



**POLITECNICO**  
MILANO 1863

DIPARTIMENTO DI ARCHITETTURA  
E STUDI URBANI



**UNIVERSITÉ  
DE GENÈVE**

# Aspects and concepts of systemic vulnerability applied to volcanic risk assessment: learning lessons from real events and improving modelling capacity

Scira Menoni



**1st IAVCEI/GVM Workshop  
From Volcanic Hazard to Risk Assessment  
Geneva, 27-28 June 2018**

$$\text{RISK} = f(\text{HAZARD}, \text{VULNERABILITY}, \text{EXPOSURE}, \text{RESILIENCE})$$

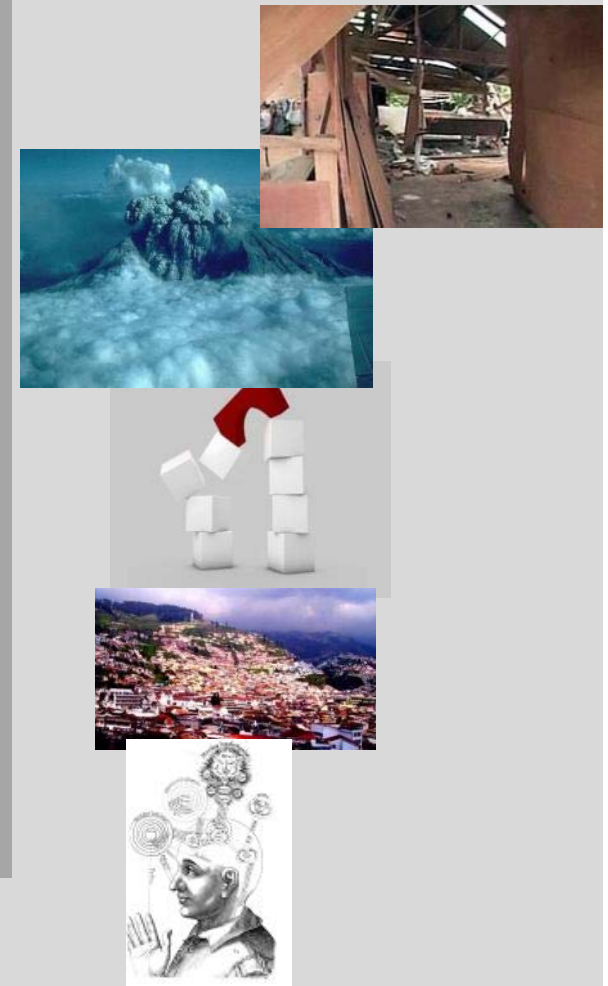
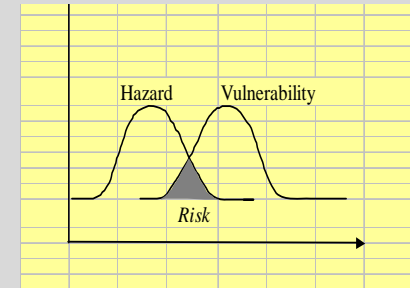
**RISK** measured in terms of expected damage

**HAZARD** = characteristics of the dangerous agent (phenomena)

**VULNERABILITY** = propensity to damage, fragility

(Exposed systems) = number and dimension of people and goods in a dangerous area

**RESILIENCE** = capacity to learn, transform losses into opportunities



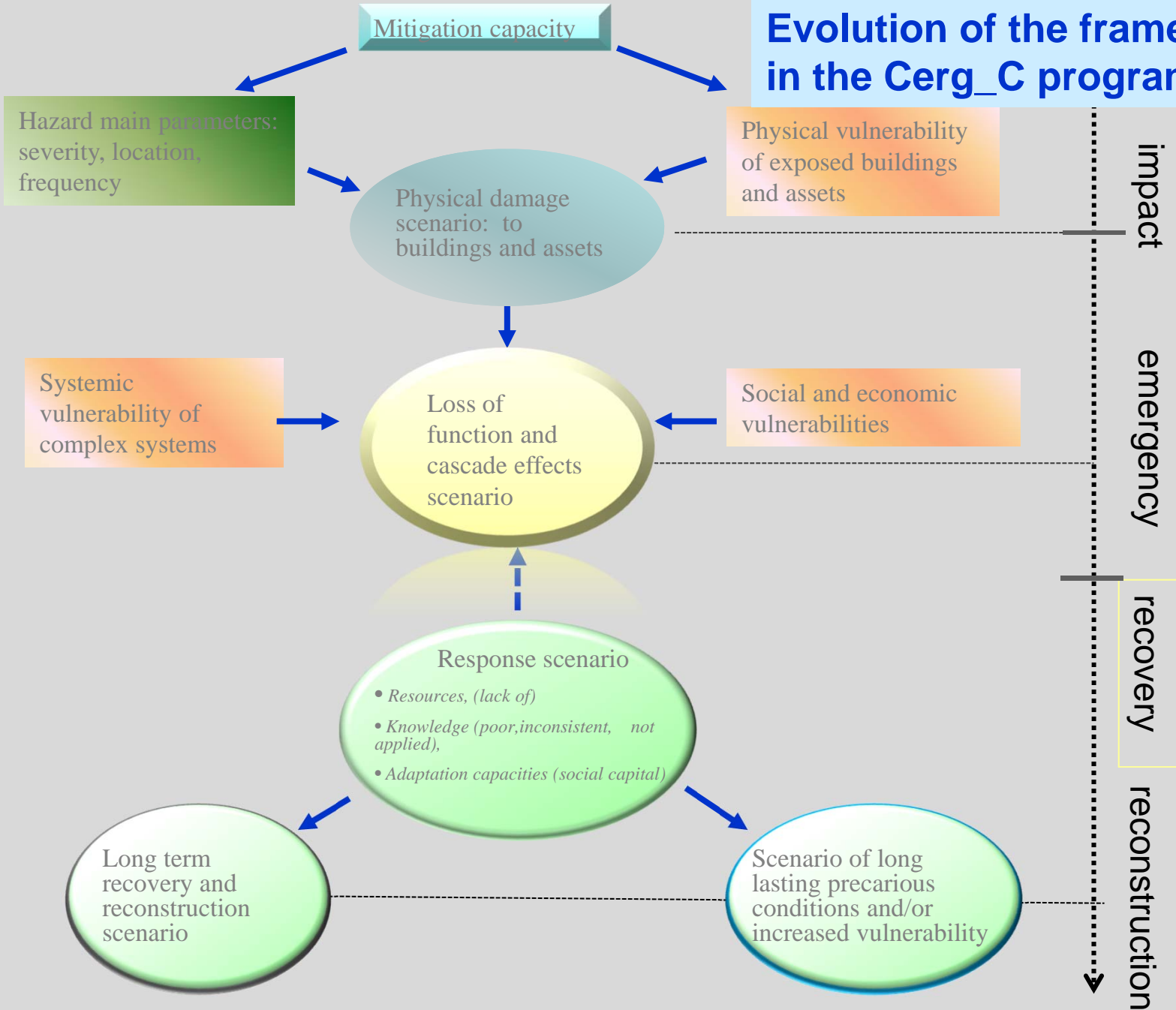
# Taking the move from two projects: Ensure and Idea; using also the PDNA for Fogo 2014

**ENSURE project (Enhancing resilience of communities and territories facing natural and na-tech hazards)**

**IDEA**  
 Improving Damage assessments to Enhance cost-benefit Analyses  
**CN: ECHO-SUB-2014-694469.**  
[www.ideaproject.polimi.it](http://www.ideaproject.polimi.it)

**Post-Disaster Needs Assessment (PDNA)  
 FOGO VOLCANIC ERUPTION  
 2014-2015**

# Evolution of the framework in the Cerg\_C program



# Systemic Vulnerability analysis:

Systemic vulnerability: propensity to systemic damage (damage as loss of function, as a disruption of activities), due to the physical damage or to failures (second order)

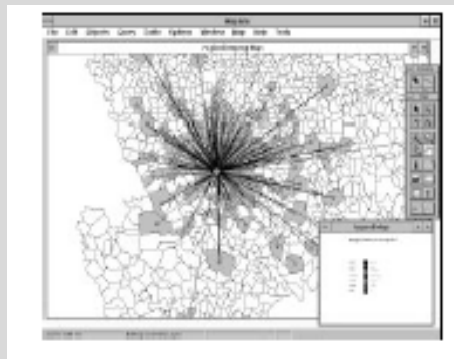
Reference: Van Der Veen, A., Logtmeijer, C., Economic Hotspots: Visualizing Vulnerability to Flooding, Natural Hazards, 36(1), 2005, pp. 65-80)

## systemic vulnerability

interdependency



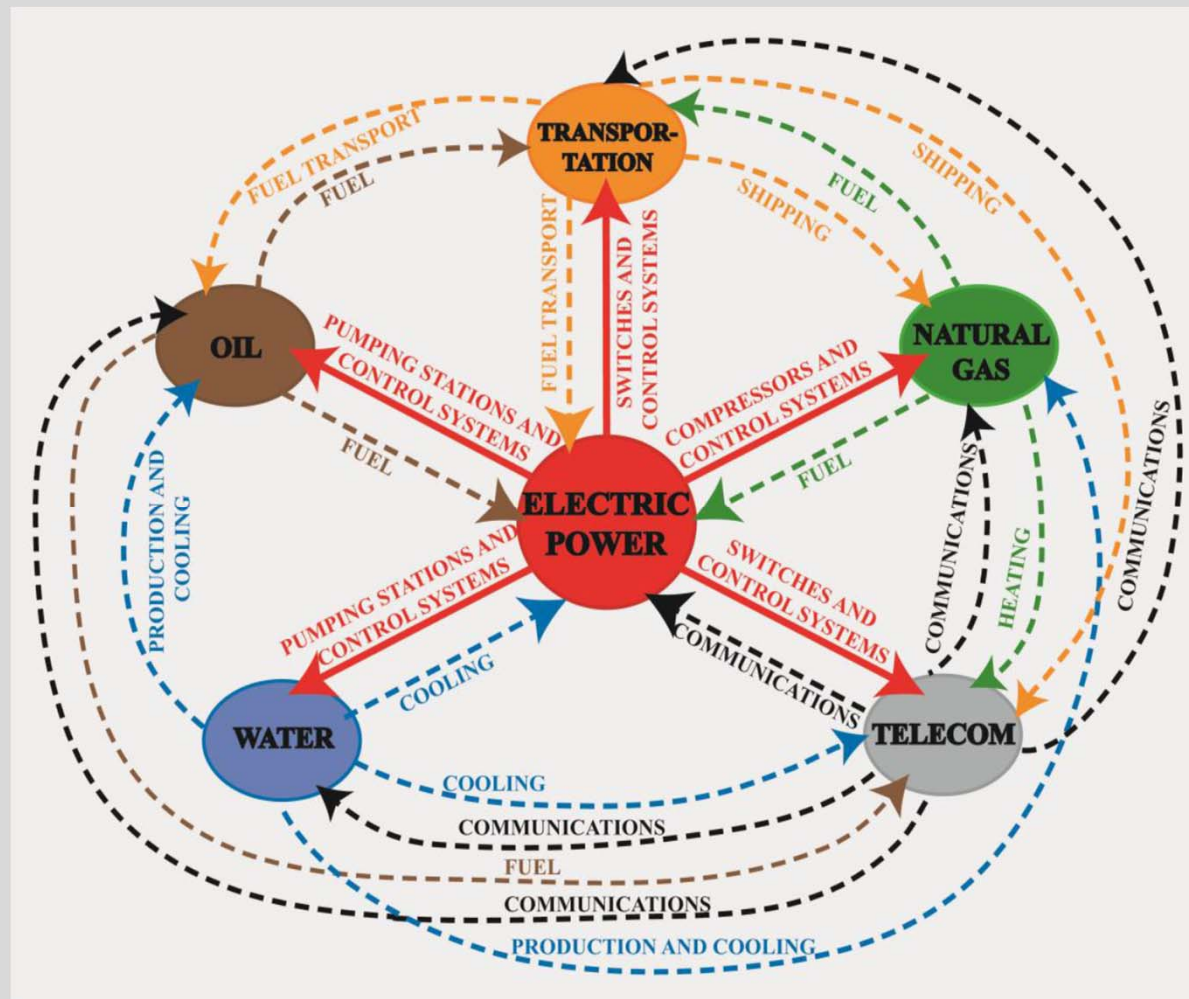
transferability



redundancy



# Systemic vulnerability analysis: interdependency



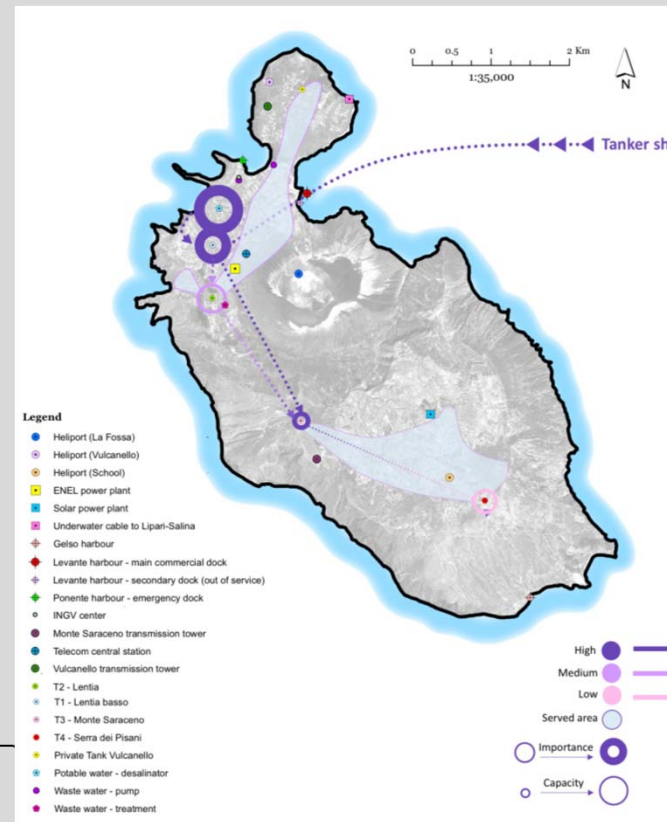
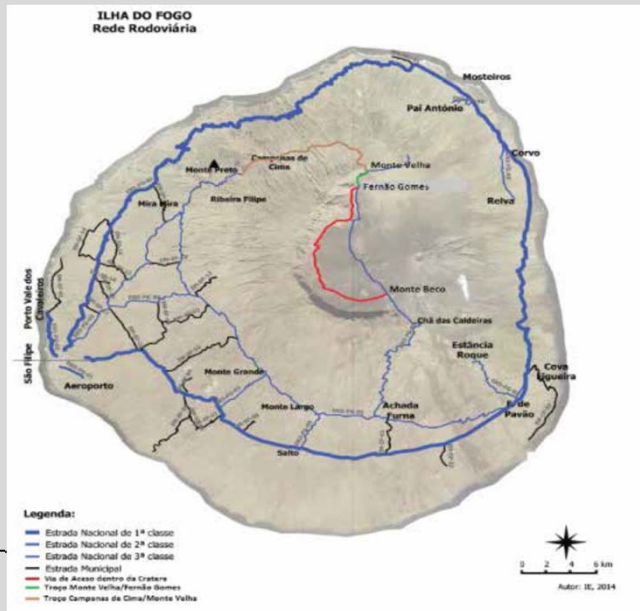
Schematic diagram illustrating some of the interdependencies between critical infrastructure systems (adapted from Rinaldi et al., 2001). Source: Source: PhD thesis J.B. Wardman, University of Canterbury, 2013 Vulnerability of Electric Power Systems to Volcanic Ashfall Hazards

# Systemic vulnerability analysis: redundancy



Clearly lack of redundancy in lifelines and critical infrastructures is a key element of systemic vulnerability.

Islands are often characterized by very little redundancy in all their system, but the same can be said for some remote mountain areas.



# Systemic vulnerability analysis: transferability



Some types of production, some very specialized services are difficult to transfer to another place.

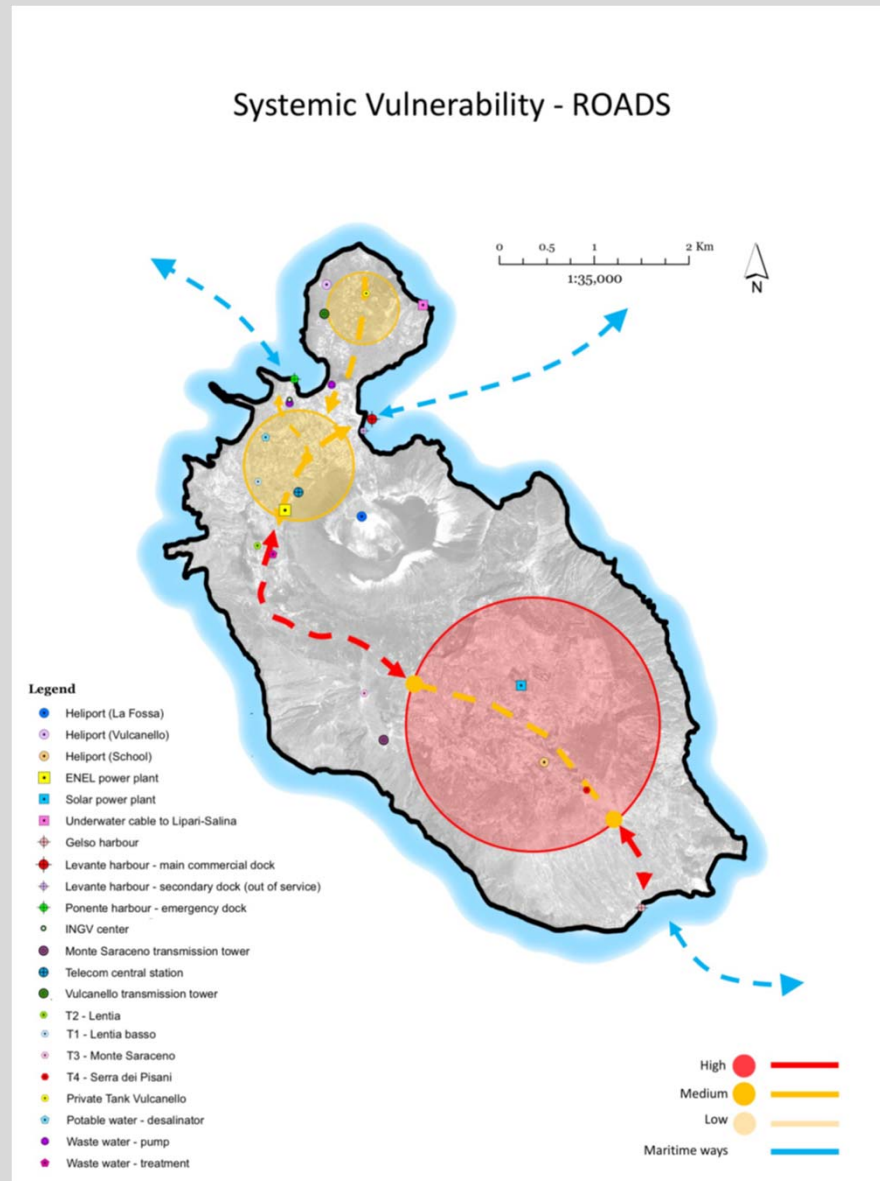
Typical local wine production is impossible/extremely difficult to transfer even in the vicinity of the cultivation/production zone.



System	Sub-system	Items/Assets	Physical vulnerability		Systemic vulnerability		Resilience	
			Aspect Parameters	Criteria for assessment	Aspect Parameters	Criteria for assessment	Aspect Parameters	Criteria for assessment
Critical Infrastructure	power	Power lines	layout of the lines	aerial lines/buried	Redundancy	redundant/no alternative	Availability of spare materials and personnel for repair	Available/partially available/not available
		Plant	see buildings assessment	result building;	Redundancy	redundant sources/no alternative		
	water and sewerage	Water and sewerage conducts	conducts maintenance	Good/poor	Redundancy and dependability on external sources	redundant/no alternative; local/external sources	Availability of spare materials and personnel for repair	Available/partially available/not available
		Water and sewerage plants	see structure and location	result building	Redundancy	redundant/no alternative		
	telecommunication	Telecommunication lines	layout of the lines	aerial lines/buried	Redundancy and dependability on external sources	redundant/no alternative; local/external sources	Availability of spare materials and personnel for repair	Available/partially available/not available
		Telecommunication plant and antennas	see buildings assessment	result building	Redundancy	redundant/no alternative		
	roads	roads	interaction with vulnerable buildings and landslides	below vulnerable buildings, in landslide areas/far from buildings and landslides	Redundancy	redundant/no alternative	Availability of spare materials and personnel for repair	Available/partially available/not available
			location	in a protected/not protected place	width of the road	narrow/large --> apt for emergency trucks		
			maintenance	maintenance	curves and inclination	plain road/mountain road		
			water drainage	existing/non-existing				
	ports	ports	interaction with vulnerable buildings and landslides	below vulnerable buildings, in landslide areas/far from buildings and landslides	redundancy	redundant/non redundant	Availability of spare materials and personnel for repair	Available/partially available/not available
			location	in a protected/not protected place	weather dependent	unusable during storms/only partially usable during storms or moderate storms/completely protected		
					type of ships/boats	can host any type/only small boats		
	heliports	heliports	interaction with vulnerable buildings and landslides	below vulnerable buildings, in landslide areas/far from buildings and landslides	redundancy	redundant/non redundant	Availability of spare materials and personnel for repair	Available/partially available/not available
			location	in a protected/not protected place				
			maintenance	maintenance				
waste management	Waste management	Collection site	protected/not protected	separated garbage collection treatment	all/only one or two/none Onsite/by ship	Identified debris disposal sites	forecasted/no	

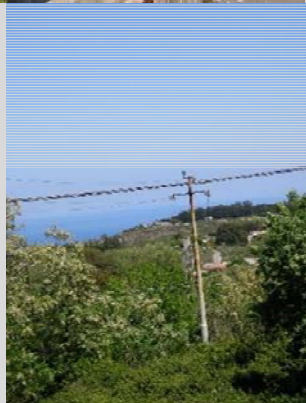
**Following the Ensure modified methodology, this is the framework we use with CERG\_C students in Vulcano island**

System	Sub-system	Items/Assets	Systemic vulnerability	
			Aspect Parameters	Criteria for assessment
Natural environment	Landscape	Vegetation cover		
Built environment	Vulnerability assessment of public facilities	Church in Porto area	Dependence on external services (electricity and water) Accessibility (internal and external)	Autonomous generators and/or tanks/dependent Redundancy/lack of redundancy
		Church in Piano area	Dependence on external services (electricity and water) Accessibility (internal and external)	Autonomous generators and/or tanks/dependent Redundancy/lack of redundancy
		School	Dependence on external services (electricity and water) Accessibility (internal and external)	Autonomous generators and/or tanks/dependent Redundancy/lack of redundancy
		First aid station	Dependence on external services (electricity and water) Accessibility (internal and external)	Autonomous generators and/or tanks/dependent Redundancy/lack of redundancy
		Other facilities	Dependence on external services (electricity and water) Accessibility (internal and external)	Autonomous generators and/or tanks/dependent Redundancy/lack of redundancy
	Vulnerability of urban blocks	Vulnerability of residential buildings	Accessibility (internal and external) Dependence on external services (electricity and water)	Redundancy/lack of redundancy Available autonomous generators and tanks/not available
Critical Infrastructure	power	Power lines	Redundancy	redundant/no alternative
		Plant	Redundancy	redundant sources/no alternative
	water and sewerage	Water and sewerage conducts	Redundancy and dependability on external sources	redundant/no alternative; local/external sources
		Water and sewerage plants	Redundancy	redundant/no alternative
	telecommunication	Telecommunication lines	Redundancy and dependability on external sources	redundant/no alternative; local/external sources
		Telecommunication plant and antennas	Redundancy	redundant/no alternative
	roads	roads	Redundancy	redundant/no alternative
			width of the road	narrow/large --> apt for emergency trucks
			curves and inclination	plain road/mountain road
	ports	ports	redundancy	redundant/non redundant
weather dependent			unusable during storms/only partially usable during storms or moderate storms/completely protected	
type of ships/boats			can host any type/only small boats	
heliports	heliports	redundancy	redundant/non redundant	



Source: Master thesis of Dehrick Guobadia, Polimi, 2018

System	Sub-system	Items/Assets	Systemic vulnerability	
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Critical Infrastructure	power	Power lines	Redundancy	redundant/no alternative
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			type of ships/boats	storms/completely protected can host any type/only small boats
heliports	heliports	redundancy	redundant/non redundant	
waste management	Waste management	separated garbage collection treatment	all/only one or two/none Onsite/by ship	

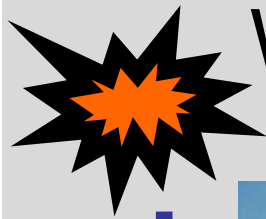


# Vulnerability (physical and systemic) and resilience of economic activities

System	Sub-system	Items/Assets	Physical vulnerability		Systemic vulnerability		Resilience	
			Aspect Parameters	Criteria for assessment	Aspect Parameters	Criteria for assessment	Aspect Parameters	Criteria for assessment
Economic system	Agriculture	Coltures	vulnerability of different typs of crops to different threats	high/medium	Dependence on transport to/from Siciliy and Calabria	highly dependend/not dependent	Insurance coverage	Full/Partial/not covered
		Cattles and Sheeps	position	can be kept in protected spaces/not sufficient protected spaces	Dependence on transport to/from Siciliy and Calabria	highly dependent/not dependent	Insurance coverage	Full/Partial/not covered
	Commercial	Commercial activities	Bars, restaurants, shops. Car rentals	See buildings' vulnerability Cars can be kept in protected spaces/cannot	Dependence on transport and critical facilities	highly dependent/not dependent	Insurance coverage	Full/Partial/not covered
			Hotels and houses to rent	Hotels and houses	Dependence on transport and critical facilities		Duration of business interruption	t < 3 Months; t > 3 months
	Industrial	Cheese factory	Factory	See buildings' vulnerability	Dependence on transport and critical facilities	highly dependent/not dependent	Insurance coverage	Full/Partial/not covered
			Machinery and material	vulnerable to ashes/not vulnerable)	Dependence on transport and critical facilities		Duration of business interruption	t < 3 Months; t > 3 months
		Other factories	same as for cheese factory		Dependence on transport and critical facilities		Seasonality of business interruption	High season/medium season/winter
							Diversification among sectors and within sectors	%each sector equal; % in one sector> 2 times the



For the vulnerability and resilience of the economic system one needs to consider the capacity to recover quickly of businesses



# What types of damages can be expected?

Direct physical damage



Induced physical damage

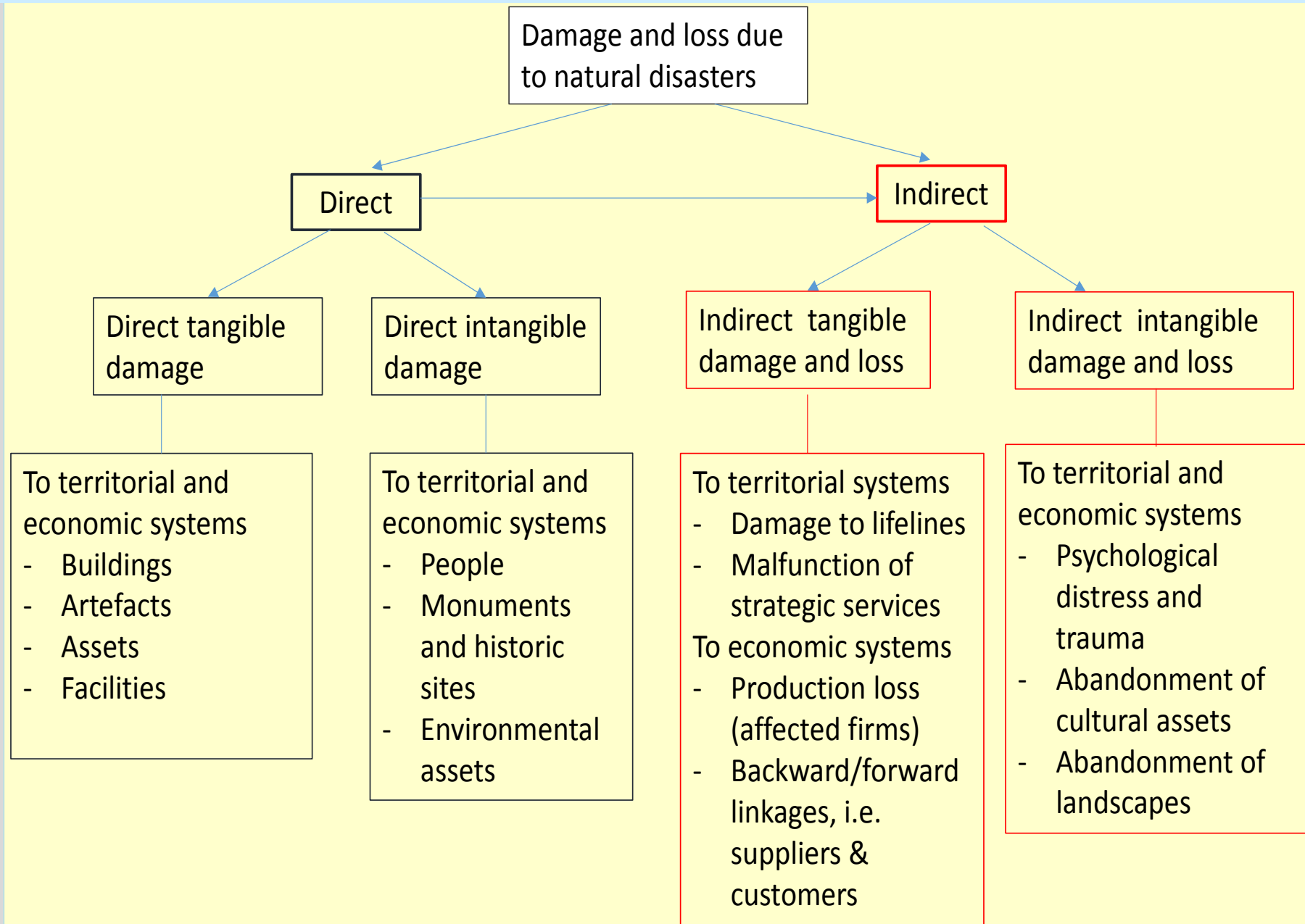


Systemic damage  
Second/  
Higher order  
damage?

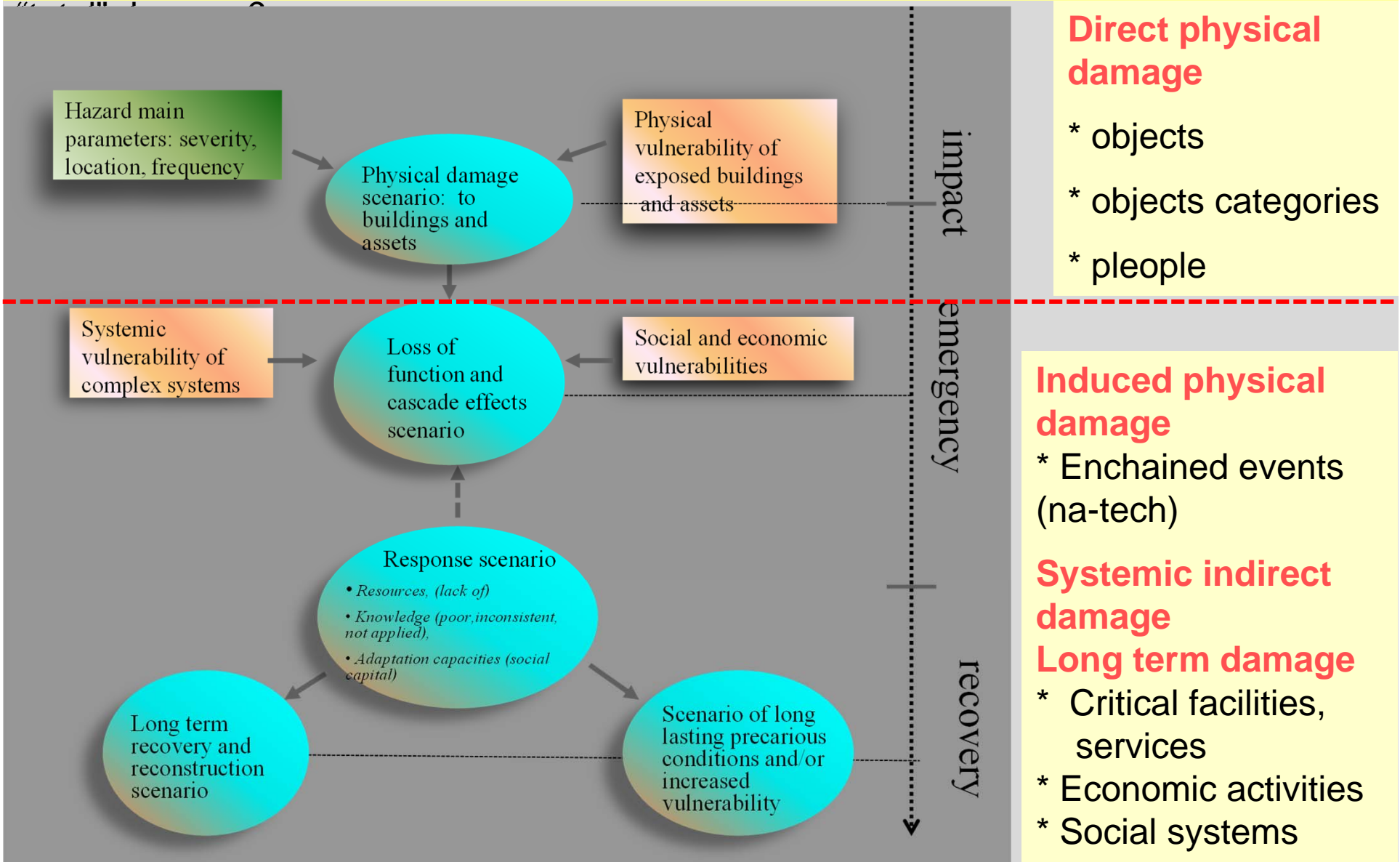
Damage in the long run

Rose, A. (2004), Economic Principles, Issues, and Research Priorities of Natural Hazard Loss Estimation, in Okuyama, Y., Chang, S. (Eds.), Modeling of Spatial Economic Impacts of Natural Hazards, Heidelberg, Springer.

# Types of damages (Disaster Science Report 2017, JRC; with Bonadonna et al.)



How the different risk components (H, V, E, R...) are responsible for the damage that has occurred ...? And how should the different damages be “summed” to get the

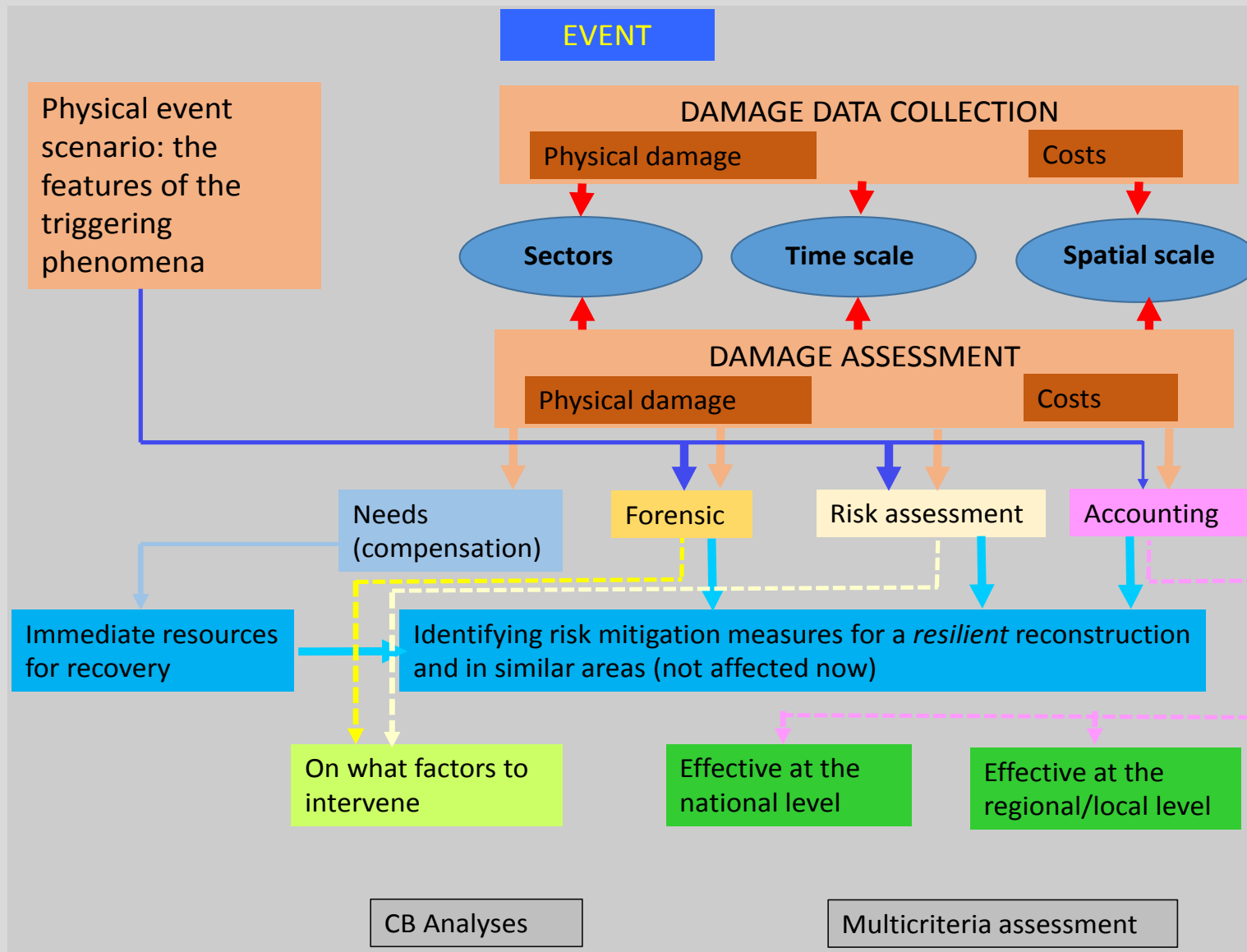


# Different types of Damages and units of measure

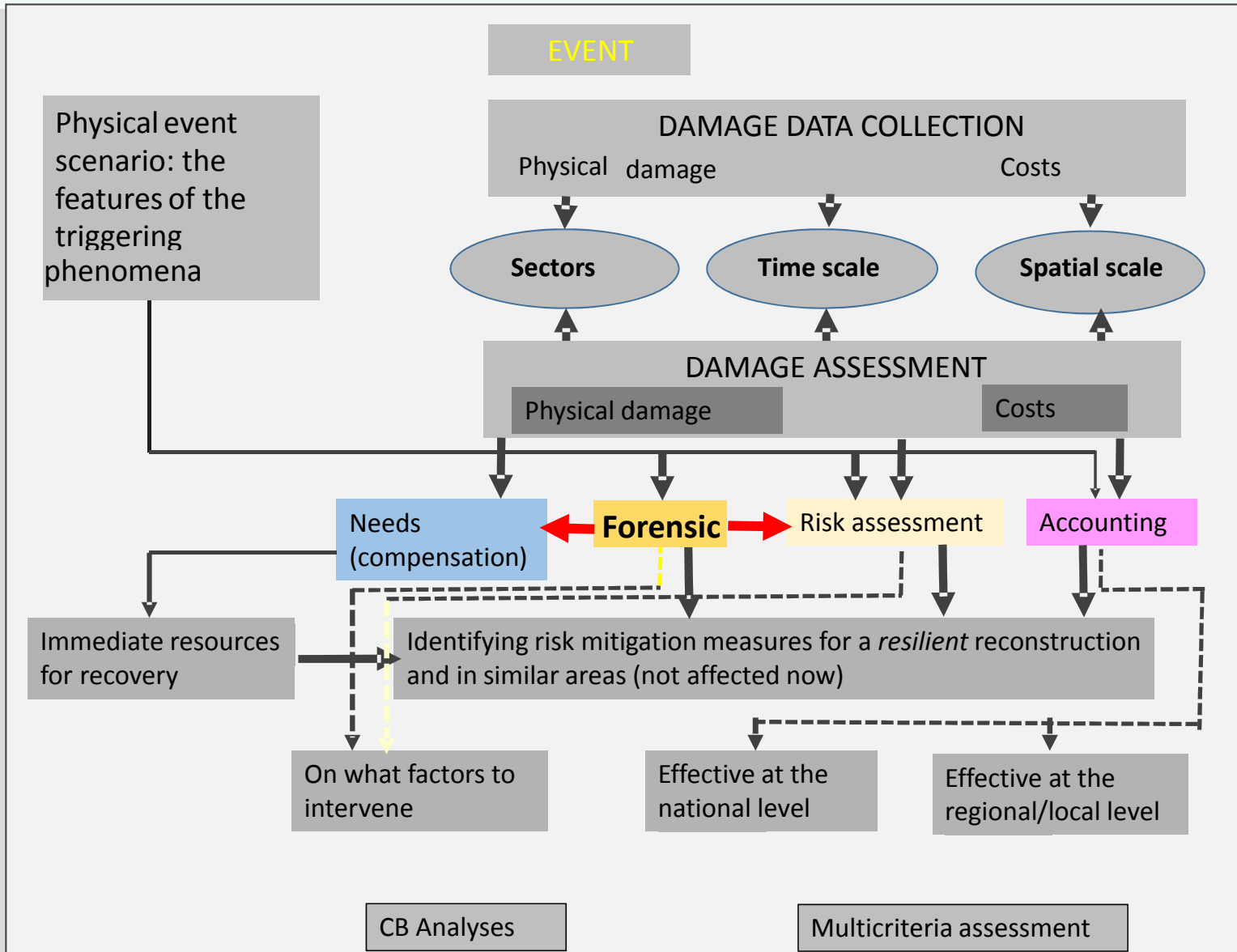
		"Target"/sector	Unit of measure
<b>Direct damage</b>	Victims	People	number
	Physical damage	Objects, assets, infrastructures	monetary
<b>Induced damage</b>	Victims	People	number
	Physical damage	Objects, assets, infrastructures	monetary
<b>Indirect damage (Second order damage)</b>	Psychological stress	People	proxy
	Systemic damage	"whole", objects, assets, infrastructures	Partially monetary
	Community disruption	People	proxy
<b>Long term damage</b>	Economic impairment	"whole", sectors areas	monetary

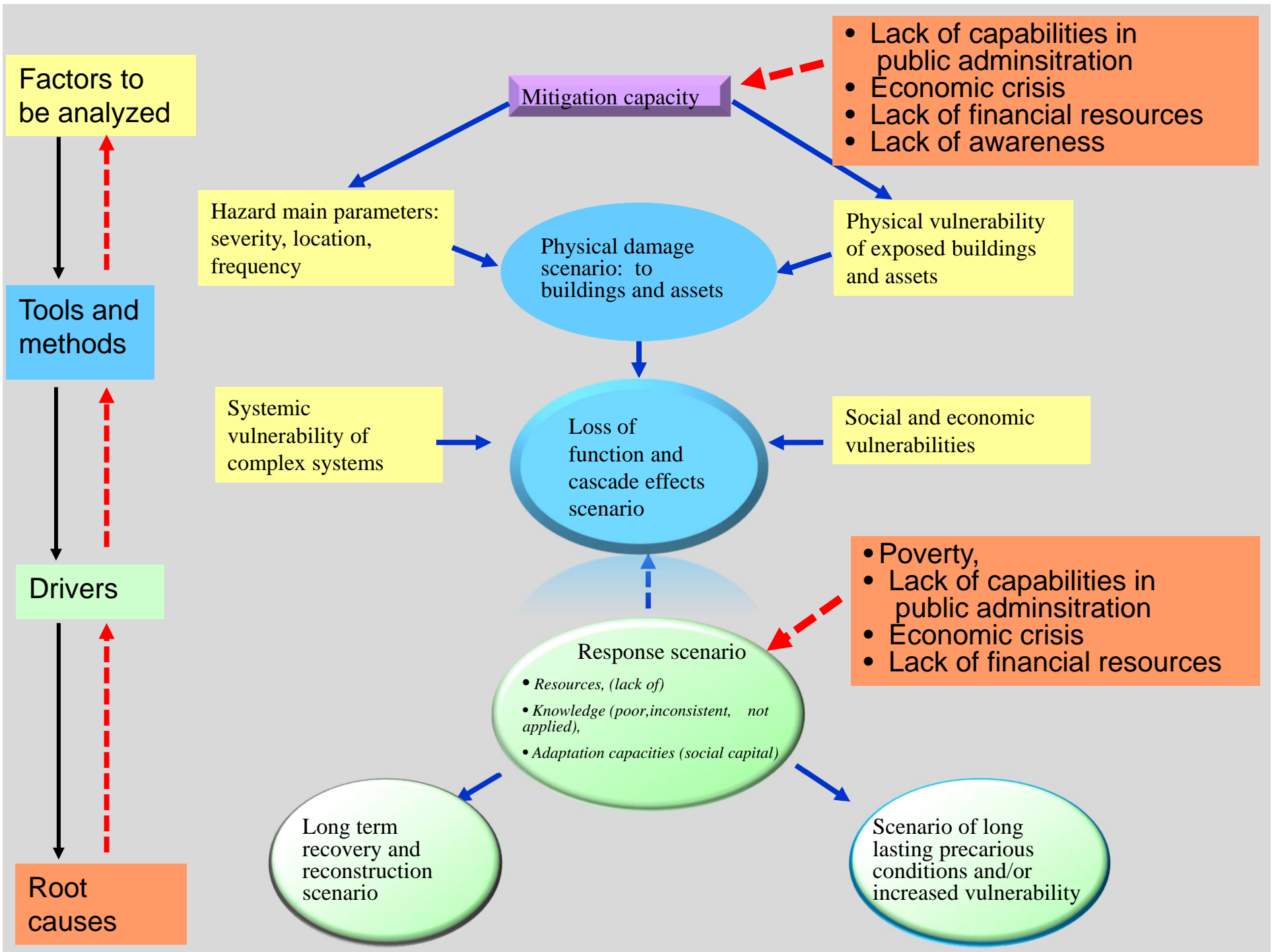


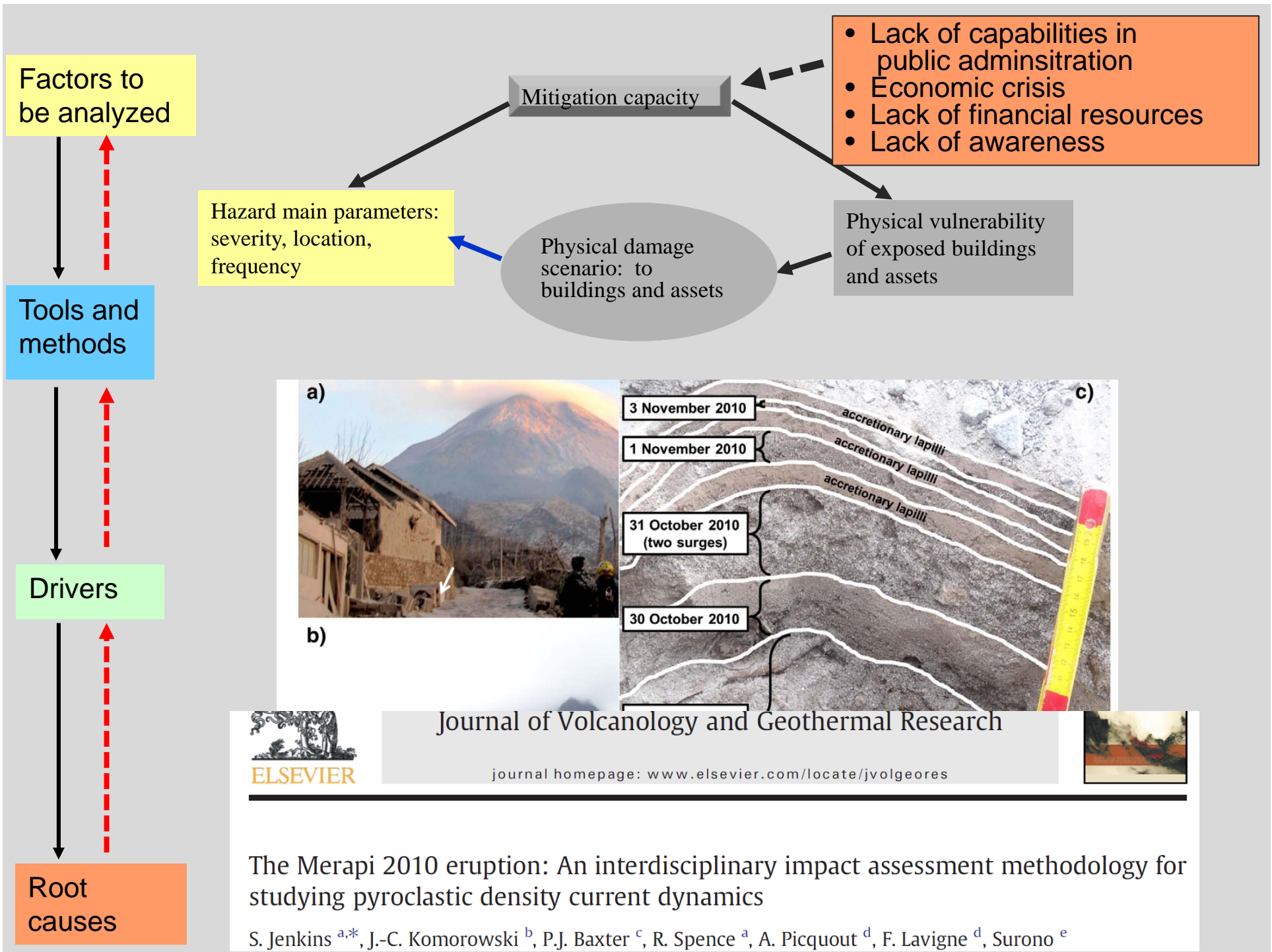
Different uses have been identified with respect to post-disaster damage data collection, including: needs (including compensation), forensic, risk assessment, accounting (De Groeve et al., 2013)

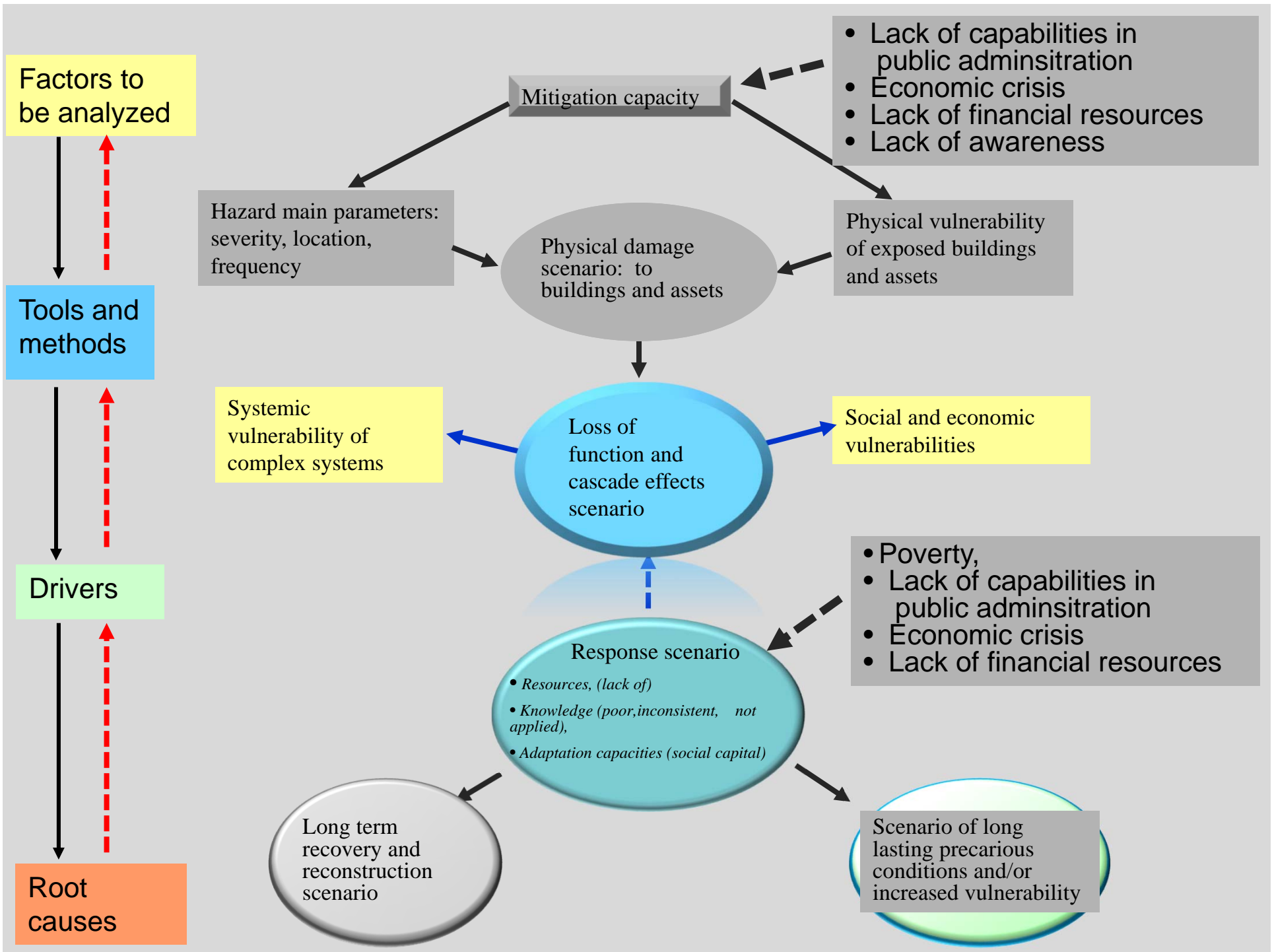


**Forensic investigation** of damage provides both information to support recovery (a more resilient recovery) and knowledge that can be translated into risk models enhancement

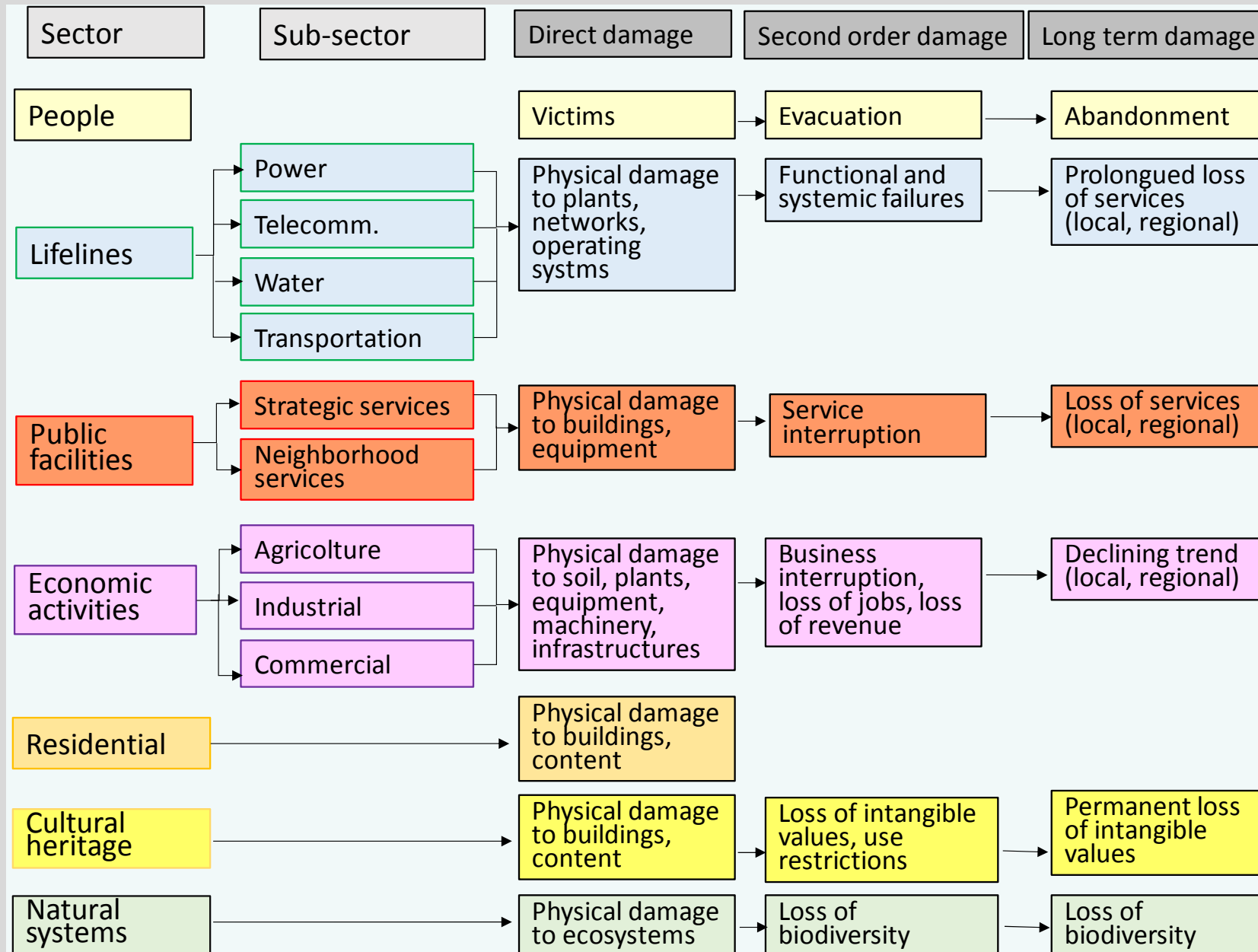


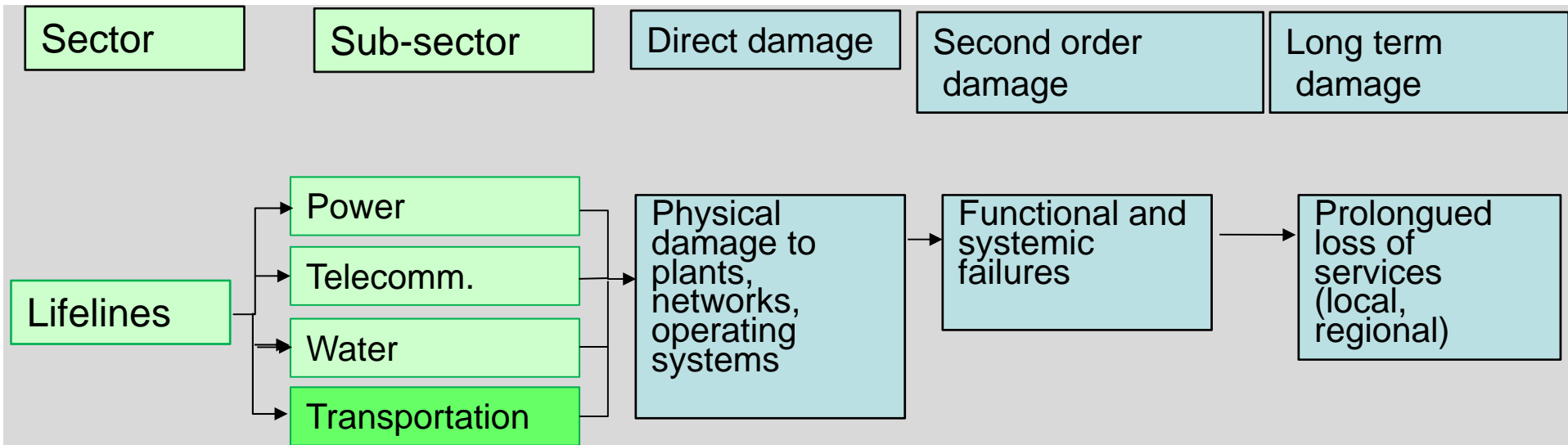






# Different sectors and sub-sectors for which damage and vulnerability assessment must be carried out





SYSTEM	PHYSICAL DAMAGE	LIFELINE FAILURE	COST REPAIR /REBUILD	SYSTEMIC FAILURE	REPAIR TIME
Transportation - roads	5.15% of paved road	road unusable no alternatives	\$1.357.126	Cha de Caldeira unaccessible	immediate temporary within 6 months (project)
	20.8% stone and dirt	road unusable (no alternatives)	\$467.138,00	agricultural land unaccessible	

From the Kobe earthquake 1995, comprehensive assessment of systemic failure and duration due to (relatively little) physical damage

SYSTEM	PHYSICAL DAMAGE	LIFELINE FAILURE	ORGANIZATIONAL PROBLEMS	SYSTEMIC FAILURE	REPAIR TIME
Gas	9%	80%	decision to shut off the system 5 hours after the quake	severe fires in some areas of the city	almost 3 months
Water	9%	almost city-wide failure	maps were lost in the collapse of the floor of the municipal building where they were stored	water invading other pipes (like gas)	3 months
Electrical	6%	city-wide failure		induced failure to pumping water stations, communication networks, traffic lights	one week
Communication	3%	25%	no priority lines or priority access system for civil protection		two weeks
Transportation - roads	8%	city-wide failure	it was impossible to leave the roads free for rescuers and technical staff		between 6 months and one year
- railway	15%				between 3 months



# Post-flood event scenario report I

Lo scenario di danno in seguito all'alluvione di Novembre 2012 nella Regione Umbria:

I risultati dell'attività di rilievo e analisi dei danni



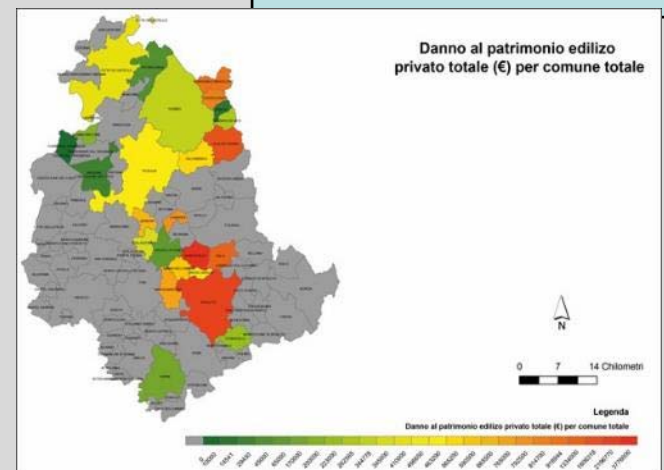
Attività condotta nell'ambito di:

Convenzione tra Politecnico di Milano e Regione Umbria inerente "lo svolgimento di studi e ricerche, formazione reciproca e sperimentazione di tecnologie innovative nel settore previsione e prevenzione rischi idrogeologico ed idraulico e in ambito di "gestione"

Lifelines

Transportation

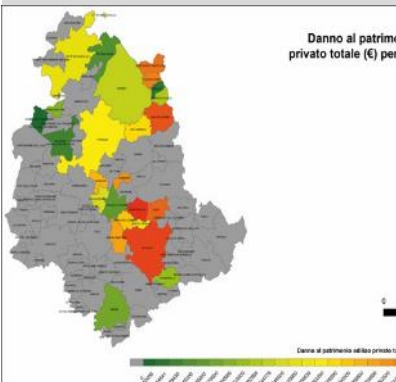
Physical damage to plants, networks, operating systems



## Forecasted costs

Sectors	Interventions to secure public and private buildings, infrastructures	Estimation of damage suffered by private	Expenses incurred by the Civil Protection for emergency management	Total
Emergency management costs (people evacuation..)			31.939,61 €	31.939,61 €
Public facilities	1.090.000,00 €			1.090.000,00 €
Lifelines	3.891.000,00 €		43.830,00 €	3.934.830,00 €
Roads	14.242.880,00 €		604.540,76 €	14.847.420,76 €
Hydraulic defence	29.677.300,00 €		238.207,92 €	29.915.507,92 €
Landslides control (buildings, lifelines)	6.196.476,30 €	290.000,00 €	66.773,80 €	6.553.250,10 €
Green areas, parks	270.000,00 €			270.000,00 €
Industry & Commercial	1.500.000,00 €	1.273.621,37 €		2.773.621,37 €
Agriculture		1.034.880,00 €		1.034.880,00 €
Residential		7.392.602,51 €	180.000,00 €	7.572.602,51 €
<b>Total</b>	<b>56.867.656,30 €</b>	<b>9.991.103,88 €</b>	<b>1.165.292,09 €</b>	<b>68.024.052,27 €</b>

## Post-flood event scenario report



Sectors	Forecasted costs			Total
	Intervention to secure public and private buildings, infrastructures	Estimation of damage suffered by private	Expenses incurred by the Civil Protection for emergency management	
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## PDNA Fogo, Capo Verde

Sector	Damage of assets	Indirect loss (flows)	Total
Civil protection (evacuation)		\$15.030,00	\$15.030,00
Agriculture	\$8.142.646,00	\$3.889.857,00	\$12.032.503,00
Tourism	\$1.456.581,00	\$571.998,00	\$2.028.579,00
Roads	\$2.066.308,00	\$1.842.265,00	\$3.908.573,00
Infrastructures	\$265.679,00	\$43.883,00	\$309.562,00
Residential	\$7.636.020,00		\$7.636.020,00

<i>Critical infrastructures</i>	Factors that make critical infrastructures stop functioning	gas, water, electricity, telecom	existence and redundancy	more than 1/ 1/ 0	
			functional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	
			dependency from other systems	dependent/autonomous	
		accessibility from damaged areas	to strategic facilities	more than 1 access/1 access/0 access	
			physical vulnerability of access ways	vulnerable/not vulnerable	
			condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt)	
		internal accessibility	in residential areas	more than 1 access/1 access/0 access	
			physical vulnerability of access ways	vulnerable/not vulnerable	
			condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt)	
		external accessibility	heliports	existent/non existent	accessibility from settlements (as accessibility to strategic facilities)
				physical vulnerability (as roads position parameter)	gathering zones close
				existent/non existent	accessibility from settlements (as accessibility to strategic facilities)
ports	physical vulnerability (as roads position parameter)		gathering zones closes		

Lifelines



Transportation

Residential

Physical damage to buildings, content

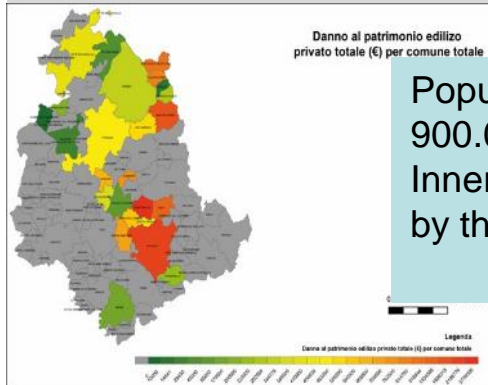
Table 2.17: Damage and Losses in Housing, Chã das Caldeiras

268 housing units

Components	Damages (private)		Losses (public)	
	CVE	US\$	CVE	US\$
Houses totally destroyed	693,800,000	7,015,167	0.0	0.0
Houses partially destroyed	46,000,000	465,116	0.0	0.0
Household furniture and other personal assets	15,402,380	155,737	0.0	0.0
Temporary shelters and rental schema (January–April 2015)	0.0	0.0	1,486,500	15,030
<b>TOTAL</b>	<b>755,202,380</b>	<b>7,636,020</b>	<b>1,486,500</b>	<b>15,030</b>

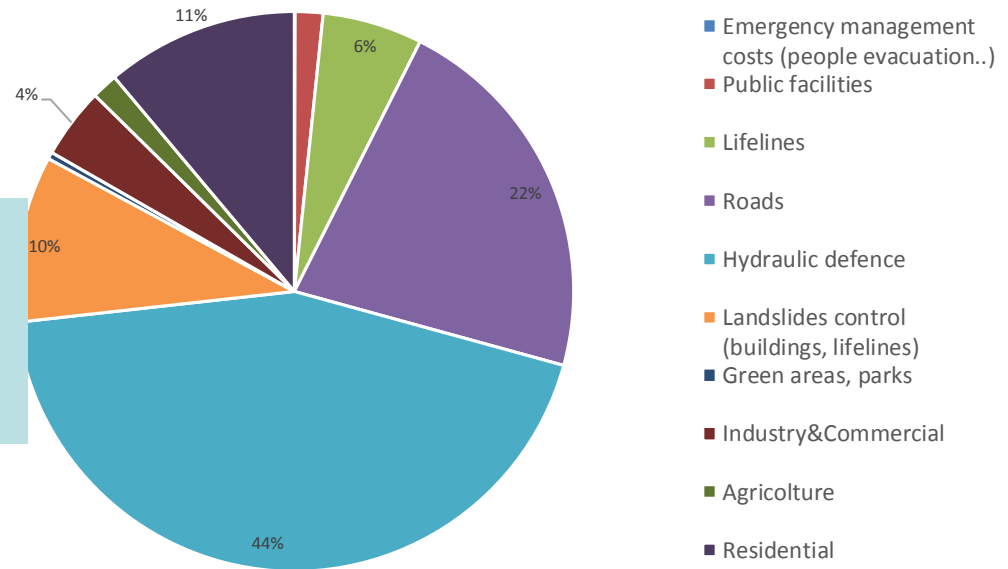
Sectors	Forecasted costs			Total
	Intervention to secure public and private buildings, infrastructures	Estimation of damage suffered by private	Expenses incurred by the Civil Protection for emergency management	
Emergency costs			31.939,61 €	31.939,61 €
Residential (170 houses)		7.392.602,51 €	180.000,00 €	7.572.602,51 €
<b>Total</b>	0,00 €	7.392.602,51 €	211.939,61 €	7.604.542,12 €

## Post-flood event scenario report



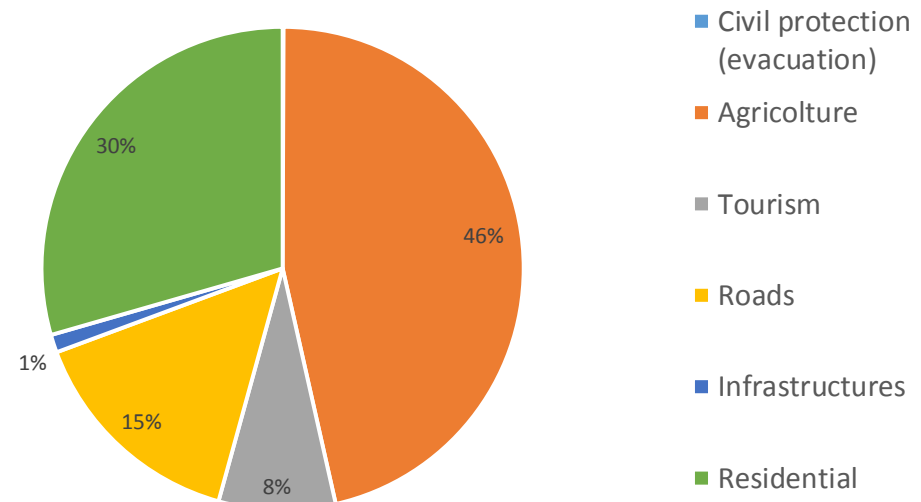
Population: around 900.000 (2011)  
Inner area as defined by the EU Commission

Damage to sectors 2013 flood Umbria

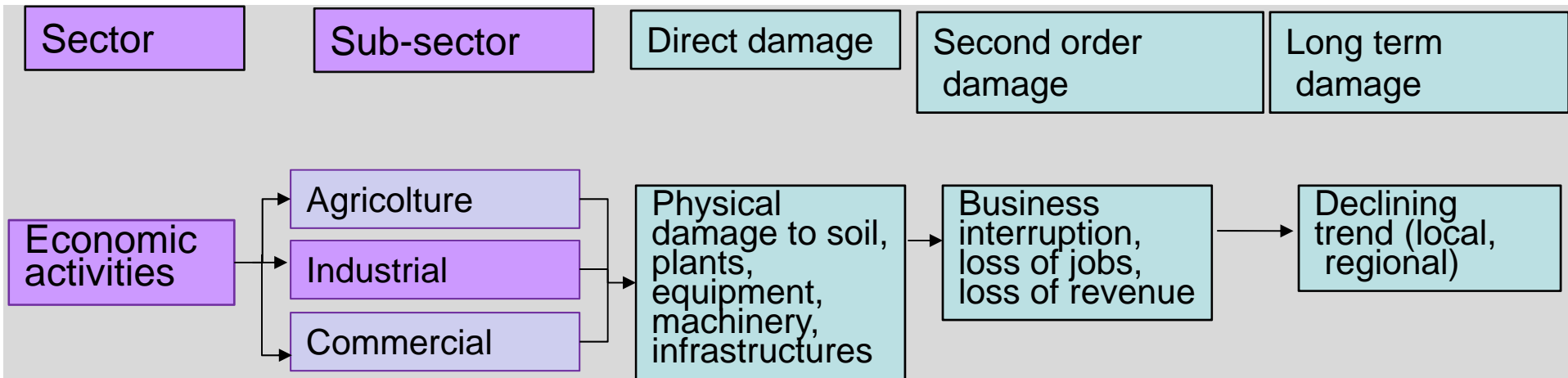


Population: around 55.000 people (2000)  
Developing country  
Poor population

Damage and losses according to the Fogo PDNA

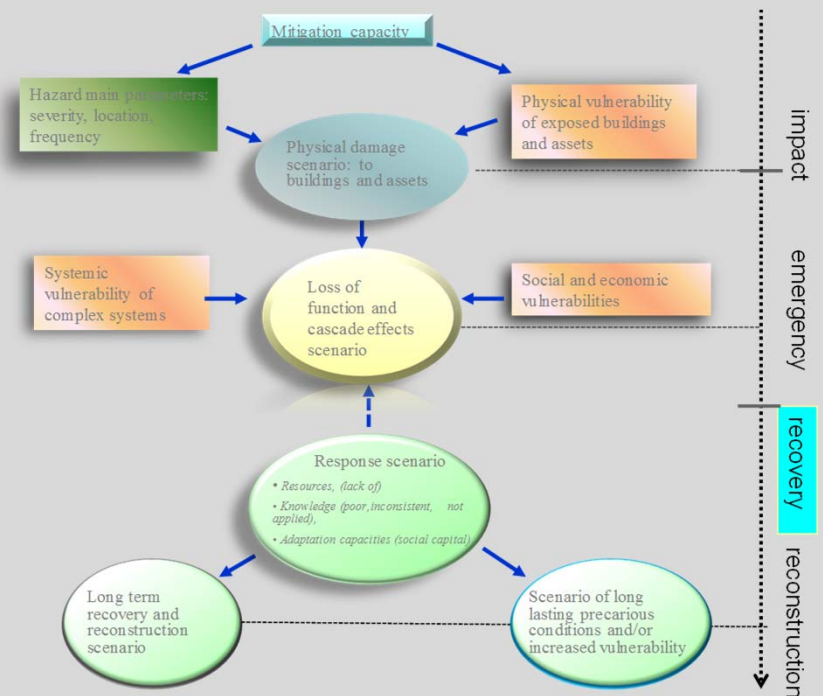


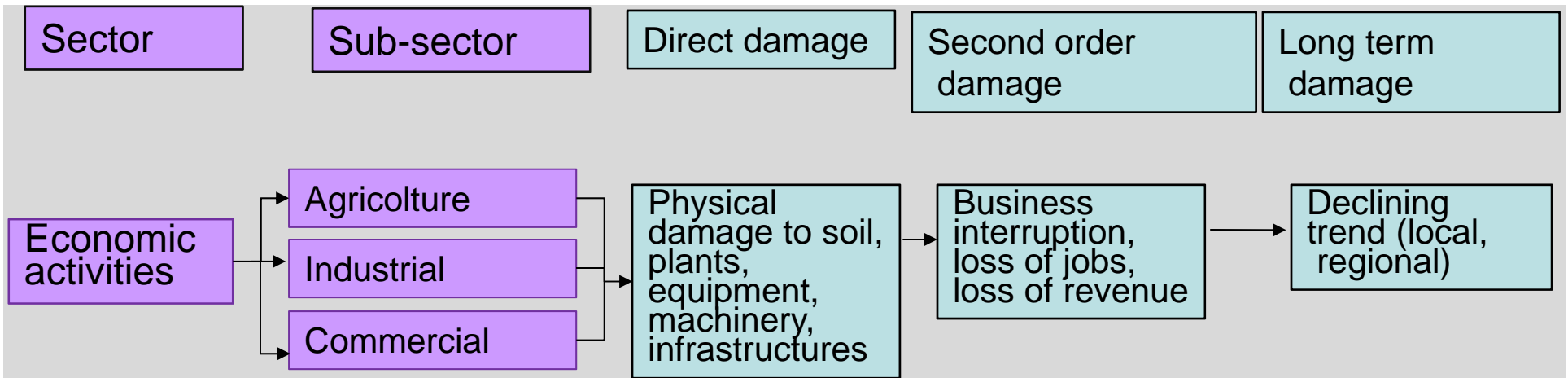
PDNA Fogo, Capo Verde



Sector	Damage of assets	Indirect loss (flows)	Total
Tourism	\$1.456.581,00	\$571.998,00	\$2.028.579,00

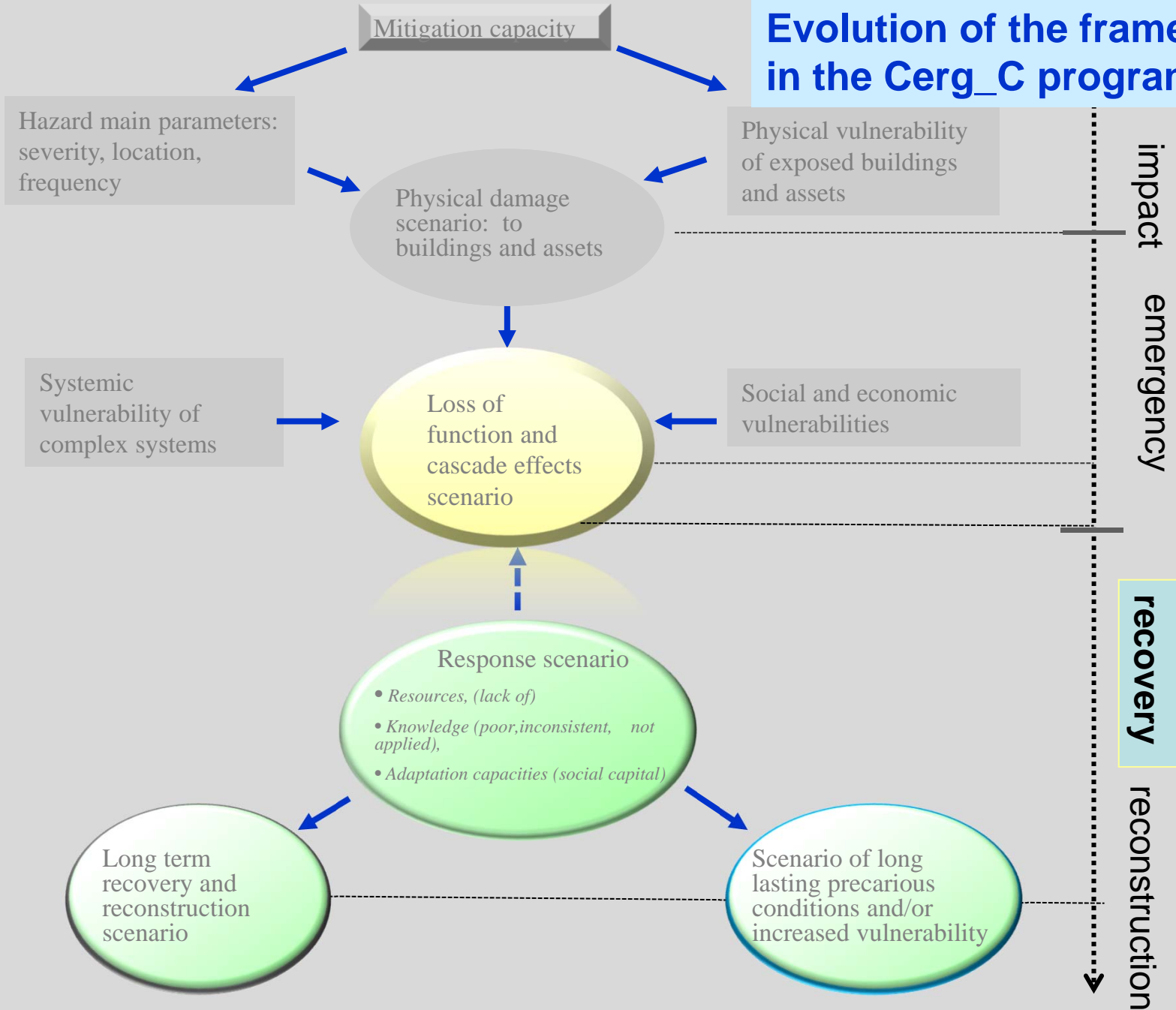
Request: to have guidelines and guidance on when and how to deal with the tourist areas of the Cha de Caldera in order to provide clues about when and at what conditions tourist activities could be resumed (interesting guidance not a « all clear» signal)





System	Component	Aspect	Aspect Parameters	Criteria for assessment	Parameters values and/or categories
Infrastructure and production sites	Production sites	Availability of tools to recover production sites rapidly and at low costs	Temporary transferability of production in case of need	binary	applicable/not applicable
			Existence of funds for fast repairs	binary	yes/no
			Existence of inspection and guiding personnel for correct repairs	binary	yes/no/forecasted in the recovery plans
			Economic sectors	Diversified or concentrated on few sectors	Few/many different economic sectors in the area

# Evolution of the framework in the Cerg\_C program





## Some conclusions...and way ahead (proposed)

1. There are many aspects in which **cross-studies among different disasters triggered by different hazards** can be very useful and provide evidence base that would be difficult to obtain with respect to one type of hazard related events only
2. To some extent the **expected damage** (physical; second order) **can be forecasted given the characteristics of the exposed assets and the type of exposed communities** and territory given some vulnerability components
3. There are different types of decisions that must be taken at different stages of the disaster, **recovery** is increasingly recognised as a crucial moment for a resilient full recovery/reconstruction
4. Damage is «provoked» or is the consequence of not only exposure, hazard, vulnerabilities, but also of **decisions and actions taken in the response phase, both during the emergency and the recovery phases**