, this condition doesn't always mirror the effective state. Hence, even if Bruneau's model is a valuable example of quantification for resilience, it presents nowadays substantial limits for a wide application and requires further developments.

4.5.2 The key dimensions to enhance resilience

In this paragraph, a first attempt to provide a logical plot of the main dimensions of resilience as they have been gathered from scientific literature is presented. Some dimensions, being very similar to or included in other dimensions, have been neglected, (e.g. cooperation and collaboration are very similar; self-reliance includes also autonomy) whereas others have been synthesized in a single concept (e.g. networks and spatial patterns have

[37] Resistance is understood as the degree of disruption that can be accommodated without the community undergoing long term change.

[38] Recovery is represented by the time taken by a community to return to its predisaster state or predisaster level of functioning (Breton, 2001 quoted by Adger, 2000) after a disruption.

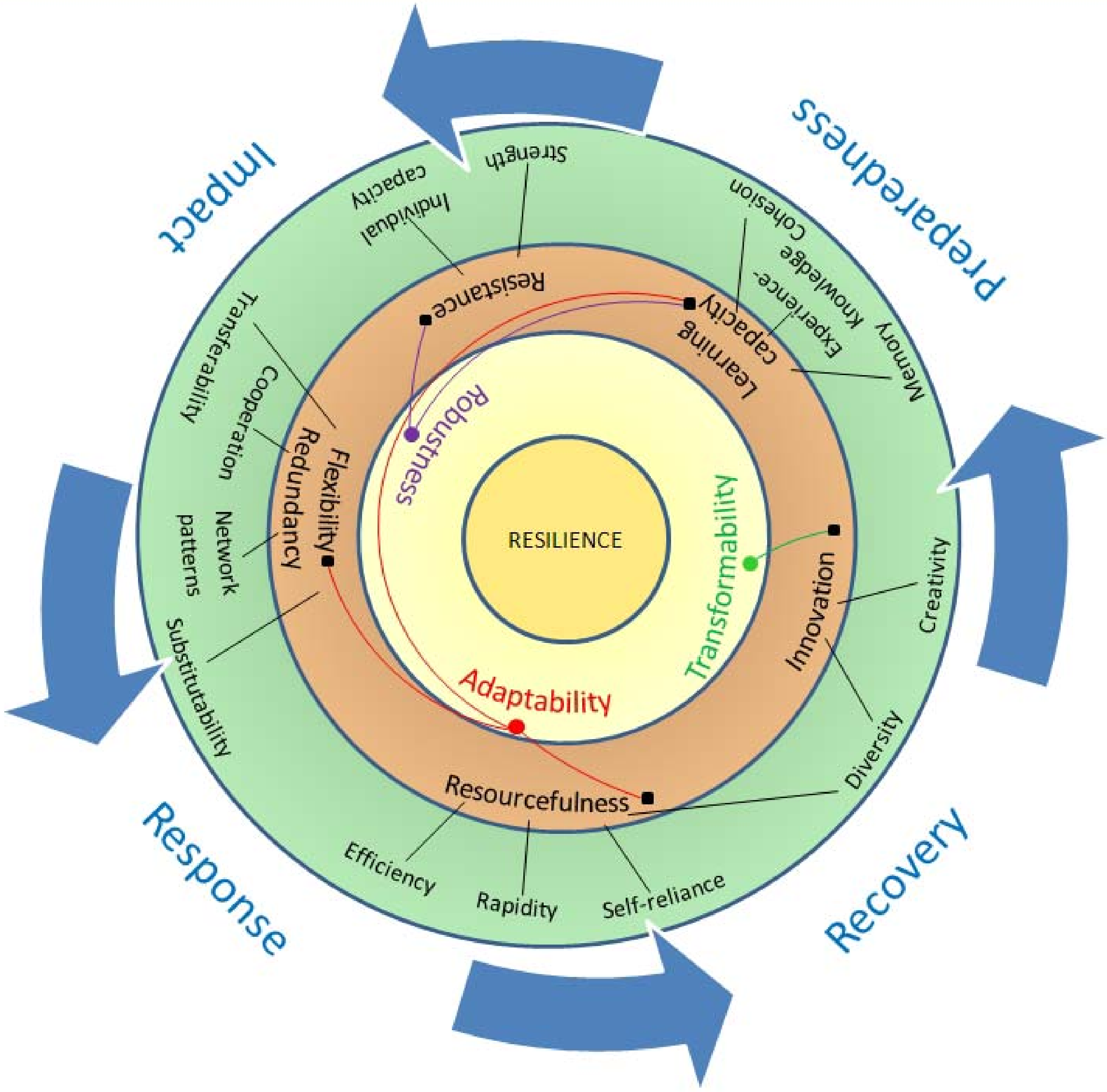

Figure 8: The key dimensions of resilience in the disaster cycle

been synthesized in the dimension "network patterns", due to the fact that networks, among the different types of spatial and organizational patterns such as hierarchical or mono-centric ones, are those that guarantee a higher flexibility). It is worth noting that the selected dimensions are very heterogeneous, in that some of them represent very wide and general concepts related for example to different meanings of the resilience itself, others are more specifically related to the abilities or features of a system which can be improved or strengthen to enhance resilience. Moreover, the different dimensions gain prominence in different phases of the disaster cycle: some of them are very relevant in face to the impact, others come on stage in the long term.

According to such considerations, the key dimensions of resilience have been arranged into a circular scheme, following the main phases of the disaster cycle: impact-response-recovery-preparedness. Moreover, within the circular scheme, the dimensions have been sorted into concentric circles that, starting from the most internal one in which resilience has been placed, drive toward a progressive specification of the resilience concept.

In detail, the most inner circle includes resilience; the second one represents the three main components or aspects of resilience itself that have been presented up to now: robustness, adaptability and transformability which can be interpreted as the main goals to achieve in relation to the different phases of the disaster cycle in order to enhance the resilience of a system; the third circle includes the key dimensions which have to be preserved and strengthen in order to enhance the three main components of resilience (robustness, adaptability, transformability); finally, the most external circle includes those dimensions, strictly related to the previous ones, that can be modified through specific policies in order to positively contribute to enhance resilience in all its components.

The previous discussion on resilience has highlighted an evolution of the concept from a meaning fairly close to the ability of elements or systems to withstand a given level of stress or demand without suffering losses or failures (robustness), to a capacity to adapt in face of the consequences (in terms of losses or failures) due to a hazardous event (adaptability) and, finally, to the possibility to turn the disaster into an opportunity by creating different conditions, sometimes more desirable, in respect to the pre-impact configuration (transformability). The three mentioned dimensions can be considered the main components of resilience; hence, they are not linked in the scheme since they can be considered as three sides of a single concept which have to be enhanced to make a system resilient in relation to a wide variety of external stresses. The three selected components clearly explain that resilience is different from being only the converse or the flip-side of vulnerability due to the fact it includes the opportunity for change and transformation that goes far beyond the assumptions of vulnerability. In other terms, looking at resilience as the flip-side of vulnerability, a primary role only to a single aspect and namely to the Robustness one is assigned. The latter is indeed strictly related to the maintenance of an equilibrium state (Carlson and Doyle, 2002) and is also identified with a structural stability concept (Tu, 1994). In this respect, only robustness can be interpreted as the "flip side of vulnerability" as already suggested by Gallopin (2006).

The three main components of resilience gain relevance in different stages of the disaster cycle. In detail, the robustness of a system arises during the impact "time"; a system can resist to the impact without showing any mark of weakening or at least showing a gap from its ordinary structural or functioning conditions that is temporary, depending on the duration of the disturbance. Adaptability is more relevant in the immediate aftermath of the impact, including the emergency phase; it can be defined as a "transition" phase, which can be referred to the short-medium term after the impact (response phase): according to its different levels of adaptability, a system can bounce back to a previous state or shift toward new ones. Finally, in long term and namely during the recovery phase there is room for changing and innovating the systems.

Shifting from the second to the third circle, some of the selected dimensions are strictly related to only one of the components above mentioned, others are very relevant to more than one.

In detail, robustness largely depends on the resistance of an element/system to an impact, that means that the hit element or system will be not damaged, or on the flexibility of the element or system, related to the capacity of quickly bouncing back after the hazardous event (Briguglio et al., 2008).

Resistance has been recognized as an important dimension of resilience by different authors; nevertheless, it represents a positive feature, in that it enhances resilience, when the hazardous event occurs but it can even represents a negative factor during the response or recovery phases. For example, the resistance of an institutional system to adapt or to change in face of an un-expected large size event, due to its rigidity or lack of flexibility, may largely frustrate quick decisions and actions (Menoni, 2001) as in case of Kobe earthquake (see § 3.3.2) during the emergency.

Flexibility and resourcefulness have been identified as the two main dimensions on which adaptability depends. Flexibility increases, on one hand, the robustness of the system by limiting the loss of functioning resulting from the impact while, on the other hand, guarantees the adaptive capacity of a system (Godshalk, 2003). In the scheme, flexibility has been associated to redundancy due to the fact that the latter represents the key-feature for increasing flexibility. Resourcefulness has been recognized as a key dimension both in response phase, to improve adaptability, and in the recovery phase, to enhance transformability. The latter is also strictly related to the dimension termed innovation, which represents the ability of a systems to reorganize itself in face of a disturbance. Innovation - arising in long term after the impact of a hazardous event - characterizes the recovery phase.

A key dimension for improving both robustness and adaptability of a system is the learning capacity one. Nevertheless, the latter plays a key role in the phase of preparedness in order to improve resilience for future events.

As mentioned above, each dimension has been linked and specified through other dimensions that are placed in the most external circle.

In detail, resistance has been linked to strength and individual capacity which can be mainly referred to the built environment and to the social domain respectively.

Flexibility and redundancy can be improved through different mechanisms aimed at overcoming dependence. Among such mechanisms it is worth mentioning transferability and substitutability (Van der Veen et al., 2005), largely widespread in relation to economic activities or to infrastructures, and intentional (designed) or spontaneous spatial and organizational network patterns, showing a higher flexibility than the hierarchical or mono-centric ones.

Another relevant dimension to improve flexibility is cooperation among the different actors of the system, especially by an institutional perspective. Cooperation or collaboration is in fact a form of redundancy in that it provides a multiplicity of opportunities that are very useful especially in the immediate aftermath of a disrupting event.

The key dimensions to guarantee or to improve resourcefulness has been recognized in rapidity, viewed by an organizational perspective (e.g. emergency), efficiency, aimed at optimizing the available resources, making a rational use of them and self-reliance, that implies autonomy, satisfaction of needs through local resource, lack of dependency linkages.

Moreover, resourcefulness is largely dependent on diversity too. The latter strongly supports the richness and the variety of available resources, enhancing in such a way resourcefulness. Moreover, it has been largely recognized as crucial to cope with uncertainty and surprise. According to Folke et al. (2002), diversity also provides a mix of components whose history and accumulated experience helps to cope with change, and facilitates redevelopment and innovation following disturbance and crisis. As a consequence diversity is also linked to transformability in that it provides spurs for innovation. The latter is linked to another non tangible resource that is creativity. This dimension gains prominence after the end of the emergency phase and in detail in that period generally defined as "window of opportunity". Creativity plays an important role also in scenario thinking - due to the fact that less expected events and combinations of effects with a low probability of occurrence could be taken into account - and mitigation measures that involve implementation of the lessons learnt in the creation of new policies and activities that will increase the community's resilience (Mileti, 1999). Both scenario thinking and design of mitigation measures are typical of the preparedness phase, completing in such a way the disaster cycle.

In this phase, wide room has been devoted to learning capacity which is key to increase both robustness and adaptability. It largely grounds on past experience that constitutes a support for the re-organization of the system requested after a disaster in face of future events. Experience should be spread and become knowledge (e.g. knowledge of events, damages, mitigation measure, good practices, etc.). Furthermore, past experience has to be included into collective memory that is an important dimension addressed not exclusively to adaptation but also to the following step that is transformation. A call to memory is in fact requested also to elaborate novelty solutions even if memory and innovation are apparently in conflict. The success of a learning process is also greatly influenced by the level of cohesion existing within the community. In fact, in case of a good cohesion level, experience is more easily communicated and memory more easily preserved.

Summing up, the plot represents an attempt to integrate different approaches and schools of thought by providing a systematization of the main dimensions enhancing resilience reported in current literature and an interpretation of their role and their mutual influences.

Such an attempt can be considered as a first step towards an operational tool for driving policies addressed to enhance resilience, even though it clearly requires further deepening mainly addressed at outlining qualitative or quantitative indicators for measuring and monitoring the efficacy of the implemented policies.

5 Vulnerability/ies and Resilience

5.1 The relationships between vulnerability and resilience

In this paragraph the relationships between vulnerability/ies and resilience with reference to the disaster field will be explored, starting from the deepening of the resilience concept carried out in the previous chapter and grounding on the inputs from previous tasks (WP1), the review of scientific literature and the analysis of past disasters.

5.1.1 Vulnerability/Resilience: inputs from previous tasks

The Work package 1, "State-of-the-art on vulnerability types", has been addressed to outline a state of the art about parameters and models to assess vulnerability from different points of view (structural, territorial, socio-economic, climate change). The deliverables provide several inputs about the relationships between vulnerability and resilience.

The Deliverable 1.1 "Methodologies to assess vulnerability of structural, territorial and economic systems" collects the state of the art of the different vulnerability assessment developed in the Task 1.1 (structural systems), 1.2 (territorial systems) and 1.3 (socio-economic systems) and is divided into three deliverables.

The Deliverable 1.1.1 is focused on the existing methodologies for physical vulnerability assessment related to earthquakes, floods, landslides and volcanoes. Therefore, specific references to relationships between vulnerability and resilience are missing: only the topic of the resilience of building materials and components to different hazard, particularly to floodwaters, is faced. From this point of view, an interpretation of resilience as capacity of building materials and components to efficaciously sustain the actions of the hazards continuing to play their structural role or, in other words, as opposite of the physical vulnerability, is provided.

The Deliverable 1.1.2 is focused on territorial systems and is, in turn, subdivided into three parts: "State-of-the-art on vulnerability of territorial systems – The case of hydro-geological hazards" (1.1.2-1) "State-of-the-art on vulnerability of territorial systems – The case of forest fire & drought" (1.1.2-2) and "Lessons learned and research windows opened by the state-of-the-art on territorial vulnerability" (1.1.2-3).

The Deliverable 1.1.2-1 aims at grouping the conceptual approaches to territorial vulnerability in order to identify major lines of thought or epistemological paradigms and to provide methodological examples of the above paradigms with reference to hydro-geological hazards. Authors underline that in scientific literature the concept of vulnerability is related to others such as resilience, marginality, susceptibility, adaptability, fragility, risk, exposure, sensitivity, coping capacity and criticality. However the reported vulnerability assessment methodologies sometimes mention the relationship between vulnerability and resilience, but precise and clear references to this topic are missing. In the research communities of Hydro-Geological Risks/Hazards and of Climate Change, the concept of Territorial Vulnerability reflects the propensity to losses of complex geographical entities due to a stressor. These complex entities incorporate physical, social, economic, cultural, organizational, institutional micro-units and macro-structures. Some researchers emphasize the "exposure" dimension of territorial vulnerability, others consider equally the "exposure" and "coping capacity" dimensions; a third group of researchers advocates a three dimensional essence of vulnerability (i.e. one comprising "exposure", "sensitivity" and "adaptive capacity" or "exposure", "resistance" and "resilience"). In this view, coping capacity, sensitivity and adaptive capacity, resistance and resilience are considered internal or inherent in the territory / community factors of vulnerability. A specific mention about the relationship between vulnerability and resilience is made with reference to an example about firms in Greece: "Territorial vulnerability is a condition created before the disaster event and undergoes internal changes rapidly after the manifestation of a hazard via redistribution processes. The latter are activated by public institutions and also by private agencies. A catalytic factor to this activation is resilience". Moreover, resilience is also "an individualized mode of coping with losses and catastrophes and thrives in contexts where public policies and interventions are weak and ineffective. While resistance can be boosted by appropriate public policies, resilience is the only possibility of survival of deprived agencies in an environment of free and tough competition for vulnerability relief. However, resilience is a mechanism of own vulnerability relief by transferring vulnerability burden to others".

In the deliverable 1.1.2-2, related to forest fire and drought, the relationship between vulnerability and resilience in relation to the forest fires ecological vulnerability has been mentioned. Vulnerability is interpreted as susceptibility of the ecosystem to change as a consequence of fire, often in an irreversible way. It changes with respect to the phases of the forest fire disastrous event. Short term ecological vulnerability refers to the soil degradation risk and it is determined by pre-event parameters. Exposure to the fire and resilience of the plant community are the basic components of medium term ecological vulnerability which refers to probable changes in plant composition and structure. Medium term ecological vulnerability is determined by the capacity of the community to return after fire to pre-fire conditions without significant changes in composition and structure (resilience). This capacity is associated with the presence/dominance of species with different reproductive strategies, structure of the community and fire frequency. In this interpretation resilience is not the flip-side of vulnerability, but it is included within it and it is referred to the pre-event conditions recovery.

In the Deliverable 1.1.2-3, similarities and differences among the most recent approaches to territorial vulnerability as well as their achievements and deficiencies are provided. The authors highlight that while most approaches acknowledge that vulnerability of spatial units is a multidimensional concept, most of the methodologies does not take into account multiple aspects of vulnerability. Each individual approach is not but a partial view of the vulnerability or of the coping capacity etc.: "this means that trade-offs between the several aspects of vulnerability and resilience are not captured". Moreover, the authors state that the sociologists' concept of vulnerability is the composite result of exposure, resistance and resilience and this is very close to the concept of vulnerability in the Climate Change Community as a synthesis of exposure, sensitivity and adaptive capacity. Not so clear is the relationship between vulnerability, resilience and coping capacity.

The Deliverable 1.1.3 is related to socio-economic systems. The authors highlight that in scientific literature, several definitions and interpretations of the vulnerability concept are available. Referring to a work of Birkmann (2006), the authors show the widening of the vulnerability concept up to include concepts as coping and adaptive capacity. Such a broadening has led to a sort of "Babylonian confusion" around the definition of the key concepts and terms in the field of disaster reduction. Moreover, related concepts, such as coping capacity, adaptation, etc., entered the vulnerability debate even though they are not defined in a uniform and crisp manner. Consequently, within the hazard literature, vulnerability has many different connotations, depending on the research orientation and perspective (Cutter, 1996). The term is used with different meanings by different authors (Adger, 1999). The authors argue that discourses on vulnerability appear to be far more numerous than the ones on resilience (since the latter emerged rather recently), nevertheless it is perhaps artificial to separate these concepts. The authors argue that "the majority of definitions largely conceive vulnerability as a function of susceptibility to loss and of the capacity to recover; this capacity is then termed 'resilience'. The term vulnerability has been said to have negative connotations and according to some authors should be turned around and approached positively as resilience, or as the capacity to cope with or adapt to change. This is broadly similar to the concept of adaptive capacity which has been used and developed by climate change researchers (Adger et al., 2004)". Consequently, some scholars prefer to use the term resilience in place of vulnerability because of its positive connotation.

Summing up, the concepts of vulnerability and resilience are related, but the specific nature of the relations is not so obvious. It has been highlighted that the term vulnerability has evolved from a rather negative concept to a concept that relates directly to more positive notions as resilience and adaptive capacity. Moreover, the traditional interpretation of vulnerability as the reciprocal of resilience is more and more challenged and replaced by notions considering resilience as an integral component of vulnerability or considering vulnerability as the static propensity and resilience as the dynamic propensity of a system in relation to a threat. A key-point arising from the relationships among vulnerability and terms as resilience and adaptive capacity is the dynamic character, including aspects such as the learning capacity within the vulnerability concept.

The Deliverable 1.2 "Comparison of vulnerability concepts used in Natural Hazards to those used in Climate Change analyses" is aimed at comparing the interpretations of the vulnerability concept provided in the field of natural hazards and in the one of climate change. Although the deliverable is not specifically focused on the relationships between vulnerability and resilience, some relevant issues arise. In scientific literature, indeed, competing conceptualizations and terminologies, especially with respect to vulnerability and resilience, are currently spread, leading to some misunderstanding between the Natural Hazards and Climate Change communities. In Climate Change research, vulnerability is generally interpreted as the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change. The authors deep the conceptual framework developed by Turner et al. (2003), interpreted as representative of the climate change community approach. This framework defines vulnerability in the context of a coupled human-environment system and exposure, sensitivity and resilience are part of what constitutes the vulnerability of a system as opposed to the risk hazard approach, where vulnerability is considered a constitutive part of risk. While in Climate Change Community, resilience is generally interpreted as part of the wider concept of vulnerability, in disaster field research the relation is not defined univocally. In fact, according to the authors, vulnerability can be defined in the hazard community in three main ways: the particular state of a system before an event triggers a disaster, described in terms of particular indicators or parameters of such a system; the probability of the outcome of a system, expressed in terms of losses, measured in terms of either fatalities or economic impact; a combination of a particular state of the system with other factors such as the inherent capacity to resist the impact of the event (resilience) and the capacity to cope with it (coping capacities). Moreover, the authors point out that a crucial disadvantage of this framework is the inclusion of many elements within a wider definition of vulnerability. This may lead to problems when identifying how to assess each of these components, and then with respect to how to combine such components to obtain the final degree of vulnerability for the system. Another characteristic of this framework is the inclusion of the adaptation concept as an element that increases resilience.

No references to the relationship between vulnerability and resilience are available in the Deliverable 1.3 "Report on an integral framework for vulnerability".

5.1.2 Vulnerability/resilience in current scientific literature

The concepts of vulnerability and resilience are linked core-concept in many fields. In disaster and climate change field, the relationship between vulnerability and resilience has been methodically deepened in 1981 by Timmermann (Schoon, 2005; Cardona 2003; Manyena, 2006). According to Timmermann (1981), vulnerability represents the level "to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system's resilience (a measure of the system's capacity to absorb and recover from the event)". This relationship remained unstudied for twenty years and has only recently been studied again by some scholars (Adger, 1999 and 2000; Turner et al., 2003). Besides the strictly theoretic researches, the relationship between vulnerability and resilience has been often faced in order to set up vulnerability mitigation strategies, especially in the socio-economic field and at community scale.

First of all, it is possible to articulate studies and researches in disaster field focused on the vulnerability and resilience relationship in two main groups: in the first one the two terms are opposite; in the second one, there are some differences between the two concepts with more articulated relationships.

The first group defines the vulnerability as "flip-side" of resilience and vice versa. In such studies, the relationship between vulnerability and resilience is direct and opposite and there are not uncertainties in the resilience assessment with respect to the vulnerability and in the setting up of mitigation measures. According to such interpretation, mitigation actions, decreasing the levels of different dimensions of vulnerability (physical, social, economic, etc.), directly contribute to improve the resilience of the considered system. However, this approach may have different levels of complexity. A simplified flip-side approach is more frequent among studies and researches aimed at defining a quantitative dimension of the two terms, due to the assessment difficulties of specific dimensions of resilience and to the partial point of view of different works, as stated in Deliverable 1.1.2-3. Among the research projects, for example, the EVI Project[39], started in 1998, was aimed at setting up a vulnerability index defined through the participation of world governments, institutions and experts. The index was designed to highlight the social and economic factors which may influence the sustainable development of different nations in a negative manner. An information pamphlet "What is vulnerability?/what is Resilience?" defines resilience as a concept referred to the "ability of an entity to resist or recover from damage" and it is defined as the opposite of vulnerability: "Vulnerability and resilience are two sides of the same coin. Something is vulnerable to the extent that it is not resilient". Moreover, the vulnerability concept as flip-side of resilience "applies equally well to physical entities (people, ecosystems, coastlines) and to abstract concepts (social systems, economic systems, countries)".

According to Villagran, the flip-side approach can be related to the definition of resilience as "an intrinsic ability of a system, an element, or a community to resist the impact of a natural or a social event" (Villagran, 2006). Resilience and vulnerability can be interpreted as "the two ends of a spectrum. High levels of vulnerability imply a low resilience, and vice versa" (Cannon, 2008). Like the vulnerability concept, resilience has a predictive character: "it involves people's conditions before a hazard strikes, as well as their ability to respond and recover afterwards" and so "it should be possible – on the basis of the characteristics of a group of people who are exposed to a particular hazard – to identify their capacity for resilience" (Cannon, 2008). Moreover, it has to be noticed that, as mentioned in the Deliverable 1.3, the flip-side approach seems to be related to the "desire to emphasize the positive side of things (enhancing resilience as opposed to reducing vulnerability)" (Klein et al., 2003). Nevertheless, some authors underline some contradictions in the operative use of the two concepts, especially with reference to the economic and social diversities of the components of a community: "if some people in a community have a 'strong' livelihood (and are wealthy) is this a 'resilience factor' for them, or a partial cause of the weaker livelihoods of others? And is being part of a particular network a capacity, or a denial of capacity to

[39] EVI Project was developed by South Pacific Applied Geoscience Commission (SOPAC), United Nations Environment Programme (UNEP) and other partners.

others (as with castes in India)? In other words, we need to acknowledge that, within communities, resilience varies according to opportunities that are distributed unequally" (Cannon, 2008). The search for social equity is the main need for vulnerability reduction and, consequently, for improving resilience.

Frequently, the overlapping of the two concepts is due to the widening of the vulnerability concept, as mentioned in Deliverable 1.1.3 quoting Birkmann (2006). Many scholars underline that vulnerability cannot be restricted to the assessment of direct damages induced by an hazard, but it has to be referred to social and economic factors that allow people to cope with the event, or that limit their capacity to resist to the impacts of a negative event (Birkmann, 2006). This broadening leads sometimes to define flip-side approaches based on a wider concept of vulnerability. On the other hand, the resilience concept has been initially defined by Holling (1973) as a measure of the ability of ecosystems to absorb changes and still persist. Thus, a resilient system may be unstable. Subsequently, resilience has become an issue of debate among ecologists and different definitions have been provided, focusing on different system properties (Klein et al., 2003). Among these definitions, a group is referred to the capacity to withstand the external stresses and to the rapidity of restoring the equilibrium (equilibrium stability) (Pimm, 1984). This definition of resilience is probably the closest to the flip-side approach. For example, Folke et al. (2002), quoting (Kasperson and Kasperson, 2001), argue that "vulnerability is the flip side of resilience: when a social or ecological system loses resilience it becomes vulnerable to change that previously could be absorbed" and, furthermore, "the antonym of resilience is often denoted vulnerability. Vulnerability refers to the propensity of social and ecological system to suffer harm from exposure to external stresses and shocks" (Folke et al., 2002). As reported by Schoon (2005), Holling refined its definition of resilience as the buffer capacity or the ability of a system to absorb perturbations, or the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behavior (Holling et al., 1995). This interpretation of resilience is based on the possible creation of a new equilibrium, and it is related to self-organizational complex systems and it is closer to the second approach (not flip-side).

The second group of studies and researches focused on the relationship between vulnerability and resilience makes some differences between the two concepts, defining more complicated relationships. Resilience concept is interpreted in these studies as more referred to the capacity to absorb a shock and it is strictly linked to the concept of resistance, whereas in the second group the concept of resilience is more linked to the regenerative capacity of a system and therefore it seems to be more connected to learning capacity and adaptation, which are the main tools to maintain the system functioning (Birkmann, 2006; Adger et al., 2005; Adger, 2006). According to such interpretation, in disaster field, resilience can be defined as "the capacity of linked social-ecological systems to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedbacks" (Adger et al., 2005 quoting Walker et al., 2004). From this point of view, the concept highlights the level of self-organization, adaptation and learning capacity (Adger et al., 2005 quoting Carpenter et al., 2001) of a complex adaptive system. Thus, other related concepts are at stake and the relationship between vulnerability and resilience is interpreted in the light of adaptation and coping capacity. Consequently, we have many different definitions and relationships among the terms, depending on the research orientation and perspective, as already highlighted in Deliverable 1.1.3.

However, different scientific positions arise within the second group; sometimes, they are produced by the overlapping of the two concepts, due to the widening of the vulnerability one, which leads to highlight some differences between them, even though "fuzzy" differences. Based on such approach, two main groups, with "inclusive" and "discrete or separate" positions with respect to vulnerability and resilience, can be identified. This rough simplification seems to be coherent with some scholars (Cutter et al., 2008; Adger, 2006) who identify the interpretation of resilience in terms of an outcome or a process as a relevant factor for the application of such a concept in disaster field. When resilience is interpreted as an outcome more than a process, it is generally related to the bouncing back capacity and it is considered as a part of the vulnerability (Manyena, 2006). On the other hand, process related definitions are referred to adaptive and learning capacity and so vulnerability and resilience are separate but linked concepts (Cutter et al., 2008). As already deeply discussed in Deliverable 1.2, the "inclusive" position belongs to climate change community. Moreover, as stated before, the widening of the vulnerability concept implies overlaps between vulnerability and resilience and, according to some scholars, vulnerability takes into account coping capacity, adaptive capacity and resilience. The relationships between these concepts determine the different positions of the authors. However, in scientific literature there is not a clear and shared definition of the framework of relationships between the concepts, especially among vulnerability, resilience and adaptive capacity (Cutter et al., 2008). As noticed by Cutter et al. (2008), according to some scholars, resilience is totally included in the adaptive capacity and thus in the vulnerability concept (Adger, 2006; Birkmann, 2006; Folke, 2006). For others the adaptive capacity is a vulnerability component (Burton et al., 2002; O'Brien et al., 2004; Smit et al., 1999). A third position singled out by Cutter et al. represents the three concepts as nested within the wider concept of vulnerability (Gallopin, 2006; Turner et al., 2003). Other authors include in the resilience the capacity to reduce or avoid losses, contain the effects of disasters, and recover with minimal social disruptions (Buckle et al., 2000; Manyena, 2006) and more specifically the adaptive capacity (Paton and Johnston, 2001 and 2006; Bruneau et al., 2003; Tierney and Bruneau, 2007). Pelling (2003) recognizes a priority role of vulnerability with respect to resilience and suggests an interpretation of vulnerability as result of exposure, resistance, and resilience: "exposure is related to the location of the system or element with respect to the hazard and the environmental surroundings; resistance is related to the economical, psychological, and physical health of systems of maintenance, as well as the capacity of individuals or communities to withstand the impact of the event and is related with livelihoods; while resilience is defined as the ability to cope with or adapt to the hazard stress through preparedness and spontaneous adaptations once the event has manifested itself". Villagran (2006) reports the Bogardi's vulnerability approach which emphasizes the temporal relationship among these three concepts and links the resistance to the "capacity of the system to remain unchanged for an interval of time after the event manifested itself". Resilience, instead, is referred to "the capacity of the system to recover to its state prior to the disaster", while coping capacity is defined as the combination of resistance and resilience. McEntire (2001) represents resilience as one of the four variables that determine vulnerability, including:

- risk, proximity or exposure to hazards, which affects the probability of adverse impact;
- susceptibility, proneness of individuals to adverse impacts of disasters, based on social, economic, political and cultural variables;
- resistance, the ability of physical systems to withstand the stress produced by hazards;
- resilience, the coping capacity and ability to recover quickly from impacts of disasters.

It is useful to highlight that McEntire (2000), in order to manage the relationships among the concepts to obtain a comprehensive risk reduction, proposes a proactive holistic approach called "invulnerable development", which involves "decisions and activities that are intentionally designed and implemented to reduce risk and susceptibility, and also raise resistance and resilience to disaster". This approach is aimed at decreasing "the quantity (or frequency) and quality (or severity) of emergencies and disasters through liability reduction and building capacity (McEntire et al., 2002)." The "invulnerable development" concept emphasizes the need for changing cultural perceptions regarding hazards and disasters, identifies specific linkages between development practices and vulnerability, highlighting the importance of strengthening all components of emergency management (McEntire, 2001).

The "discrete or separate" position is represented by scholars who put their attention to the process character of the resilience concept, emphasizing the role of learning capacity and of the decision processes in facing hazards. Moreover, according to this group of scholars, who consider vulnerability as the static and resilience as the dynamic propensity of a system in relation to a threat, as already stated in the Deliverable 1.1.3, resilience and vulnerability are distinct but connected concepts (Cutter et al., 2008). The two concepts are interpreted as discrete processes that don't lead, as often assumed, to opposite outcomes (Linley and Joseph, 2004), but such processes are seen as independent (Paton, 2008). For instance, in poor communities characterized by a strong social structure, sometimes the scarce access to the resources produces a strong social cohesion and participation which, in turn, increases the community adaptive capacity. In such a case, as noticed also by Paton (2008), the vulnerability features coexist with characteristics that improve the adaptive capacity. On the contrary, in disaster literature it is often assumed that resilient communities are the less vulnerable to hazards than the less resilient. From this point of view, Cumming et al. (2005) argue that methodologies for assessing and improving resilience are currently crucial. In fact it is not obvious, in natural-anthropic coupled systems, which features of the system induce resilience or which variables have to be taken into account to assess it, especially due to its multidimensional character (Cumming et al., 2005).

Cutter et al. (2008) developed a disaster resilience of place (DROP) model in order to "ameliorate the shortcomings in existing vulnerability and resilience models and to provide a conceptual basis for establishing baselines for measuring resilience" (Cutter et al., 2003). The DROP model represents the relationships between vulnerability and resilience from a social point of view and at community level scale. The external influences on the post event behavior of the community are not taken into account. The starting point is singled out in the conditions before the disaster that are, in turn, a "product of place-specific multiscalar processes that occur within and between social, natural and built environment systems", determining both inherent vulnerability and inherent resilience. Such concepts overlap so that: "they are not totally mutually exclusive, nor totally mutually inclusive" (Cutter et al., 2008). The action of the hazard on the pre event conditions produces immediate effects which are mitigated or amplified by the presence/absence of mitigation measures and by "coping responses in the community, which themselves are a function of antecedent conditions", or in other words actions which allow the community to respond to the first impact of the event (evacuation plans, creation of shelters, information dissemination, and emergency response plans). Thus, the total hazard impact is a cumulative effect (or sum) of the antecedent conditions, event characteristics, and coping responses. Impact can be absorbed by the community "using predetermined coping responses". If the response is sufficient and the capacity to absorb the impact is not overcome, a high level of recovery will take place, on the contrary the disaster will happen.

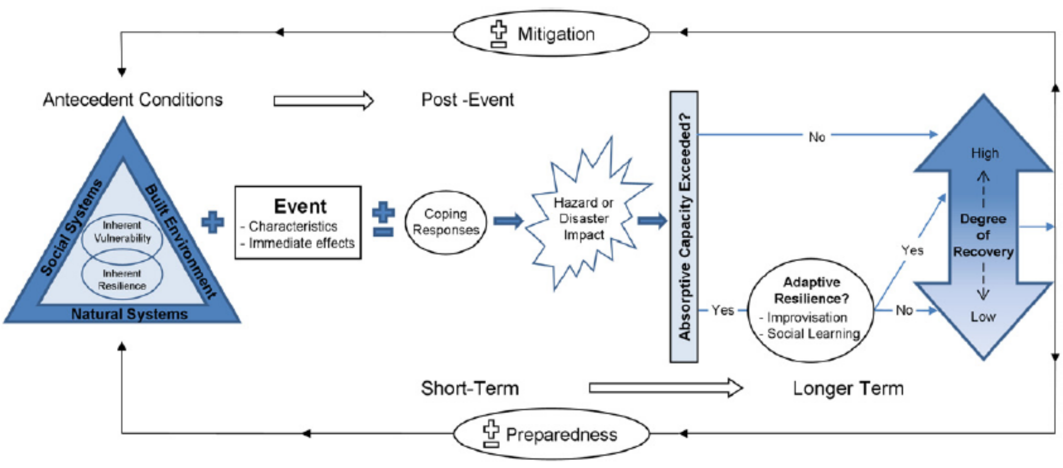

Figure 9: The DROP model (Cutter et al., 2008).

The community exercises its adaptive resilience through improvisation, which includes impromptu actions which may aid in the recovery phase, and social learning defined as "the diversity of adaptations, and the promotion of strong local social cohesion and mechanisms for collective action" (Adger et al., 2005). From an operational point of view, Paton (2008) highlights that hazard impacts cannot be reduced only to the direct damages, but they have to be connected to the community features which "increase susceptibility to experiencing loss from exposure to a hazard (i.e. increase vulnerability) and those that facilitate a capacity to adapt or adjust (i.e. increase resilience)". Thus, from this point of view, adaptive capacity is included in the resilience concept. Manyena (2006) states that, according to Paton, the two concepts have to be considered as discrete: "we can possess characteristics that can make us vulnerable and that can influence our capacity to adapt at the same time. . . . Until it can be demonstrated to the contrary, I think they should be viewed as discrete". Resilience and vulnerability are therefore considered as independent factors, acting in different phases after the event (readiness, response and recovery) at individual, community and institutional level in order to determine respectively adaptation and losses (Paton, 2008). Manyena (2006) states that vulnerability and resilience are two distinctly separate constructs: "the absence of vulnerability does not make one resilient". Other "discrete" positions can be identified in some studies in which resilience is connected to the environmental conditions and to the management of resources (Cutter et al., 2008), like a concept existing at a wide scale. For example, deforestation increases the flood hazard, as in the 1998 floods in China (Wisner et al., 2004), as well as the lack of coastal eco-systems produces high impact of hurricanes and storms. In fact the relationships between vulnerability and resilience have to be searched also in the connections among social and natural systems. Such connections are very tight: "the impacts and recovery from Asian tsunami of 2004, or the ability of small islands to cope with weather-related extremes, for example, demonstrate how discrete events in nature expose underlying vulnerability and push systems into new domains where resilience may be reduced" (Adger, 2006).

Summing up, the outcomes arising from the review of scientific literature are quite heterogeneous. The two terms suggest different but complementary views: "vulnerability generally has a human or society-centered perspective. This contrasts with a great deal of the early resilience literature which focuses more generally on eco-centric analyses" (Schoon, 2005).

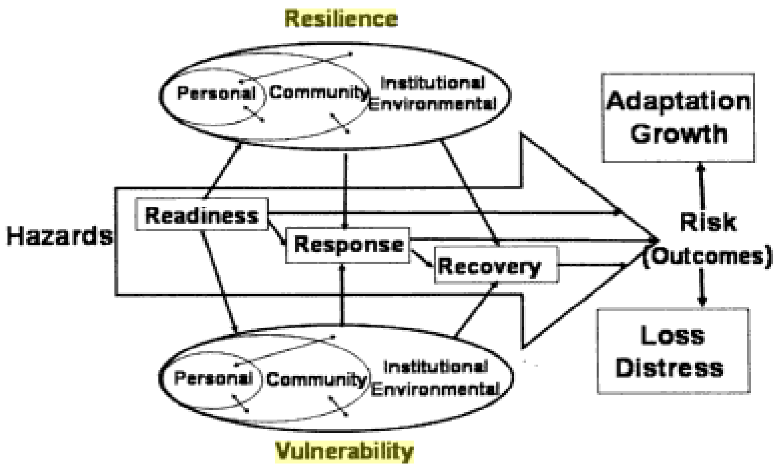

Figure 10: A Risk-Resilience-Vulnerability management model (Paton, 2008).

In the wider interpretations of the vulnerability concept, "vulnerability and resilience have common elements of interest: the shocks and stresses experienced by the social and ecological system, the response of the system, and the capacity for adaptive action" (Adger, 2006). Consequently, "the points of convergence are more numerous and more fundamental than the points of divergence" (Adger, 2006). Moreover, "there is no single universally accepted way of formulating the linkages between human and natural systems" (Berkes and Folke, 1998 quoted by Adger, 2006). In spite of this, the diversity of different scholars reflects the multiple aims of the researches in which the definitions are expressed and probably it could be "a strength and sign of vitality, not a weakness" (Adger, 2006).

Manyena (2006) reports a P. O'Keefe's statement of which clarifies the aim of the search of the relationships between vulnerability and resilience: "while vulnerability is not necessarily the 'flip side' of resilience, it does not mean that we can fold vulnerability into resilience or vice versa. How we produce environment and how to change environment are key to understanding social resilience".

5.1.3 Vulnerability/resilience in the aftermath of disaster

In this paragraph the relationships between vulnerability and resilience are deepened through analysis of past disasters. It is possible, indeed, to find in scientific literature different cases of territorial systems that even though characterized by similar features, react to the impact of similar hazardous event in very heterogeneous ways or show after the event different evolution trajectories. Moreover, in some cases, territorial systems apparently very stable and with a huge amount of resources show relevant difficulties to recover from an hazardous event. The deepening of such case-studies helps us to highlight the relationships existing between vulnerability and resilience.

First of all, with respect to the relationship between physical vulnerability and resilience of communities and territories, it has to be noticed that very often high levels of physical vulnerability of a system are interpreted in scientific literature as synonymous of lack of resilience. This assumption can be modified if we shift our attention from the impact and the first emergency to the recovery phase. In some cases, indeed, a high possibility of rebuilding, and therefore a high capacity to recover from the adverse event, correspond to an high physical building vulnerability. Villagran underlines, for example, that African populations "build houses out of mud and straw, two elements commonly found near rivers. Houses of this kind are easily destroyed in the case of floods, but since the construction elements are easily available, then one could say that such communities are resilient, as their houses can be easily destroyed, but easily reconstructed. The contrasting view would pinpoint houses as very vulnerable to floods, but assigning the community the coping capacities to reconstruct them after they have been damaged or destroyed" (Villagran, 2006). Moreover, it seems to be useful to remark that some past events highlight the not linear relationship between the physical vulnerability of buildings in which economic activities are located and recovery capacity of such activities in the post event phase. It is generally recognized that the recovery after a disaster of economic activities, decisive for the recovery of the whole community, depends on the amount of physical damages and consequently on the physical vulnerability of their buildings and spaces. On the contrary, a study on the post event performances of economic activities in different communities of USA, especially Homestead in Florida, after the Andrew Hurricane of 1992 (Alesch et al., 2001), highlights that the relationship between the physical damage suffered by the activity during the disaster and its recovery capacity is not direct. Some economic activities, although suffered heavy physical damaged, recovered very quickly, while other activities that suffered light physical damages never recovered. The activity recovery depends on many factors; among them the loss of clients plays a relevant role, because the population hit by disaster is resettled in safe locations, and the inadequate decisions of their managers.

The recovery capacity of economic activities after an hazardous event has been also deepened in a research on the communities hit by the Midwest floods in 1993 (Xiao, 2008). This study highlights that local economy showed, after the event, a high resilience, in terms of capacity and rapidity of recovery. In detail, through the analyses of some variables –GDP, unemployment rate and number of economic activities– the study shows that the floods produced only a limited and temporary business interruption in hit communities. After only two years from the event, indeed, the traces of the floods could not be recognized in the considered economic indexes. Although, the key-point of this study is that the analyses do not show a return to the pre event economic conditions, but a recovery driving towards conditions different from the previous ones. The Grafton case-study (Xiao, 2008), a small tourist coastal town of Illinois heavy damaged by floods, showed relevant changes in land tenure, characteristics of population, real estate, economic activities after the event. Indeed, a program for the delocalization of the population out of the flooding area based on the public acquisition of lands and houses was defined. While the tourist activities and accommodation facilities had a quick recovery, with an improvement of the number and of the earning capacity, the home market economic activities suffered relevant impacts due to the loss of clients produced by the delocalization. This fact highlights that resilience represents, in some cases, the capacity to adapt to changed market conditions, more than the capacity to return to pre disaster conditions (Xiao, 2008).

A further example of complexity is the relationship between social vulnerability and resilience. A paradox is represented by homeless and poor people resilience. These people, indeed, always dealing with natural events, floods for instance, "have developed coping mechanisms, but even these, which demonstrate a resilience and determination beyond the understanding of citizens of most developed countries, have been overwhelmed and suggest great suffering to come" (OCHA 2004). This statement seems to be in contrast with typical disaster reportage that finds that 'most of the victims were from vulnerable groups': vulnerability is often 'discovered' after the event (Cannon, 2008). The role of the capacity of vulnerable populations has been recognized in literature for about twenty years (Anderson and Woodrow, 1989; Cannon, 2008). From this point of view, it is decisive the shift from an interpretation of people not as "helpless victims, but as agents with the ability to cope and demonstrate resilience with their own resources. For instance, it is widely known that the greatest share of emergency response and rescue in most disasters is carried out by the local people themselves, demonstrating that they have important capacities and are not simply vulnerable and waiting passively for outside help" (Cannon, 2008). An interesting example is provided by Cannon (2008) with reference to the 2001 Gujarat earthquake. Three years after the earthquake "many people consider that 'they are still ten years away from getting their life back on track'. But one group of very poor craftswomen have found a way to make their lives better even than before the disaster. The key to this success has been their membership of a union supported by the Self-Employed Women's Association. This has enabled the women embroiderers to get raw materials, tarpaulin covers for working under, and also the opportunity to rebuild safer houses (with roofs that collect rainwater, too) (Gidley, 2004). Their livelihood has been restored but to a better condition than before" (Cannon, 2008). In this case, the role of social networks within vulnerable groups is decisive. Some authors argue that these networks can turn social vulnerability into a resource and resilience (Enarson E. quoted by Mason, 2006). Migrants, sexual and religious minorities and other individuals isolated from social networks of their community are the less resilient among social groups, but they don't produce necessarily a scarcely resilient community: a low resilience community is not a community of victims (Enarson E. quoted by Mason, 2006). But, a discrepancy is represented by the relationship among social and knowledge community networks and individual reactive capacities: in many cases "self-protection is likely to be a very individual process" (Cannon, 2008). Sometimes capacities or negative actions of individuals emphasize their role with respect to the networks enhancing aspects of vulnerability, as in 1999 earthquake in Turkey where "some of the contractors who put up the substandard buildings that collapsed and killed the majority of the people, and the local officials who were supposed to enforce the codes, must have been members of the community" (Cannon, 2008). With respect to these themes, some authors suggest making a difference in disaster analysis among impact, response e recovery. In the first phase, adaptation depends on individual self-reliance capacity (Lasker, 2004; Paton, 2003). Then, demands and needs change and there are more possibilities of interacting with neighbors to cooperate. In the response phase, adaptation depends on the possibility of interaction among communities, agencies and institutions, while in the recovery phase there are similar relationship processes (Paton, 2005).

Some authors frame the vulnerability and resilience relationship within a social context in which different groups are in struggle for resources. From this point of view, the link between the two concepts, interpreted as opportunity for social change, can produce new vulnerabilities. This point of view has similarities with the transfer of vulnerability mechanism already emphasized in previous deliverables. In some cases, the outcomes of disaster produce new social groups characterized by high levels of vulnerability and low resilience. For example, the Philippine tsunami produced social groups without properties and subsistence. The recovery of such groups, without reliefs external to the hit communities, should have required very long time. The recovery of ordinary living conditions are in these cases decisive for the recovery process and it has to include social and economic cohesion and inclusion of delocalized populations and their participation. In other cases, the recovery processes and the actions with the interpretation of resilience as recovery capacity after the event are debated from a social point of view. Why is it necessary to restore unequal pre event conditions? In other words why is it necessary to restore previous levels of vulnerability?

A study about the relief and recovery efforts in the aftermath of the 2001 floods in Rawalpindi–Islamabad conurbation in Pakistan (Mustafa, 2003) test "the veracity of the lessons learnt in earlier work on disaster relief and recovery". Analyses of empirical evidences are directed towards questioning the idea of recovery, since the pre event conditions may be characterized by such high levels of poverty, inequality and environmental degradation that "the question 'recovery to what?' becomes the core concern" (Mustafa, 2003).

Vulnerability can be interpreted as power of individuals, groups or classes to influence decisions which may produce their exposure to hazards or their susceptibility to be damaged. The construction of the Sindhay spillway channel in the area of the poor villages of Pindi and Qatalpur in India represents an interesting experience from this point of view (Mustafa, 2008). The spillway built up by central government, changing its original pathway, produced the frequent flooding of a territory which had never been exposed to such events in the past. The population of the hit villages had in theory the possibility of orienting the decision process through their voting power, but "in practice that vote counts for little" (Mustafa, 2008). The inhabitants of Pindi and Qatalpur villages understood their exposure and vulnerability to floods "as a function of their powerlessness and poverty. In contrast, the more "educated" engineers and bureaucrats at water-related agencies at the provincial and federal level were unwilling or unable to see the connection" (Mustafa, 2008). The vulnerability of social groups is largely dependent on the level of politic and economic influence of the community and, therefore, the long term mitigation program has not to build up more resistant levees or dikes but it has to be addressed to achieve equity and social justice in resource management (Mustafa, 2008).

Up to now, the relationships among some aspects of vulnerabilities and resilience have been deepened. Now, we will focus on the relationships among some resilience dimensions. In detail, a relevant example of complex relationships among vulnerability features and resilience dimensions emerging from past disaster is the one between redundancy, key dimension of the resilience itself, and physical vulnerability, mainly with respect to infrastructural networks. For example, as mentioned in chapter 1, although the magnitude and impacts of Kocaeli earthquake was higher than Kobe earthquake, in the first case the infrastructural system performed better. In both cases underground networks were seriously damaged. Furthermore, in Kobe case damages in gas pipes caused vast fires. In Kocaeli case, road network redundancy played a crucial role. Despite the high capacity transportation road was not working because of the fire at TUPRAS Oil Refinery, alternatives roads were available for search and rescue activities. On the opposite, Vale and Campanella (2005) highlight that, even though also after September the 11^{th} the spatial distribution and the redundancy of the road network in New York played a fundamental role in order to manage the crisis post event, "conversely, it meant little to mud-brick Bam in 2003".

Thus, it could be assumed that a high redundancy of the infrastructural networks does not necessary result in a high resilient response after hazardous events. Its relevance depends not only on the features of the affected territory but mainly on the type of hazard at stake. For example, for "spread" hazards "the network redundancy has a much smaller influence, since nearby potential alternative links are often also disabled" (Jenelius, 2009). From this point of view, it has to be noticed that: "the more tightly coupled and interconnected the infrastructure system (Perrow, 1999), the less resilience it exhibits" (Cutter et al., 2008). In other words, a too much high level of interdependency can reduce resilience "since a disruption (either upstream or downstream) in one sector cascades into impacts on other sectors (Chang et al., 2007; McDaniels et al., 2007)". With respect to the previous examples, it is worth noting not only that the relationship vulnerability/resilience is not univocal but the relationships between the resilience and its dimensions can be ambiguous too. Moreover, it is clear that even though the concept of resilience includes the ability to recover from a hazardous event, such a recovery has to be interpreted as ability to adapt to (or to create) new conditions (physical, social, economic, etc.) rather than ability to go back to previous conditions. This position seems to be coherent with the adaptive complex systems behavior hit by an external factor. Territorial systems can be interpreted as complex adaptive systems characterized by self-organization processes which enable them to transform the discontinuity in the system evolution due to an external stress into an higher level of complexity and into an opportunity for change.

A consideration can be made about the root causes of vulnerability to floods with reference to the agricultural practices. Studies developed in Honduras, Nicaragua e Guatemala (Holt-Gimenez, 2002) showed that little agro ecological farmers revealed themselves as more resilient to hazards than their neighbors using traditional intensive approaches with an higher earning capacity. For example, agro ecological farms showed after the Mitch hurricane a lower soil erosion and lower losses than conventional farms. This case highlights not only the link between sustainable development and disaster mitigation, but also that the factors that produce damage are included in the type of agricultural production determined by local community dynamics which depend on economic, cultural, historical, ecological components. These practices need a relevant support by NGO, governments and agencies to be implemented since they require labor-intensive methods and often they have difficulties to deal on the market.

5.2 Does reducing vulnerability always lead to enhance resilience?

This paragraph raises a key question for the Ensure Project: is it possible to state that reducing vulnerability always leads to increase the resilience of communities and territories?

To answer such a question, in the following paragraphs some case studies will be provided in order to highlight that:

- mitigation measures addressed to reduce one or more aspects of vulnerability can increase other aspects of vulnerability or the same one in relation to a different hazard;
- mitigation measures addressed to reduce one or more aspects of vulnerability can be ineffective for enhancing resilience or, even, should result in a decrease of the resilience;

- mitigation measures addressed to increase the resilience of the community may led to reduce some aspects of vulnerability of the settlements.

For what concerns mitigation measures aimed at reducing vulnerability to individual hazards, this topic has been already faced in the task 2.3, in the light of the deepening of the relationships among physical, social and economic vulnerability. In deliverable 2.3, examples of social changes or mitigation actions aimed at reducing physical vulnerability enhancing vulnerabilities to other hazards are provided. So in the next paragraph, two examples and a synthetic table are provided, while the topic related to mitigation measures aimed at reducing specific aspects of vulnerability but decreasing resilience has been more in depth investigated.

5.2.1 Mitigation measures addressing the reduction of vulnerability of specific elements or systems to individual hazards

The paragraph provides two examples of structural mitigation measures addressed to reduce vulnerability of specific elements or systems to one hazard which result in an increasing of the vulnerability of the same elements or systems to other ones. The concrete examples of hazard-oriented measures which had led to higher damage facing earthquakes are the Bam earthquake (December 26th 2003) and the Kobe seismic event (January 17th 1995).

On December 2006, an earthquake struck the South-East province of Kerman in Iran, next to Bam city. The magnitude of the seism was 6.6 on Richter scale and 80 after-shocks followed in the days after. More than 31.000 people were killed during the earthquake (Spence, 2006) and 40.000 to 60.000 were homeless. Indeed a large number of typical constructions were destroyed during the earthquake and the damages were even visible on satellite images. The typical houses were built in adobe, "derived from an appropriate response to the climate of

		Phenomena				
					Climate	
Elements	**Typology**	**Earthquakes**	**Floods**	**Landslides/ Volcanoes**	**Typhoons / Hurricanes**	**Heat wave / Cold wave**
Buildings	*Pilotis / stilts /piles*	Pilotis and soft storeys to be avoided	Pilotis raise the height of the building and limit water entry in the building (UN ISDR, 2004)			
	Height / number of levels	High buildings may be more vulnerable in some cases depending on the soil conditions	- High buildings with many levels allow to move valuable items out of the water (UN ISDR, 2004) - Reducing the ground surface reduces flooded surface and thus drying and cleaning periods			
	Walls	- Non-homogeneous wall construction to be avoided - Rigidity of construction materials have to be homogenous on all the height of the building (to avoid the flexible level effect)	Different materials to be used (e.g. materials with low permeability up to 0.3m) (UN ISDR, 2004)			
	Roofs	Heavy roofs favour collapse (Coburn et al., 1993)		Roofs designed to support heavy loads from Tephra falls (e.g. R.C. roofs)	Heavy roofs avoid them to be blown off	

					For hurricanes, 4-slope roofs with maximal pitch of 30° are recommended (MEEDDAT, 2009)	For snowy episodes, 2- slope roofs with important pitch are recommended
	Localisation	Avoid building near a slope and on site with known site effects (Bouchut, 2006)	Better to build on high grounds; out of reach of floods	Avoid building near a slope (landslide)	Building near a slope or a cliff can protect buildings from winds	
	Mass	Light structures are less vulnerable (Spence, 2006)	The building shouldn't be too light in order not to float and not to be too vulnerable to debris and currents		Light structures are more vulnerable to winds	Light structures reduce thermal isolation
	Mass repartition	- Mass repartition should be as homogeneous as possible - Avoid putting mass high up	Important device and installation should be put high up (MEEDDAT, 2009)			
	Shape	- T- or L-shape to be avoided (Bouchut, 2006) - Avoid elevation irregularities (Bouchut, 2006)	L-shape buildings can concentrate streams			
	Walls materials	- Structure should be tied (Coburn et al., 1993) - Bricks or concrete blocks structures are identified as the most dangerous ones and must be chained horizontally and vertically	- Drying quickly: engineering bricks, concrete blocks and gypsum plasterboards (UN ISDR, 2004) - Engineering bricks also limit water entry during flood events (UN ISDR, 2004) - Steel of reinforced structures is vulnerable to salt corrosion in case of coastal flooding		Balconies or external roofs should not be tied to the rest of the structure	Bricks provide high thermal isolation
		Wood buildings are quite resistant to earthquakes	Wood structure are vulnerable to floods (ex: Sri Lanka)		Wood structures are vulnerable to strong winds (Coburn et al., 1993)	
		Adobe construction to be avoided (Coburn et al., 1993)	Adobe construction is to be avoided (not resistant)			Adobe construction generally react well to extremes temperatures weather
	Basements	Deep foundations provide better earthquake response	Basements are vulnerable		Basements are very resistant and constitute shelters to strong winds	Basements provide thermal isolation for extreme weather
	Openings	Better to minimize openings	Openings may be a way to let the water enter and to save the structure	Better to minimize openings in order to slow the ingress of hot gases, together with a reduction of the fire load (Pyroclastic flows)	Better to minimize openings (MEEDDAT, 2009)	Large openings result in less thermal isolation
Infrastructures (roads, pipelines…)	*Electric networks*	Underground lines are less vulnerable (ERDF, 2008)	Underground lines are vulnerable to floods (ERDF, 2008)		Underground lines are less vulnerable to wind (ERDF, 2008)	Underground lines are more vulnerable to heat waves (ERDF, 2008)

	Bridges	Particularly vulnerable to earthquakes	Raising roads on bridges or piles can be a solution to preserve roads serviceability from floods			
	Pipelines	Less vulnerable when built underground	Underlines pipelines may be more vulnerable to floods			
Other elements: Embankments, levees, slopes	*Slopes*	Toe weight would destabilize the slope even more (wave trapping)		Toe weight stabilizes the slope (landslide) (Bouch ut, 2006)		

Table 4: Inconsistency between some hazard-oriented mitigation measures

Southern Iran, with high diurnal temperature swings" (Spence, 2006) but they were very vulnerable to earthquake.

During the earthquake of Kobe on January, 17th 1995, more than 5500 people were killed, nearly 94.000 buildings collapsed and 106.000 were partly damaged. It has to be noticed that mainly traditional buildings were destroyed because of their heavy roofs. Those roofs constructed with mud and tiles were designed to resist typhoons (Menoni, 2001). "Failures in these buildings were typically caused by large inertial loads from the heavy roofs exceeding the nominal lateral-load-resisting capacity of the supporting walls" (Scawthorn and Yanev, 1995). The table 4 synthesizes examples of hazard-oriented mitigation measures, preventive or corrective, which lead to the increase of the vulnerability of the same element to another hazard. The two major hazards taken into consideration are earthquakes and floods, but example of other hazards (landslides, volcanoes, hurricanes and heat or cold waves) are included when possible.

5.2.2 Mitigation measures addressing the reduction of specific aspects of vulnerability

In this paragraph some case-studies, aimed at highlighting that measures addressed to reduce one or more aspects of vulnerability can, sometimes, lead to a decreasing of territorial system resilience, rather than to a direct improvement of the resilience itself. This may happen because: the mitigation actions aimed at decreasing some vulnerability features of territorial systems increase other aspects of vulnerability which may induce, in turn, a decreasing of the resilience of the system as a whole; mitigation measures, acting on specific aspects of vulnerability or on other risk components, influence negatively resilience dimensions of territorial systems, or trigger chains of events that produce unexpected new vulnerabilities or a new system state characterized by a lower level of resilience. These causes often overlap, making difficult their clear identification in the case-studies; moreover, the complexity of the relationships among vulnerability aspects and resilience dimensions sometimes belies what clearly arises from other cases and contexts. Therefore, in this paragraph some examples rather than a strict classification, aimed at highlighting specific aspects of such complex relationship, are provided.

A first consideration refers to the often conflicting relationships among social and physical vulnerability and to the outcomes that such a struggle may have on the resilience of a community. Very often a change of building typologies and features corresponds to the improvement of economic and social conditions of communities. Generally, due to an increase of economic wealth, the traditional and poor houses are replaced by more stable buildings made with materials and construction techniques unconnected with local traditions. This process starts from an improvement of social vulnerability conditions and may have two different outcomes:

- a higher vulnerability to some types of hazards of the new buildings (due to the loss of local traditional building techniques and to the construction of buildings sized on major hazards);

- a lower physical vulnerability of buildings and, in the meanwhile, a lower resilience of the system due to a lower rapidity in re-building after the event.

Many of the houses re-built after floods or earthquakes by NGO have specific aspects of traditional buildings which, although often characterized by high levels of vulnerability, are examples of remarkable adaptation to hazards (Jigyasu, 2008), due to the traditional local materials and to the ease of rebuilding. Social vulnerability reduction and the consequent physical vulnerability reduction not always lead to an improvement of community resilience. This is clear when the improvement of social and economic conditions of communities is promoted and implemented by intentional – for example the Chinese urbanization policies – or spontaneous migrations from country to city related to the opportunities of social and economic improvement provided by the city. The moving of a huge amount of population produces, in many cases, urban settlements, frequently illegal, localized in hazard prone areas and characterized by high levels of physical vulnerability: for example, thousands of people living in the *favelas* all around Rio de Janeiro, placed on steep slopes prone to flash floods. In such a case, people cannot build up their houses in safer areas due to poverty, social conditions and high land prices (Cannon, 2008).

The relationship between physical and social vulnerability can be analyzed from a different perspective: in many cases, indeed, physical vulnerability mitigation measures are characterized by great difficulties in their implementation, due to the social and economic conditions of the community. Physical vulnerability mitigation measures are generally expensive and not so feasible in low income communities. For example, the mitigation program promoted by NGO and Red Cross in Caribbean islands and aimed at reducing physical vulnerability of residential buildings to hurricanes, through incentives for the structural reinforcement of the roofs, was largely opposed by the population: "why spend money on a roof that will be proof against hurricane winds that may never happen, when each and every day the household has to cope with an inconvenient and unhealthy kitchen? When faced with this dilemma, the Red Cross society decided to help people to improve both" (Cannon, 2008). It is necessary to act in a integrated manner on the physical vulnerability and on the social conditions of the population to achieve a comprehensive improvement of resilience of a territorial system.

A first relevant contradiction arises from case-studies: measures aimed at improving social and economic living conditions may produce an improvement of physical vulnerability and, on the contrary, measures aimed at decreasing physical vulnerability may result as scarcely feasible without such an improvement. In both cases, the actions aimed at reducing social, economic or physical vulnerability, do not necessarily imply an improvement of resilience. On the contrary, there are examples of mitigation measures aimed at mitigating single aspects of vulnerability which have positive influences on others. In scientific literature there are many cases, indeed, of mitigation measures addressed to reduce physical vulnerability of buildings in which relevant economic activities are located that produce lower damages and a shorter recovery time phase after the event. The case of the mitigation program of the Van Nuys brewery in California (CSSC, 1999) highlights that after the 1971 earthquake, this building was damaged and suffered a large business interruption. From the early 1980s, a structural mitigation program allowed the retrofitted buildings and equipment to suffer only low damages during the Northridge earthquake in 1994. The brewery quick returned to fully operation (in only 7 days) and had benefits exceeding the cost of mitigation program. This example highlights the role of some key-dimension of resilience such as the memory of past events and the capacity to learn from them (learning capacity) which, in this case, triggered the activation of mitigation measures. These latter, reducing the physical vulnerability of buildings and equipments, produced a lower economic vulnerability of the community, being this activity relevant for the local economy. Nevertheless, also the relevance of memory and learning capacity in order to support the implementation of mitigation measures aimed at reducing specific aspects of vulnerability is not always proved. For example, with reference to the California case, Godschalk (2003) argues: "Comfort (1999) showed how emergency managers learned to adapt and improve their disaster response activities over the course of three earthquakes: Whittier Narrows, Loma Prieta, and Northridge. Following each disaster, their response management improved as they adapted their community practices". On the contrary, similar outcomes did not take place in other areas affected only by a big earthquake: "after earthquakes in Ecuador in 1987 and Armenia in 1988, there was little change in community mitigation practices. Comfort (1999) called these "non-adaptive" systems, low on technical structure, flexibility, and openness to new information and methods".

While some resilience dimensions play a central role to promote and support the implementation of vulnerability mitigation measures, the community have not always such social, economic and organizational characteristics that allow resilience dimensions to activate themselves, although they are intrinsic properties of complex systems. Moreover, memory, which has a relevant role in building up learning capacity, depends more on the frequency of calamitous events than on their intensity. Further remarks arise from case-studies related to mitigation measures aimed at reducing specific aspects of vulnerability or other risk components – as hazard or exposure – which negatively influence some resilience dimensions or, vice versa, from cases referred to measures aimed at increasing specific resilience dimensions which lead to a vulnerability improvement. A typical example of the first case is related to structural mitigation measures, always considered as a decisive factor in natural risk reduction and for the improvement of disaster resilience of communities. The reduction of physical vulnerability obtained through building codes or spread reinforcement of the building stock has often induced in the population a false sense of safety or even the certainty that, in case of event, building damages would be negligible. This certainty often led to neglect other not structural measures – which may play instead a decisive role in the hazardous event response and recovery – and to promote a further growth of exposure in prone hazard areas. Structural measures, both hazard or physical vulnerability oriented, may have relevant limits and produce higher losses in case of hazardous events (Alexander, 2000). Moreover, during the recent Abruzzo earthquake or the Kocaeli earthquake, most of the collapsed buildings were built after 1980s, according in theory to anti-seismic codes: the main reason for such a failure was related to the miss-implementation of the existing building codes. Another example of mitigation measures which may have negative outcomes for resilience can be identified in the risk transfer mechanisms due to insurances. The spread use of assurances, particularly if it is not well regulated, may lead to a reduced attention for the static improvement of buildings and for an effective emergency preparation, since the risk has been transferred to insurance companies. Such a mechanisms can produce a decrease of the resilience and the inhibition of cultural and learning processes which determine the adaptation to adverse events. The re-building fund after the disaster is a similar mechanism: why to worry about the risk if someone will pay for repairing damages?

Examples of spread risk mitigation measures that, in many cases, have negative outcomes are related to the resettlement of exposed population and assets towards safe locations. First of all, such measures are difficult to be implemented since the resistance of local communities which generally prefer to continue their live in the same place, even though aware of the risk conditions. In other cases these measures induce degenerative processes of the communities, increasing other vulnerability factors, especially economic and social ones. The work of Gaillard (2007) about the resettlement of populations due to volcanic phenomena provides some relevant examples and interesting ones can be identified in Italy too: for example, the failure of the recent measures aimed at stimulating the decreasing of building and population density in the Vesuvius' area through a voluntary delocalization of the population. Unfortunately, even in this case population, although aware of the risk, prefer not to leave their houses. This choice seems to show a low learning capacity and a rootedness that is opposite to the rule of evolution towards more resilient systems (Baker, 2009). Therefore, also in this case, measures aimed at reducing the exposure of vulnerable assets, rather than supporting an evolution of settlements and communities towards lower risk conditions and higher resilience, maintain or improve risk conditions.

Furthermore, it seems to be useful to think about the outcomes of some preventative structural measures for some natural hazards. For example, measures aimed at preventing flooding through dikes, channels and levees addressed to change the characteristics of natural watershed are very spread. In some cases, such measures produce relevant changes in eco-systems which, in turn, can induce relevant modifications in the livelihoods of local communities (fishing, tourist activities, etc.). Hence, the impacts of such consequences induce relevant changes in their social structure. Such changes produce, in many cases, new vulnerabilities also related to a weak social structure which make the community less resilient. These circumstances, quoted in scientific literature (Weichselgartner, 2005; Klein et al., 1998; Wisner et al., 2004), are largely verifiable in some territorial contexts and especially in developing countries where hazards may be a resource, although this assumption can be paradoxical. A typical example is represented by the Delta of MeKong river in Vietnam where "flood policy has to minimize the adverse impacts of flood damage and disruption as well as to maximize the productive use and conservation values of the floodplains" (Weichselgartner, 2005). The case of Bangladesh (Wisner et al., 2004) is representative too; the estimated damages caused by the mitigation measures (dikes, channels, etc.) are, indeed, much bigger than the expected ones caused by floods: in this case, mitigation measures cause relevant changes and potential losses in fishing activities, which represent the main livelihood of the poor population. Therefore, new vulnerabilities arise, the existing ones increase and the resilience of local community decrease.

Another example of complex relationship between vulnerability and resilience is provided by a study related to the vulnerability mitigation measures defined by experts, government and NGO after the 1999 Chi-Chi (Taiwan) earthquake (Lin et al., 2006). The report singles out the different effects of such measures in different territorial contexts, highlighting that in some poor villages prone to frequent mud-flows and floods triggered by earthquakes, these measures caused an improvement of vulnerability at local scale. The work identifies as main root of such a failure the lack of interface between science and practice. In detail, the study considers two villages, singling out both the types and the chains of hazards to which they are prone to and their connections with human activities, both the process of knowledge sharing and the institutional organization. This comparison brings out that the first community (Pu-li) has a better science-practice interface because the knowledge is included in its social texture and this changed the community from vulnerable to resilient; the second one (Song-ho) demonstrates the science-practice interface to be a failure due to the disregard of multiple nature of hazards as well as social capitals (Lin et al., 2006). In this example, mitigation measures caused an improvement of vulnerability at local scale due to weaknesses in some resilience dimensions.

It is worth underlining that in many cases the efficacy of mitigation measures depends not only on the type of actions but also on the features of the decision process and on the way in which such measures are implemented, especially the structural ones: "when the management of a resource or facility is shared by a diverse group of stakeholders (e.g., communities with varying economic conditions, government, or business community), decision making is better informed and more options exist for testing policies" (Prasad et al., 2009). Nevertheless, decision processes are not always efficient: in many cases a breakdown happens in the chains of control, which particularly paralyzes the emergency management activities, as in the Kobe earthquake in 1995, when the un-awareness of decision makers in Kobe (indeed in Osaka and Hyogo Prefecture) about the size of the event made a quick response impossible. Moreover, many mitigation measures need a high level of participation and a decision process shared by the whole community in order to be effective. For example, the enforcement and effectiveness of land use zoning mitigation measures are largely dependent on the inclusionary and consensual nature of the decision making process. Tompkins and Adger (2004) argue that key vulnerable groups are often excluded and frequently largely ignored when infrastructures are being designed to reduce vulnerabilities due to the poor living conditions in risky areas (Cutter et al., 2000; Pelling, 2003). When collaborative planning is ignored, the sustainability of plans and their implementation come into question (Tompkins and Adger, 2004). Therefore, some resilience dimension, such as collaboration, cohesion or networking are very relevant in order to guarantee the effectiveness of mitigation measures addressed to reduce different aspects of vulnerability.

5.2.3 Mitigation measures aimed at enhancing resilience

Several case-studies show that mitigation measures aimed at increasing some resilience dimensions may result in an improvement of some aspects of vulnerability.

These cases are often focused on the self-organization of communities. For example, mitigation or reconstruction programs based on the social cohesion, participation and self-organization of communities that, in practice, lead to an increase of the physical vulnerability since population do not have cultural and technical capacities to fairly implement them. Moreover, some mitigation measures, particularly the ones related to the emergency management, are based on, or aim at increasing, the self-organization capacity of communities. Unfortunately self-organization, interpreted in scientific literature as a key factor of resilience, may have negative outcomes too. In communities hit by earthquakes, for instance, the population often go back spontaneously to their damaged houses before the experts have assessed the real safety conditions of buildings, or create improvised and temporary "settlement" near the hit buildings to be close to their own houses, without taking into account the possible collapse of these buildings (Sapountzaki and Dandoulaki, 2006). These behaviors show that the self-organization capacity of individuals or groups, in some cases, do not improve the resilience of the community as a whole, increasing on the contrary the risk conditions.

In some cases, mitigation measures acting on different aspects of resilience may have negative outcomes, since these aspects may clash with each other: for example, the relationship among measures aimed at preserving natural resources, decisive to prevent or mitigate the impacts of some natural hazards, and the ones aimed at achieving a social and economic development, which are also relevant to improve the resilience of communities. Therefore, unbalanced local development need to be oriented: "the means of enhancing both social and ecological resilience may in some cases be found in supporting communities in traditional management approaches" (Tompkins and Adger, 2003). Another example provided by Baker (2009), quoting the work carried out by Barbier (2007), is related to the relationship between social and economic wealth related to tourist development and to changes induced in coastal eco-systems by deforestation of mangrove trees which amplified the tsunamis impacts in Asian countries in 2004.

Finally, it has to be noticed that the information provided by local authorities and media about new infrastructures development, safeness of buildings, efficacy of emergency management tools and procedures and so on, has to be careful considered. In some cases, indeed, if the communities believe that they are prepared, a false sense of security can be created which can significantly increase some aspects of vulnerability. For example, Etkin (1999) highlights how reliance on structural flood defenses increases vulnerability over the time through the so-called "risk transference". These defenses generally produce a short term flood risk decreasing and a long-term flood risk improvement, transferring the risk into the future. People exposed to floods in this time loose the correct perception of the risk and feel a false sense of security, while with their actions increase vulnerability.

6 Integrating vulnerabilities to natural and na-tech events

6.1 Relationships among vulnerabilities

In this paragraph the main outcomes of previous WP2 tasks have been synthesized with the aim of drawing out inputs for building up the methodological framework for an integrated vulnerability assessment.

General definitions

First of all, it is worth mentioning some shared ideas and definitions which represent a relevant and common background for the future work.

A first relevant shared concept is that vulnerability has to be referred both to the susceptibility to losses and to the capacity to recover. Such a broad interpretation drives to investigate all the different aspects of vulnerability emerging at different scales and at different phases of the disaster cycle, from the pre-disaster to the reconstruction phase. A relevant distinction has been introduced between vulnerability to stress and vulnerability to losses. Such a distinction "introduces a dynamic component in the analysis (….)", highlighting that "in looking at vulnerabilities one should also take into consideration time factors as well as phases of the disaster cycle when a given type of vulnerability becomes more prominent" (deliverable 2.1.2, § 3.2).

Furthermore, the relationships among vulnerability and the main concepts in the disaster field (hazard, exposure, coping capacity) have been explored. The close relation between vulnerability and hazard – mainly between physical vulnerability and hazard – has been clearly recognized. The deliverable 2.1.2 remarks that vulnerability to stress (mainly referred to the physical one) "depends on the characteristics of the stress, in the sense that an artefact may be vulnerable to earthquakes but not to floods and vice versa". Thus, since physical vulnerability depends upon the type of physical stress that arises from different hazards, this vulnerability type cannot be generalized to all hazards, but represents an intrinsic quality of any given object that in turn, depends on its resilience capacity to any given external shock". Hence, according to the results of deliverable 2.1.3 (§ 3.2), physical vulnerability has to be "specified and elaborated for the different types of hazards (….)".

As concerns the relationships among vulnerability, exposure and coping capacity two main points of view can be recognized:

- the first one provides an interpretation of vulnerability as "a composite outcome of exposure, resilience and adaptive capacity (or coping capacity) (del. 2.1.1, § 2).
- the second one highlights that exposure, in the disaster community's perspective, "is a property external and independent from vulnerability" (deliverable 2.1, § 3.4). Moreover, coping capacity is recognized as a very relevant feature in the post-disaster phase, largely dependent on risk knowledge, experience, psychological predisposition, internal and external economic relations.

Even though the two positions are apparently divergent, it has to be recognized that if it is surely true that exposure can be analyzed as a property independent from vulnerability, the opposite is not true: only exposed elements and systems can be vulnerable. Thus, we will always refer to the vulnerability/ies of exposed elements and systems. Nevertheless, it is worth stressing that increasing exposure in hazard prone areas cannot be automatically interpreted as an increasing of vulnerability.

Elements and systems are not necessarily vulnerable, even though exposed.

As concerns coping capacity, the latter is surely part of the vulnerability concept meant as "susceptibility to losses and capacity to recover". The close relation between vulnerability to losses and coping capacity has been widely emphasized; in detail it has been highlighted the dependence of the former on the latter (del 2.1.2, § 9). In many cases, in fact, interventions carried out in the emergency phase (in order to copy with the impact) largely contribute to increase or decrease the vulnerability to losses. Moreover, coping capacity may be even interpreted as a part of the resilience. The close relationship between coping capacity and resilience has been largely emphasized, defining the latter as "the ability of an actor / system to develop inherent resources and means usable to response and recovery and / or to extract from the social, economic and ecological environment means and resources to engage and commit them consequently for the purpose of own response and recovery or improving own position" (del. 2.1.2, § 9).

Largely shared by partners is the idea that vulnerability represents a "'whole' which has several facets. Each facet is intrinsically related to every other facet, although the nature of these relations varies, i.e. some are closer or stronger than others" (del. 2.1.1, § 2). Moreover, "vulnerability components have strong relationships among them, therefore this systemic condition makes difficult to measure vulnerability at a certain point without considering reflections from other components" (del. 2.1.2, § 3.1). Hence, each aspect has to be analyzed taking into account the multiple relationships between such aspect and all the others.

Due to the central role of relationships in analyzing vulnerabilities, the different types of relationships have been singled out and synthesized into three main typologies:
- cause-effect relationships;
- dynamic relationships of transformation/transfer;
- relationships arising from the structural connections within or among systems (dependency, interaction, complementarities etc.).

Main Relationships

Grounding on the above mentioned shared concepts, the main relationships among the different facets of vulnerability – namely among physical, social, economic, institutional, territorial and systemic vulnerabilities – have been investigated.

Even though the relationships between social and economic aspects should appear as the simplest ones, the outcomes of the task 2.1, mainly focused on these aspects, provide some relevant input for an integrated assessment of vulnerabilities.

First of all, the difficulty in examining the relationships between social and economic vulnerability outside of the context of physical and institutional vulnerabilities has been underlined in that "without these contexts it would be very difficult to explain social and economic vulnerabilities and their linkages" (del. 2.1.1, § 7). Moreover, a distinction among factors (or external forces) inducing vulnerability, vulnerability itself and its consequences in terms of losses has been introduced: in many cases, indeed, social, economic or institutional factors significantly contribute to social, economic or even physical vulnerability. It is worth underlining that, even though this point has been specifically mentioned with respect to social and economic factors/vulnerabilities, the difference among factors contributing to vulnerability, vulnerability itself and the consequences of vulnerability clearly arise from most of the provided case-studies. For example, the Katrina case clearly shows that many factors contributed in a long term perspective to increase vulnerability of natural system that, in turn, contributed to increase the susceptibility of New Orleans to be flooded. The complex chain of hazard, impact and damages triggered by the flood had, in turn, relevant repercussions on the natural system itself (del 2.1.2 § 6.2).

The strict relations among physical, social and economic vulnerability, as well as the distinction between social and economic factors and social and economic vulnerability have been recognized even in the task 2.3. As specifically concerns the relationship between social and economic vulnerability, it has been stressed that economic vulnerability influences social vulnerability and vice versa or, even, that economic vulnerability is transferred to social one and vice versa: "It is clear that economic vulnerability may affect social vulnerability, and that the consequent social vulnerability may subsequently feedback to affect economic vulnerability. In fact over time this dynamic process may go through successive cycles of influence-feedback-influence. These cycles may deepen or relieve social and economic vulnerability, or alter it in a way which rebalances it, over time" (del. 2.1.1 § 5.4).

Furthermore, in many cases, the relationships between social and economic vulnerability are *mediated* by physical or institutional vulnerability: "physical vulnerability is transformed into economic vulnerability, and institutional vulnerability is transferred into social and economic vulnerability" (del. 2.1.1 § 5.3). The feedback loops between social and economic vulnerability and their relationships with all the forms of vulnerability will occur and develop over time, affecting different territories: "although physical vulnerability may be considered to be contained inside a territory, economic systems linkages and vulnerabilities, as well as social, systemic and institutional vulnerabilities, are not necessarily contained in one territory (….)" they can "spill-over into neighboring territories" (del. 2.1.1 § 6.1). Hence, links among different facets of vulnerability develop themselves both in time and in space.

As concerns the relationships among physical vulnerability, social and economic factors and vulnerabilities, which have been in-depth investigated in the deliverable 2.1.3, "not one single root cause or main cause-effect relationship can be identified" but a "web and chains of relationships within the vulnerability framework" (§ 3.3). Moreover, the two-ways relationships among physical, social and economic vulnerabilities, the relevant influences of social and economic factors on physical vulnerability have been clearly highlighted: "physical vulnerability is not primarily or even mainly a technical and engineering problem but that it is correlated with social and economic factors" (del. 2.1.3 § 9.2). Furthermore, some case studies clearly demonstrate that institutional vulnerability, whether meant as an independent component or as a part of a wider concept of social vulnerability, can produce or increase physical vulnerability. To better explain how social, economic and institutional factors can positively or negatively influence physical vulnerability, a list of influencing factors and their consequences in terms of physical vulnerability has been proposed with respect to floods. Nevertheless, even though such kind of lists can be very useful to understand the influences of external factors on physical vulnerability, " there is a risk of over-simplification because there is a multitude of circumstances in which physical vulnerability to floods changes" (del. 2.1.3 § 9.3).

Finally, the influences that social and economic factors may have on hazard triggering and the direct link between hazard and physical vulnerability have been highlighted. The latter, in fact, largely depends on the type of hazard at stake. This aspect is very relevant as hazard-oriented mitigation measures or unintentional changes in building practices may decrease the physical vulnerability to one hazard, increasing the one to other hazard factors.

In the complex web of relationships within the vulnerability framework, a central role is played by the "systemic" vulnerability. First of all, it is worth mentioning that, even though the concept of systemic vulnerability is commonly referred to vulnerability of engineering systems, lifelines and infrastructure networks, or public facilities, such a concept has to be applied to other "complex "wholes" (social, economic, spatial), which clearly exhibit systemic behavior" (del 2.1.2 § 3.1). Furthermore, a distinction among an internal and an external systemic vulnerability has been introduced. "Each system can carry vulnerability due to its internal features and structure (internal systemic vulnerability) and additional vulnerability owing to external factors and other systems (external systemic vulnerability)" which, in turn, can affect the internal vulnerability. In detail, systemic vulnerability can be referred to:

- "how systems are able or not to continue functioning despite some level of physical damage (input= disaster impact). In this regard we are interested in the internal vulnerability of the system (which may be also defined as "functional vulnerability").
- how relations among systems may influence their capacity to function. In this case vulnerability to losses is the main aspect to consider (input factor are, in this case, the losses or the lack of functioning in related systems)" (del 2.1.2 § 4).

The latter distinction is relevant to understand the relations between physical and systemic vulnerability or, in other terms, how physical damage may affect systems, either directly or indirectly.

As underlined in the deliverable 2.1.2, "the interactions between physical elements failures and technical systems functionality appeared to be the easiest vulnerability aspects to quantitatively integrate together" (§ 8) and they have been largely investigated in current literature. Nevertheless, as clearly arisen from case studies, "the vulnerability of the techno-human systems facing hazard is not the result of only individual physical vulnerabilities, but also the consequence of deficiencies in other sectors of the society", such as lack of redundancy, or little awareness of residual risks. Hence, systemic vulnerability is largely due to physical one, but it is closely related to all other aspects of vulnerability. According to the multiple relationships among different types of vulnerability above mentioned, some attempts for representing such complex framework of components and relationships have been developed. The different facets of vulnerability can be easily represented through the diamond analogy in which each facet has the same relevance with respect to the others (del 2.1.1, §.2). Nevertheless, such a representation seems to be very reductive, since it does not allow to emphasize the different roles and the mutual relationships among the many facets of vulnerability. Hence, other graphic representations have been carried out in order to highlight the mutual interactions between different forms of vulnerability (fig.11). Both schemes provide a conceptualisation of the mutual interrelationships among vulnerabilities, highlighting the central role played by systemic vulnerability through which all forms of vulnerability are interdependent (del. 2.1.1 and 2.1.2). Moreover, as concerns the territorial dimension of the complex network of vulnerabilities, it has been stressed that the way in which the different aspects of vulnerability will combine with each other and the mutual influences among them, such a "unique assemblage of these vulnerabilities, can be expressed as territorial vulnerability" (obviously referred to a specific territory). Obviously the affected territory can change, especially over time, as different vulnerabilities act on different portions of territory.

Methodologies for integrating vulnerabilities

As concerns the practical integration between social and economic vulnerability, some of the attempts to integrate them through indexes have been analysed and reported. Among the available methodologies, the one developed by MacKendrick and Parkins (2005) has been considered as interesting for the ENSURE project. It incorporates thirteen indicators of vulnerability into a socio-economic vulnerability index. Social and economic vulnerabilities have been analyzed taking into account indicators of physical and institutional vulnerability too. "This form of methodology could be employed in the case study areas (in which case other indicators may be constructed)". The authors "recognise that the vulnerability of socio-economic systems is a function not only of the damage susceptibility which causes economic loss, but also a function of the coping and adaptive capacities of communities at risk i.e. this is very similar to ENSURE's conceptual understanding" (del 2.1.1, § 6.2).

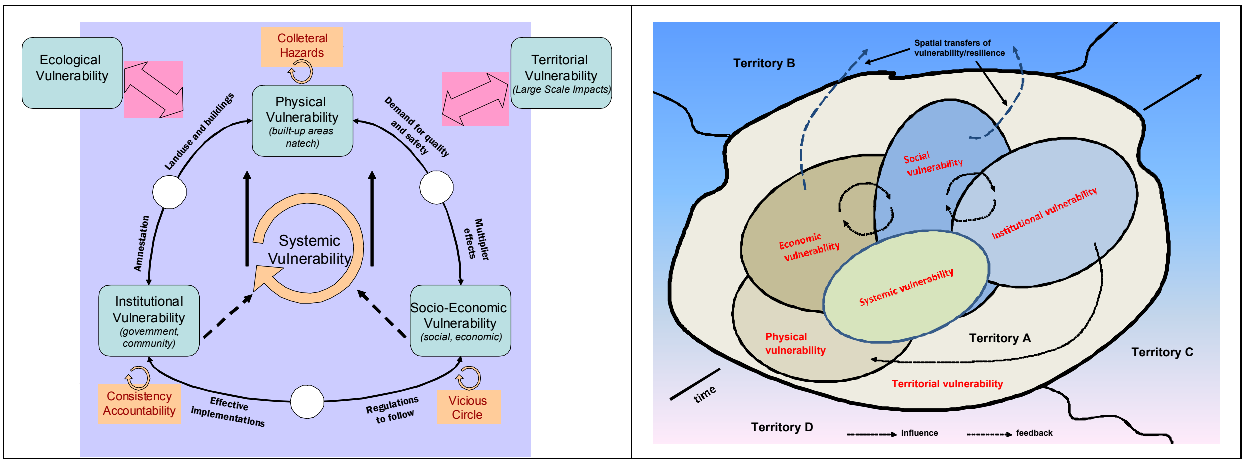

Figure 11: Interactions among different forms of vulnerability

Other indicators enabling us to take into account the different scales (national or local) of exposure and the main aspects of vulnerability (economic, social, institutional) have been mentioned (Del. 2.1.2. §. 8). Furthermore, "another opportunity for integrating and measuring the total potential of vulnerability" has been identified in "the possibility of considering the particularities of the stages of the disaster cycle and the distinct vulnerability relationships and accordingly determinant parameters that appear within each of these stages". Such distinct vulnerability and related parameters have been specifically listed in the Del. 2.1.2 (§ 8).

Changes of vulnerabilities and relationships over time and space

Besides the complex framework of relationships among vulnerabilities, it has been largely stressed that vulnerabilities significantly change both across time and space. As a consequence, also the relationships among them change, sometimes according to influence – feedback–influence cycles which take place continually over time.

Hence, a relevant point arising from the previous tasks refers to the integration and measurement of vulnerabilities over time, "considering" as mentioned above, "the particularities of the stages of the disaster cycle and the distinct vulnerability relationships and accordingly determinant parameters that appear within each of these stages" (del 2.1.2, § 8). Moreover, it has been clearly stressed that the different aspects of vulnerability (physical, social or economic) seem to change, sometimes to increase, "in a largely unforeseen way", due to "decisions made concerning other priorities" or to "a 'run-away' process of change to do with modernization" (del. 2.1.3 §. 9.3).

Also intervention mechanisms play a fundamental role in changing vulnerabilities in time and in space: both actions carried out by public or private sector or by civil society and specifically addressed to deal with vulnerability and actions aimed at promoting a general development of the society or the territory by modifying social and economic factors may induce relevant and sometimes un-intentional changes in vulnerabilities. It is even worth reminding that, in some cases, mitigation measures able to prevent or mitigate hazard can result in an increase of vulnerability. For example, some past events clearly highlight that "institutional coping or response capacity can partly be seen to have been a function of the risk culture as, due to flood defences being in place, there was little awareness of residual flood risk and thus appropriate preparedness strategies were not in place" (del. 2.1.2 § 4.1). Moreover, in many cases "the everyday perturbations on natural resources due to human activities can be a factor which causes or accelerates or amplifies the effects of a natural hazard" (del. 2.1.2, §6.2) and, consequently, they can change or alter the framework of vulnerabilities in a given area.

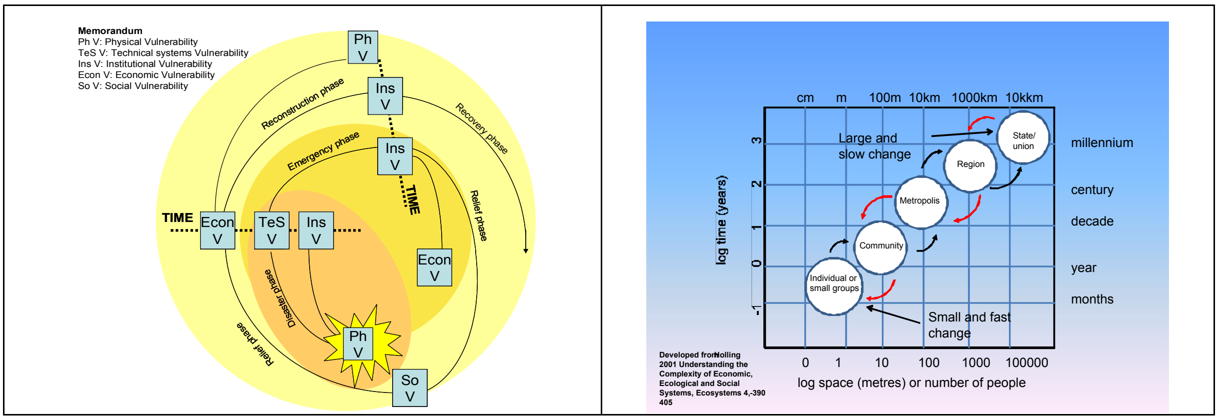

Figure 12: Activation of different types of vulnerability (left) and cross-scale propagation of vulnerability (right)

With respect to their key-role in changing vulnerabilities over time, land use planning policies have to be mentioned. Some examples clearly show the complex relationships among land use planning policies, spatial pattern of development (obviously depending not only on planning choices), hazard and vulnerabilities (see del 2.1.2 § 7c, § 7d).

Many other factors can alter vulnerabilities and their relationships over time and in space. These factors have been deeply investigated in the deliverable 2.1.2. and some of the main "drivers of change", able to modify vulnerabilities and their interactions, have been identified. It is worth mentioning that Resilience has been identified as one of the main "driver of the change" in emergency, relief and recovery period, able to facilitate "vulnerability transfer and redistribution among actors, communities, territories" (del. 2.1.3, § 8.1).

Finally, some attempts to represent the change of vulnerabilities and of their relationships over time and in space have been carried out. In the deliverable 2.1.2 (§ 7d), the spiral which, starting from the hazardous event, develops along the different phase of the disaster process, affecting different areas and activating different vulnerabilities and different relations among them, has been represented. A further attempt to take into account how vulnerability and resilience are likely to be inter-connected over space and time has been developed, grounding on Holling (2001) "who focuses upon 'adaptive cycles'. Small and fast changes are likely to take place at the small-scale level whereas changes at the large-scale level are likely to be larger and slower. Spatial linkages in vulnerability and resilience move up and down the spatial hierarchy. Over time vulnerability or resilience can be propagated by these linkages and transfers" (del. 2.1.1, § 6.1).

Nevertheless, according to the Dow of the Ensure project, vulnerability factors with respect to time and space will be further developed in WP3.

6.2 Key aspects of vulnerabilities with respect to complex hazardous events

The topic of vulnerabilities to complex hazardous events and mainly to technological hazards triggered by natural ones (na-techs) has been explored in this deliverable leading to a better understanding of the challenges that such phenomena lay down for hazard and vulnerability analyses. First of all, it has been underlined that in case of complex events an effective vulnerability assessment requires a clear understanding of the threats/hazards which elements and systems are exposed to and of their evolution over time and space. As clearly shown by the Katrina case study, the underestimation of the potential chains of hazards may drive towards the implementation of ineffective structural preventative measures which, in turn, induce a false sense of safety, opening the floor to an increase of exposure and vulnerabilities. Therefore, the overcoming of current approaches to hazard analysis is required.

Up to now, many authors have stressed the fact that, namely in urban areas, hazards are changing, shifting from individual hazards towards "an interactive mix of natural, technological and social events" (Mitchell, 1999). Such "hybrid" or "complex" hazardous events are generally characterized by low probability of occurrence - even though this probability is becoming higher and higher in case of na-tech due to the increased complexity both of hazards and territories – but also by heavy consequences in terms of damages. To deal with such events, the still widespread reductionist approach - that has for long driven to analyze separately the different hazards - has to give way to a holistic approach, aimed at exploring potential sequences and chains among the multiple hazards which potentially threaten a given territory.

Therefore, according to the main outcomes rising from the provided case studies on complex events, in order to face the challenge stemming from such events, some key points have to be taken into account for renewing the current approach to both hazard and vulnerability assessment.

As concerns hazard analysis, two main points can be listed:

- *Holistic approach to hazard analyses*

  The focus of hazard analysis has to be shifted from individual, separate hazards to the interactive mix of natural, technological, social hazardous phenomena; the rising relevance of complex hazardous event, mainly in case of na-tech, is due to the interactions of the tightly coupled natural-human-technological systems which have prompt and major impacts on each other.

- *Dynamic hazard scenarios*

  Hazard analysis has to focus, even though only qualitatively, on the different hazards at stake, on their temporal and spatial evolution paths, including the potential sequences or chains of events. Different hazard scenarios, from the most-likely case to the least likely one (worst case), have to be taken into account.

As concerns vulnerability assessment some key points can be singled out:

- *Complex framework of vulnerabilities*

  The growing complexity of territories, according to some scholars, increases both exposure and vulnerability, producing as effect more frequent and severe disaster. In case of complex events, vulnerabilities depend on intrinsic features of the phenomena themselves, on the consequences of the interactions between hazards and the affected areas and, in many cases, on the lack of an adequate preparedness to such events. The latter induces ineffective interventions that, in turn, may increase vulnerabilities and damages, involving targets not affected by the hazards themselves. Therefore, in these cases, vulnerability assessment has to take into account not only the heterogeneous vulnerabilities due to the different hazard factors at stake and their relationships but, also, the potential effects due to the synergies among different hazard factors and to other factors such as lack of preparedness, not adequate interventions which may, in turn, increase or transfer vulnerabilities from one element to another or even form one area to another.

- *Vulnerability of coupled ecological-human systems*

  The case studies related to na-tech events clearly highlight how the complex network of relationships between ecological and human systems may increase the complexity of such events. Modifications on the natural environment induced by human beings determine conditions that influence the trigger of hazards or increase their intensity and effects. Such hazards, mainly in case of na-tech, may induce in turn relevant consequences on the affected environmental systems. Since the latter often represents a key element of local economies, the damages on natural resources reverberate on social and economic systems which are often largely dependent on the integrity of a whole ecosystem rather than on a specific resource.

– *From static to dynamic vulnerability assessment: the time factor*

  According to hazard evolution over time (sequences, chains, etc.), different areas and targets can be involved. Each target can be hit by different hazards over time (simultaneously or in a very short time) or the same target can be hit by the same hazard more than once during a given temporal span. Obviously, mainly with respect to physical vulnerability, which is the most hazard-dependent component of vulnerability, the assessment of vulnerability with respect to each hazard does not allow the evaluation of the progressive decrease of the structural efficiency of the exposed elements hit, over time, by the same phenomenon or by different phenomena.

  Furthermore, mainly in case of complex events, different aspects of vulnerability (to stress and to losses) arise in different temporal phases. Thus, vulnerability assessment has to take into account the changes over time of the peculiar aspects of vulnerability, the different aspects of vulnerability rising in the different phases of the disaster cycle (sometimes as a consequence of inadequate or wrong interventions carried out in emergency phase) and the changes over time of the relationships among vulnerabilities.

– *Vulnerability assessment: cross-scale effects*

  Complex hazardous events generally induce cross-scale effects which cannot be neglected in vulnerability assessment. For example, multi-site phenomena may affect different points within a wide area: therefore, both detailed vulnerability analyses for each site potentially affected and large scale analyses aimed at analyzing potential relationships among exposed elements and areas will be required. Moreover, in case of chained events (na-na or na-tech), spread phenomena may trigger very localized ones. For example, an earthquake may induce one or more technological accidents which, in turn, will affect a small area surrounding the industrial plant: in this case, vulnerability analyses have to be developed at different scales and potential overlapping among different impacts have to be taken into account.

  Furthermore, due to the many interactions among different hazards and different aspects of vulnerability, both internal and external systemic vulnerabilities (del 2.1.2 § 4), which are often related to different spatial scales, become relevant in vulnerability analysis.

– *Resilience dimensions in facing complex disasters*

  Most of the mentioned dimensions of resilience (§ 4) are crucial to analyze the capacity of a system to adapt to and recovery from a complex disasters. For example, one of the main problems in case of complex hazardous events is the lack of preparedness both of communities and institutions. Such a lack is generally due to a lack of memory and experience. Since the rareness of such events, indeed, communities and institutions do not develop their capacity to learn from past experience, whereas learning capacity represents a key point for improving resilience and is crucial to build up mitigation measures able, in turn, to effectively reduce vulnerability. Moreover, in case of complex events, the emergency due to the triggering event combined with the effects of the generally unexpected secondary events compete for the few available resources, reducing efficiency and rapidity in response.
  Summing up, the main dimensions of resilience are very relevant to a better understanding of the behaviors of the territorial systems hit by complex events.

– *Tools for analyzing vulnerabilities to complex hazardous events*

As clearly arises from some case-studies, it is very difficult to identify main cause-effect relationships among vulnerabilities with respect to complex hazardous events. Thus, a systemic approach to understand vulnerabilities and their relationships is required and conceptual maps seem to fit this purpose. In fact, conceptual maps represent useful tools for exploring the chains of relationships among different vulnerabilities and their development over time and space. Such a tool, even though based on a qualitatively approach, can be very useful both for describing and interpreting past events and for outlining future scenarios.

6.3 Relationships among vulnerabilities and resilience

The relationship vulnerability/resilience represents a key question within the Ensure Project. The latter indeed is aimed to integrate different perspectives of vulnerability in order to enhance resilience: such a goal clearly requires to clarify how the two concepts influence or interact with each other.

Both the concepts (vulnerability and resilience) and their relationships are largely debated within scientific community and finding out some shared ideas in order to drive future approaches is not an easy task. As broadly mentioned, at present, a sort of "Babylonian confusion" characterizes not only the concepts of vulnerability, resilience but even some other relevant terms in the disaster field (coping capacity, adaptability,..). As underlined in the previous chapter, the idea that vulnerability and resilience are two overlapping concepts or more precisely that vulnerability represents the "flip-side" of resilience and vice versa is largely disproved by many scholars and above all by the case-studies. According to the flip-side approach, "high levels of vulnerability imply a low resilience, and vice versa" (Cannon, 2008): most of the case studies highlight, on the opposite, that a system can show high levels of physical vulnerability with respect to the impact of a hazard and, in the meanwhile, high level of resilience mainly referred to the capacity of recovering after the event or, even, low levels both of vulnerability and resilience. Moreover, as mitigation measures aimed at reducing some aspects of vulnerability can result in an increase of others, in the same manner, measures addressed to reduce some aspect of vulnerability do not necessarily achieve an increase of resilience and measures addressed to enhance resilience do not necessary reduce vulnerability.

Hence, it is possible to state that as the relationships among different facets of vulnerability and different dimensions of resilience can be ambiguous, the relationship between vulnerability and resilience cannot be reduced to a flip-side one.

On the contrary, the idea that the two concepts are separate, even though linked, is largely shared and supported by several case studies. Nevertheless, even according to such a position many different points of view and some open questions are at stake.

Some scholars highlight that vulnerability and resilience have to be interpreted as independent factors or processes, both of them acting in different phases of the disaster cycle, at different levels (individual, communities…) and contributing respectively to losses and adaptation (Paton, 2008). Other scholars underline that these concepts are partially overlapping: hence, "they are not totally mutually exclusive, nor totally mutually inclusive" (Cutter et al., 2008). By this perspective, adaptive capacity plays a core role in that it determines the distinction between the inclusive and the separate position, both related to the "no flip-side" interpretation. Furthermore, up to now some attempts for identifying and measuring (in quantitative or qualitative terms) the main factors influencing or determining the different aspect of vulnerability have been carried out – even though an integrated approach to all these aspects is still missing. On the opposite, the studies focused on resilience, since the latter has gain prominence in the disaster field only recently, are less numerous than the ones on vulnerability and very few among them include methods for quantifying resilience. Moreover, it is still so unclear which are the main factors affecting resilience or even which are its main components and which variables or indicators have to be taken into account in order to measure such components so that Rose (2007) stated that "resilience is in danger of becoming a vacuous buzzword from overuse and ambiguity".

Based on these premises and according to the review provided in the present and previous WPs on vulnerability and resilience, we will try to draw out some first ideas on this crucial topic for the Ensure project.

- *Vulnerability and Resilience are multifaceted concepts*

  It has been largely highlighted that vulnerability and resilience are multifaceted concepts. Moreover, the different facets of vulnerability and the mutual relationships among them and the different dimensions of resilience and their relationships have been defined.

- *Vulnerability and Resilience are separate concepts, partially overlapping*

  A shared idea rising from the tasks of WP2 is that vulnerability has to be referred both to the susceptibility to losses and to the capacity to recover. In the meanwhile, one of the most recent definition of resilience refers to "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UN/ISDR, 2009). Therefore, recognizing that these concepts partially overlap, it is worth stressing that within the overlapping area both the robustness of elements and systems and their coping capacity, largely interpreted as a part of vulnerability as well as of the resilience one, have to be included. Some scholars identify adaptability as the overlapping part between resilience and vulnerability. Clearly, coping capacity and adaptability are closely linked, even though the latter cannot be interpreted only as a part of the coping: it is indeed closely related to learning, which is recognized as a premise for adaptability (Folke et al., 2002), and implies a flexibility to change (Godshalk, 2003) which is not necessarily included in the concept of coping. Moreover, stressing on the aspects of vulnerability and resilience which do not overlap, it is worth mentioning that resilience includes both the ability to restore previous conditions and the ability to adapt to (or to create) new conditions (physical, social, economic….). By this perspective, innovation is part of the resilience concept but not of the vulnerability one (fig. 13).

  Summing up, whilst vulnerabilities refer to the susceptibility to be damaged of elements or systems, taking into account the capacity of individuals, communities or institutions to cope with the impact of a given event, avoiding further losses and guaranteeing the "bouncing back" of the hit area to a previous state, resilience includes dimensions as robustness, which can be interpreted as the flip-side of vulnerability, but also as adaptability or transformability which represent the capacity of elements and systems to adapt or transform themselves after the impact of an event. According to this, elements and systems may be vulnerable to a given event and, in the meanwhile, they can be resilient in that they can transform the disaster in a "window of opportunity" for changing.

– *Vulnerability and Resilience are dynamic concepts related to the different phases of the disaster cycle*

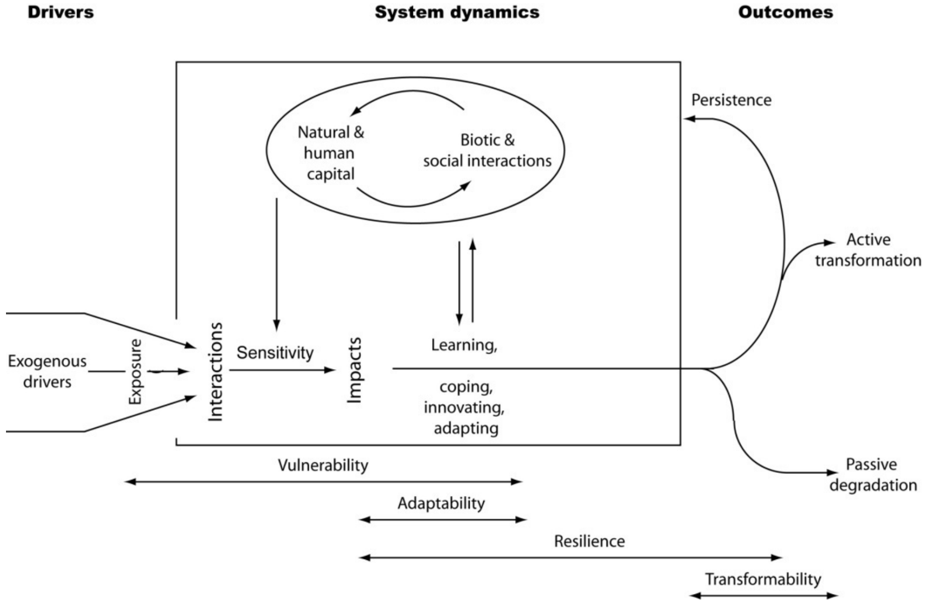

Figure 13: Integrate vulnerability, adaptability and resilience (Chapin, 2009)

Some scholars identify vulnerability as the static and resilience as the dynamic propensity of a system in relation to a threat. Nevertheless, it has already been stressed that the different aspects of vulnerability emerge at different scales and at different phases of the disaster cycle, from the pre-disaster to the reconstruction phase. Hence, time is a key factor in analyzing vulnerabilities. With respect to resilience, different dimensions (robustness, adaptability, etc) come on stage in different phases of the disaster cycle and it has already been stressed that most of the identified dimensions of resilience (e.g. learning capacity, rapidity, …) are largely time-related.

Summing up, both concepts refer to features and behaviors of coupled human-natural systems that change over time and space, both due to endogenous factors and to external stress factors. Hence, both vulnerability and resilience have to be interpreted as dynamic concepts.

– *Vulnerability and Resilience have mutual influences*

As already mentioned, vulnerability and resilience have mutual influences. In detail, Resilience may have a relevant role during emergency, relief and recovery periods in facilitating "vulnerability transfer and redistribution among actors, communities, territories" (del. 2.1.3 pr. 8.1) or in producing new vulnerabilities. Moreover, some examples of changes (generally due to the implementation of specific mitigation measures) of vulnerability features which induced negative effects on some key dimensions of resilience have been provided. Hence, the change of the different aspects of vulnerability over time has to be investigated taking into account the mutual influences among vulnerabilities and the key dimensions of resilience.

– *Vulnerability and Resilience: "lenses" for understanding the complex behaviors of territorial systems exposed to a threat*

The two concepts, as well as their facets or dimensions, can be interpreted as two different "lenses" or conceptual categories for analyzing how a complex system, namely a territory in all its aspects, reacts to an hazardous event. Obviously, the behavior of a complex systems hit by an external stress depends on many factors: some of them can be categorized and analyzed under the lens of the vulnerability, others under the one of resilience.

In detail, the lens of vulnerability is more focused on the features of elements or systems allowing them to resist to the impact of a given event, in terms both of not being damaged and of reducing losses through an effective management of emergency phase (*conservative approach*). The lens of resilience is more focused on the features of elements or systems allowing them, even though hit and damaged by a hazardous event, to adapt or change according to new conditions, modifying and sometimes improving their previous state (*adaptive approach*).

– *Vulnerability and Resilience assessment*

According to the provided interpretation of the two mentioned concepts, it is worth noting that whilst in the field of vulnerability analysis many steps toward an effective assessment of the different facets have been done, even though an integrated assessment of vulnerabilities is still lacking, methods and tools for an effective Resilience assessment are still at an early stage.

Since resilience has gain prominence in the disaster field only recently, available studies are still largely focused on theoretical aspects (which are the main factors affecting resilience or even which are its main components). The few researches addressed to provide methods and tools to measure resilience seems to be still largely focused on the idea that resilience represents the ability of a system to bounce back or to restore a previous state of the system itself or, in other words, on the idea of resilience as a flip-side of vulnerability. Therefore, starting from the definition of the key-dimensions of resilience and their relationships provided in this work (see § 4.5.2), a further step toward the definition of adequate qualitative or quantitative indicators for an effective assessment of resilience is required.

6.4 Basic principles for integrating vulnerabilities to natural and na-tech events

Many hints arise from the work developed in WP1 and WP2: many questions have been faced, a common background on the main topic related to vulnerability analysis has been set up; the concept of resilience has been deepened; the relationships among the different facets of vulnerability have been investigated; the key dimensions of resilience have been identified; the dynamic feature both of vulnerability and resilience, the mutual influences between them and the key role of some factors (e.g. land use planning policies, mitigation measures or even resilience itself) in changing vulnerabilities over time or in space, through mechanism of transfer and redistribution among actors, communities, territories have been highlighted.

Summing up, some relevant steps forwards along the path for integrating the different facets or the different perspectives of vulnerability in order to enhance the resilience of communities and territories have been taken, even though many questions are still open. According to the Dow of the Ensure project, the development of a new methodological framework for an Integrated Vulnerability Assessment represents the main objective of the WP4. Therefore, this paragraph, grounding on the achieved results, provides some general principles for building up such a methodological framework. These principles provide a first answer to the many questions raised along the research path developed up to now, open the floor to other questions to be developed in the WP3 and represent the key points which cannot be missed for renewing the field of vulnerability assessment in terms of approaches, methods and tools.

Which aims for an integrated vulnerability assessment?

First of all, it is worth stressing that an integrated assessment of vulnerabilities can be addressed to different aims. For example, it can be carried out to support land use planning choices or civil protection strategies or even economic or social policies at different scales (local, regional, national…). Therefore, the specific aims of these policies and the different scales they refer to require different types of analysis at different scales with different focuses. Hence, the methodological framework would provide a general path in which flexible procedures and indicators have to be specified according to different aims, contexts and scales.

Vulnerability as a "whole"

Largely shared by partners is the idea that vulnerability represents a 'whole' characterized by numerous facets characterized by close relationships. Hence, the methodological framework has to be based on a holistic approach in that each aspect has to be analyzed taking into account the multiple relationships between such aspect and all the others.

Qualitative or quantitative assessment?

In previous tasks some practical attempts to integrate some of the many facets of vulnerability or resilience through numerical indexes have been provided. These studies, based on quantitative approaches, often drive towards simplified and aggregate numerical indexes, neglecting aspects of vulnerability and resilience which, even though difficult to quantify, are relevant to a fully understanding of complex systems (e.g. territorial and social ones) behaviour, hit by an external stress. Moreover, aggregate indexes, which are very useful to rank different territories according to their vulnerability or to support choices related to resource allocation, have to be coupled with disaggregate information in order to effectively drive policies aimed at reducing vulnerabilities and/or enhancing resilience.

Therefore, vulnerability assessment has to be based on a coupled qualitative and quantitative approach in order to provide a variety of inputs flexible to different aims and able to support different policies.

A shift in thinking in hazard assessment for an effective integrated assessment of vulnerabilities

Taking into account the many facets of vulnerability with respect to an individual hazard is already a relevant step towards an integrated vulnerability assessment. Nevertheless, hazards are changing, shifting from an individual form towards "an interactive mix of natural, technological and social events" (Mitchell, 1999). As a consequence, the still widespread reductionist approach to hazard analysis drives us to underestimate potential chains and synergies among such events and, consequently, to neglect relevant aspects in vulnerability assessment.

Therefore, an effective integrated assessment of vulnerability requires first of all a shift in thinking in the field of hazard analysis: besides the understanding of the different hazards which potentially threaten a given territory, the evolution paths of such hazards including the potential synergies and chains among them have to be in depth investigated.

Assessing vulnerability taking into account its dynamic feature

Vulnerability cannot be interpreted as a static concept: all facets of the vulnerability and the relationships among them change over time due to external factors and to mutual influences among them and among vulnerabilities and reliance dimensions.

Therefore, an effective vulnerability assessment has to be based on a constantly updated knowledge of the different facets of vulnerabilities and on the many factors which can contribute to induce, modify and transfer vulnerabilities over time. In other words, vulnerability assessment has to be structured as a "continuous cycle", in which the preventive assessment of the potential outcomes of mitigation measures – in terms of effects on vulnerability and resilience – and the monitoring of the effects due to their implementation have to be included. As previously stated (see § 5), measures aimed at preventing hazards or at reducing some aspect of vulnerability or even at enhancing some dimensions of resilience do not necessarily result in a reduction of risk, driving sometimes towards an increase of other aspects of vulnerability or a decrease of resilience.

Assessing vulnerability along the stages of the disaster cycle

This principle is closely linked to the previous one; indeed, vulnerabilities and their relationships change over time and mainly, as stressed before, over the different stages of the disaster cycles, according to the evolution paths of the hazards, to the mutual influences among the different facets of vulnerability, to the interventions set up at different stages of the disaster cycle. Some facets of vulnerability are very relevant in some stages of the disaster cycles but they can be neglected in others: for examples, some facets do not appear at early stage whereas they can become more and more relevant in long term and vice-versa.

Therefore, along the "continuous cycle" of the vulnerability assessment, the changes affecting each facet of vulnerability and their mutual relationships over the different stages of the disaster cycle have to be taken into account.

Space and time factors in assessing vulnerabilities

Territorial systems change dynamically over time. Moreover, as well as vulnerabilities are linked to each other, different territories will have many connections and mutual relationships with the surrounding ones. Small and fast changes are likely to take place at the small-scale level whereas changes at the large-scale level are likely to be larger and slower reverberating on a local scale. According to such changes vulnerabilities and the mutual linkages among them may change, propagate or transfer over time from one territory to another one.

Therefore, vulnerability assessment has to look beyond the area under investigation, taking into account the relationships among the investigated area and the wider regions that it belongs to and their changes over time.

Multi-scale and cross-scale analyses

Some factors influencing vulnerabilities at local scale may be understood at large scale and not be recognized locally. On the opposite some features, even though rather evident when looked at from a short distance, fade away on a larger scale. At different levels, interactions among systems and subsystems vary in quantity and quality, emerge in different ways, shaping social, cultural, economic and territorial processes. Furthermore, as stressed with respect to complex hazardous events, vulnerability analyses have to take into account the different scales of hazards' impacts and the potential overlapping among impacts due to phenomena acting on different scales and/or to the repercussions of local events on areas placed far from the main event. Therefore, multi-scale and cross-scale analysis cannot be neglected in vulnerability assessment.

Taking Resilience into account

Resilience and vulnerability have been recognized as separate processes, acting in different phases of the disaster cycle, at different levels (individual, communities…), even though characterized by some areas of overlapping. The two concepts can be interpreted as two different "lenses" or conceptual categories, both of them useful for analyzing how a complex system, namely a territory in all its aspects, reacts to an hazardous event. The behavior of a complex system hit by an external stress depends on many factors: some of them can be better categorized and analyzed under the lens of the vulnerability (namely that one related to the ability of an element or a system to resist and to cope with a hazardous event avoiding or reducing the losses), others under the one of the resilience (namely that one related to the ability of an element or a system to change and innovate themselves after the impact of a given hazard).

Therefore, even though the two concepts have to be separately investigated, vulnerability assessment has to take into account the role of resilience, in that the processes of change and/or innovation of a territorial system hit by a hazardous event may modify vulnerabilities, facilitating vulnerability transfer and redistribution among actors, communities, areas or producing new vulnerabilities.

Coping with uncertainties

Due to the growing complexity of urban and territorial systems, their behaviors in case of external stresses will be characterized by a high level of uncertainty. Thus, based on the consciousness to act in a state of uncertainty, that not all the changes of the variables at stake are predictable, the whole process aimed at analyzing such behaviors through the selection and the measurement of the multiple variables at stake (knowledge phase), at defining measures able to influence these variables (decision phase) and implementing such measures (action phase) would have to be iterative and flexible, taking into account the unpredictable changes of the initial conditions which could occur during the time.

Tools for understanding, assessing and communicating vulnerabilities

An innovative approach to vulnerability assessment requires innovative tools for understanding and assessing vulnerabilities and for communicating technical outcomes to experts from different fields (e.g. land use planners), to decision makers and to communities.

Different tools are currently available for carrying out an integrated and dynamic assessment of vulnerabilities. The choice of such tools is closely related to the aims of the assessment itself. A first one is related to the use of conceptual maps for exploring the complex web of linkages among hazards, vulnerabilities, factors contributing to vulnerabilities and consequences of vulnerabilities in terms of damages. In fact, a conceptual map allows to single out the different types of relationships among the above mentioned elements. Such a tool can be referred to the different phases of the disaster cycle and allow us to explore future scenarios (e.g. due to the change of one or more elements at stake as a consequence of mitigation measures). Moreover, the different elements and relationships can be weighted according to their relevance in a given space and in a given temporal span. Finally, it is worth noting that conceptual maps can be easily understood even by no expert users.

Methods and procedures to integrate vulnerabilities through numerical indexes are available too, even though they consider only some aspects of vulnerability. Numerical indexes are very useful to rank different territories according to their vulnerability and to support choices related to resource allocation. Nevertheless, such methods do not allow a fully understanding of the mutual relationships among the many factors at stake. Such an understanding is very relevant even to explore the consequences of development trends related for example to land use planning choices or to social and economic policies. Moreover, it is worth stressing that such methods generally provide very technical outcomes that are difficult to communicate to no expert users. Hence, even though some tools are available, they require some improvements in order to adequately support an integrated assessment of vulnerability: most of the current methods do not allow to take into account the dynamic features of vulnerabilities, the multiple scales at stake, the need for coupling both quantitative and qualitative information. Moreover, current techniques for representing vulnerabilities are very often not addressed to involve communities in the assessment process, making, even through adequate representation tools, the existing technical knowledge available and sharable.

Methods and techniques aimed at analyzing, assessing and representing the change over time and in space of vulnerabilities will be further investigated in the next WP.

7 Conclusions

In this task some crucial questions for vulnerability assessment have been answered and the work developed in previous tasks has been collected and systematized, in order to provide some general principles on which the setting up of a methodological framework for an integrated vulnerability assessment has to be based.

In detail, the growing complexity of hazards has been emphasized, highlighting the need for a holistic and dynamic approach both to hazard and vulnerability assessment and suggesting some tools for exploring the complex chains of hazards, vulnerabilities and damages which characterize complex events.

Moreover, the resilience concept has been deepened and some inputs for turning it into operational terms have been drawn out. In detail, grounding on the main studies focused on resilience developed in different disciplinary fields, the main performance dimensions of resilience have been singled out: some of them represent very wide and general concepts related for example to different meanings of the resilience itself, others are more specifically related to the abilities or features of a system which can be improved or strengthen to enhance resilience. Each dimension gains prominence in different phases of the disaster cycle: some of them are very relevant in face to the impact, others come on stage in medium or long term. According to such considerations, the key dimensions of resilience have been arranged into a circular scheme, following the main phases of the disaster cycle: impact-response-recovery-preparedness. Moreover, within the circular scheme, the dimensions have been sorted into concentric circles that, starting from the most internal one in which resilience has been placed, drive toward a progressive specification of resilience itself. The provided framework should be an useful supporting tool for the definition of policies aimed at enhancing resilience, even though its effectiveness requires the definition of adequate indicators for each dimension, allowing an effective implementation and monitoring of such policies.

Furthermore, the relationships between vulnerability and resilience and the effectiveness of mitigation measures based on current analysis of vulnerability have been explored. With respect to the first point, based on the inputs from previous tasks, on the current scientific literature and on case studies showing the behaviors of different territories and communities hit by different hazards, vulnerability and resilience have been interpreted as two separate concepts, two "lenses" both of them useful for understanding and assessing the many factors contributing to the behavior of a complex system hit by an external stress.

In detail, the lens of vulnerability has been interpreted as the one more focused on the features of elements or systems allowing them to resist to the impact of a given event, in terms both of not being damaged and of reducing losses through an effective management of emergency phase (*conservative approach*). The lens of resilience has been interpreted as the one more focused on the features of elements or systems allowing them, even though hit and damaged by a hazardous event, to adapt or change according to new conditions, modifying and sometimes improving their previous state (*adaptive approach*).

In relation to the second point, based on several case studies, it has been highlighted that mitigation measures aimed at reducing individual aspects of vulnerability can result in an increase of others; that measures addressed to reduce some aspect of vulnerability do not necessarily increase resilience and that measures addressed to enhance resilience do not necessary reduce vulnerability. In other terms, since the two concepts are separate, even though with some overlapping areas, only some policies addressed to reduce vulnerability may affect resilience dimensions and vice-versa. Nevertheless, changes within a given system due to its resilient behavior may induce changes in vulnerability features of such a system and such changes, as demonstrated by case studies, are not always positive.

Finally, according to the main outcomes of this task and of the previous ones, some general principles for setting up a methodological framework driving an integrated vulnerability assessment have been provided. Such principles represent the main requirements that the methodological framework should meet. In detail, the methodological framework for an integrated assessment of vulnerabilities has:

- to be flexible, in order to allow procedures and indicators according to the different aims, contexts and scales of the assessment;
- to look at vulnerability as a whole, taking into account its multiple facets and the mutual relationships among them;
- to couple qualitative and quantitative approaches in order to provide a variety of inputs flexible to different aims and able to support different policies;
- to be based on hazard analyses which take into account the different hazards which potentially threaten a given territory, the evolution paths of such hazards, including the potential synergies and chains among them;
- to take into account that vulnerabilities and the relationships among them constantly change over time and in space and that different facets of vulnerability raise at different stages of the disaster cycle;
- to be based on multi-scale and cross-scale analyses;
- to take into account resilience dimensions;
- to provide innovative tools for understanding and assessing vulnerabilities and for communicating the outcomes of such a work to other experts, to decision makers and to communities.

Finally, based on the consciousness to act in a state of uncertainty, the methodological framework should outline an iterative and flexible process allowing us to analyze the behaviors of territories and communities hit by a hazardous event through the selection and the measurement of the multiple variables at stake (knowledge phase), to define measures able to influence such variables (decision phase) and to implement these measures (action phase), taking into account the unpredictable changes of the initial conditions which would occur during the time.

The provided principles have been defined according to the main findings of the work developed in the first two tasks of the Ensure project and they should drive the setting up of the methodological framework for an integrated vulnerability assessment in the WP4. Some points related to the vulnerability analyses over time and across space will be further developed in the WP3 as well as the role of resilience in transferring and modifying vulnerabilities.

8 Annex 1 Panarchy

Panarchy is a representation of a hierarchy as a nested set of adaptive cycles (Holling, 2001). The term was created by Holling and the other members of the Resilience Network, with the aim of capturing the adaptive and evolutionary nature of adaptive cycles that are nested one within each other across space and time scales. A stylized representation of a single adaptive cycle is shown in fig. 14.

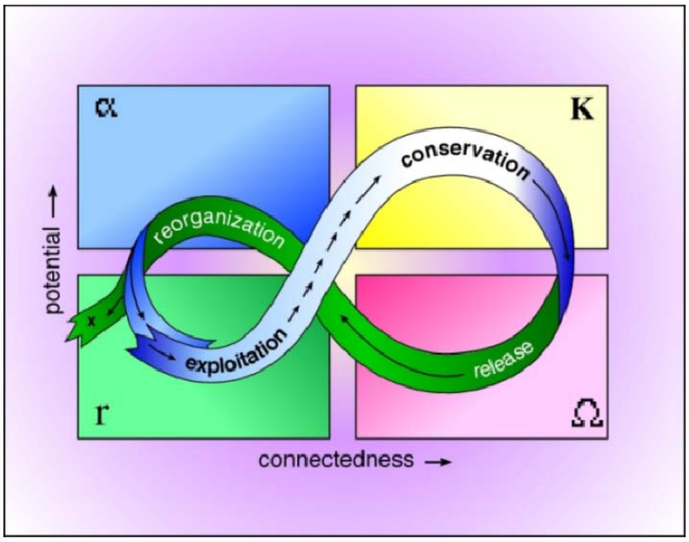

Figure 14: The ecosystem functions in the model of panarchy (Folke et al., 2007)

The adaptive cycle involves the movement of a system through four phases through which it is possible to describe the ecosystem behavior: a period of rapid growth and exploitation (r); leading into a long phase of accumulation, monopolization and conservation of structure (K); a very rapid breakdown or release phase (Ω); and finally, a relatively short phase of renewal and reorganization(α). If in this phase, the system still retains sufficient of its previous components, it can reorganize to remain within the same configuration as before. (Walker et al., 2002).

The cycle reflects changes in two attributes: on the Y axis, the amount of accumulated capital (e.g. natural and social capital according to more recent insights) stored in variables that are dominant keystone variables at the moment, and, on the X axis, the degree of connectedness among variables that represent the internal controllability of a system. The arrows show the speed of the flow/change in the cycle: short, closely spaced arrows indicate a slowly changing situation; long arrows indicate a rapidly changing situation (Holling, 2001).

Holling has further embodied the concept of "creative destruction" in the panarchy one. The term was coined in 1942 by the Austrian economist Shumpeter to refer to a phenomenon in which bankrupties eliminates inefficient enterprises, freeing up resources for more efficient use. Similarly, Holling adopts the term to refer to the phase from Ω to α that is a period of rapid reorganization during which novel combinations, some of which nucleate new opportunity (Holling, 2001), can unexpectedly seed experiments that lead to innovations in the next cycle.

The author argues that, apart from potential and connectedness, there is also a third dimension of the adaptive cycle that is resilience. It is high in the α phase accordingly with potential whereas connectedness or controllability is low and it is just in this period that foster novelty and experiment can occur.

The other aspect distinguishing the panarchy model from the hierarchical one is the connection between phases at one level and phases at another level which are labelled as "revolt" and "remember" and become important at times of change in the adaptive cycles (fig. 15).

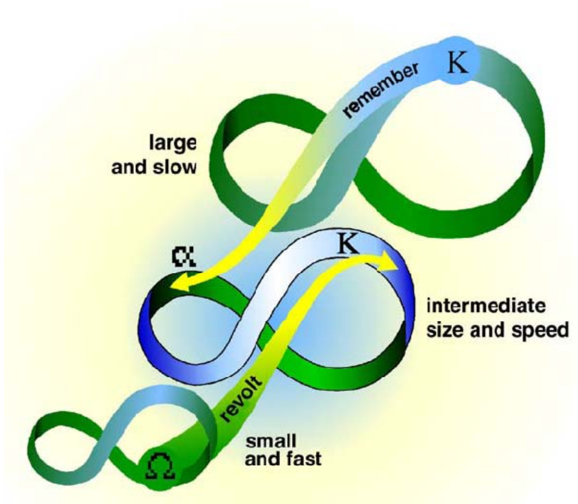

Figure 15: Panarchical connections (Holling, 2001)

Revolt and remember are critical in creating and sustaining adaptive capacity. When a level in the panarchy enters in the Ω phase of creative destruction, the collapse can cascade to the next larger and slower level by triggering a crisis. Such an event is most likely if the slower level is at its K phase, because at this point the resilience is low and the level is particularly vulnerable. On the other side, remember connection facilitates renewal by drawing on the potential that has been accumulated and stored in a larger, slower cycle (Holling, 2001). Revolt and remember connections are typical examples of cross-scale interactions.

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