Shelter

Sustainable Historic Environments hoListic reconstruction through Technological Enhancement & community-based Resilience

D.2.2. HA Systemic resilience assessment and monitoring framework

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SHELTER - Sustainable Historic Environments hoListic reconstruction through Technological Enhancement & community-based Resilience

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0.3	01/09/2020	TEC, UNIBO, EHU, IHED, CRCM	Advanced draft
0.5	19/10/2020	TEC	Final version included the feedback from OL

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Glossary

Acronym	Full name
C3S	Copernicus Climate Change Service
CA	Consortium Agreement
CCA	Climate Change Adaptation
CH	Cultural Heritage
CHM	Cultural Heritage Management
CNH	Cultural and Natural Heritage
CST	Climate Suitability for Tourism
DRR	Disaster Risk Reduction
DRM	Disaster Risk Management
DoA	Description of Action
EEA	European Environment Agency
EC	European Commission
ECV	Essential Climate Variables
EFAS	European Floods Awareness System
EFFIS	European Forest Fire Information System
FWI	Fire Weather Index
GCOS	Global Climate Observing System
HA	Historic Areas
HW	Heat Waves
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LST	Land Surface Temperature
LSWT	Lake Surface Water Temperature
MTMSI	Mountain Tourism Meteorology and Snow Indicators
NDVI	Normalized Difference Vegetation Index

NBS	Nature-based Solutions
OL	Open Labs
PDSI	Palmer Drought Severity Index
PGA	Peak Ground Acceleration
RH	Relative Humidity
SES	Socio-Ecological System
SIS	Sectoral Information System
SWI	Soil Water Index
UHI	Urban Heat Island
WMO	World Meteorological Organization
WOS	Web of Science
WP	Work Package

1 Executive summary

The identification of metrics for measuring the resilience of Historic Areas (HA) remains a challenge due to the heterogeneity of historic environments in terms of scale, heritage type, multi-hazard scenarios and diverse social-cultural contexts, interests, circumstances and expectations. SHELTER aims to link physical vulnerability and risk management concepts and approaches, following the latest approaches of the Intergovernmental Panel on Climate Change (IPCC), with a more general and multidimensional resilience approach focused on the singularities of the resilience in HA. This report establishes a coherent and manageable indicator framework for the quantification of a multidimensional, cross-scale and systemic resilience.

The framework has been established taking advantage of the results of the first stage of the SHELTER, that allowed to identify and adapt already existing indicators frameworks and models and to provide an integrated approach. The review of literature has provided a long list of indicators covering all the considered hazards (heat waves, earthquakes, floods, subsidence and wildfires) but also indicators to measure a more generalised resilience (including indicators to measure the coping, adaptive and transformative capacities of a community). The identification of the measuring objectives together with the RACER methodology allowed to reduce (and complete) the list to a shortlist that will ultimately represent the replicable SHELTER Resilience Indicators including the SHELTER monitoring indicators (i.e., indicators that can measure the strategies, tools and solutions developed by SHELTER). From these two lists, the Open labs (OL) have prioritised to build their own tailored monitoring strategies.

The overall indicator system will serve as a starting point for further discussion and work in WP2, WP3, WP4 and WP5. But especially, this list of indicators aims to be the basis for the risk assessment methodology and Resilience Index to be developed in T2.5 (Specific hazard risk assessment) and T2.7 (Systemic resilience assessment methodology). Developed as an initial base, it is expected that the framework of indicators will evolve with the results of other tasks and the implementation of monitoring strategy in WP7.

2 Introduction

2.1 Aims and objectives

The identification of metrics for measuring resilience remains still a challenge [1], especially for Historic Areas, since the existing frameworks for resilience and vulnerability assessment do not yet consider fully the specificity of the Cultural and Natural Heritage (CNH) assets [2]. A robust, flexible and replicable resilience capacity measurement framework for HA has to be suitable for different scales, different CNH hazards and different potential multi-hazards scenarios but also it has to consider the diverse social-cultural contexts, interests, circumstances and expectations [3]. SHELTER aims to link physical vulnerability and risk management concepts and approaches, following the latest approaches of the Intergovernmental Panel on Climate Change (IPCC), with a more general and multidimensional resilience approach focused on the singularities of the resilience in HA.

The first step for building this framework is to establish a set of indicators that will contribute to quantify the performance of the system as a whole regarding its preparedness and the ability to absorb disturbances, to efficiently respond, and adapt to (and be transformed by) new conditions. Deliverable 2.1[1] established the conceptual basis for the resilience improvement of HA. This report addresses the next logical step: the quantification of the multidimensional, cross-scale and systemic resilience through a coherent and manageable indicator framework.

The set of indicators aims to set the base for a knowledge generation methodology that will allow measuring the singularity of CH physical vulnerability against single and multi-risk contexts and framed in a broader concept of multidimensional HA resilience. This comprehensive indicator system supports the identification of the key indicators for each Open Lab establishing the baseline and monitoring strategy for case studies and measuring the success of adequate Climate Change Adaptation (CCA) and Disaster Risk Management (DRM) policies and strategies (including the ones proposed by SHELTER).

The indicator system has been developed in collaboration with stakeholders to support the development of action plans for enhancing resilience. The feedback from the Open Labs (OLs) has shown us that there is a necessity to make the indicators as clear as possible. *"Indicators may mislead decision-making if practical considerations of cost, data availability, and measurability are prioritized over validity"* [4]. Therefore, a factsheet for each selected indicator has been developed including:

- **Description of the indicator:** name of the indicator, phase of DRM, hazard, objective, type, scale, definition, focus/objectives and CH singularity
- **Data and measurement**: required data, complexity level, input type (qualitative, quantitative, …), data source, frequency (how often to use this indicator?), measurement unit, required tool, calculation method, output type and examples

[1] SHELTER deliverable "D1.2: Building of best/next practices observatory"

- **Links and references:** keywords and references

2.2 Relations with other activities in the project

SHELTER project has been structured in 8 Work Packages (WP) to ensure cross-fertilization among the different steps and partners. The main objective of WP2 (Knowledge generation: Systemic HA resilience assessment and monitoring) is to produce a knowledge generation methodology to build multidimensional, cross-scale and systemic resilience assessment and monitoring workflows that will provide information in all the phases of Disaster Risk Management (DRM) (see **¡Error! No se encuentra el origen de la referencia.**):

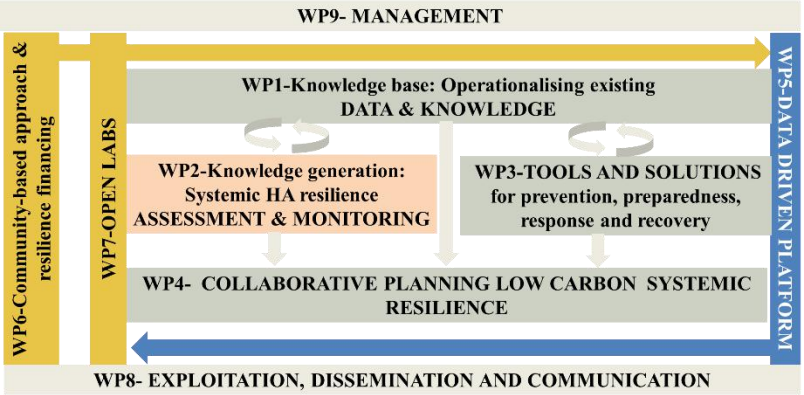

Figure 1: PERT chart of SHELTER

Within WP2, the work developed in Task 2.1 (Conceptual design, architecture and workflow of SHELTER framework operative knowledge) established the base of the resilience assessment and the architecture of the framework. Task 2.1 frames all the development of WP2, especially of Task 2.2. Here, the indicators for resilience assessment and monitoring have been developed.

Task 2.2 has a strong relation with all the WPs in SHELTER project. The main relationships are the following:

- **WP1** (Knowledge base: operationalising existing data and knowledge) is generating the knowledge base through operationalizing existing data, information and (local) knowledge available and usable. T2.2 will help to define the role of the information and knowledge management defined in T1.3 (Data Lake) and T1.4 (Multiscale Multisource data model). Moreover, the literature review carried out in this task will feed T1.2 (Codification of existing knowledge).
- **WP3** (Tools and solutions for prevention, preparedness, response and recovery) seeks to characterize and develop cost-effective low carbon technological solutions for prevention, preparedness, response and recovery through building back better (BBB) and integrate them in a dynamic portfolio to be used for the data-driven platform in Strategic DSS. Solutions are also aimed at reducing risk (T2.5) and improving the resilience of historic areas and assets (T2.7), and CH characterization (T2.3) is used to analyse the suitability of the solutions.

- **WP4** (Collaborative planning for building low carbon systemic resilience) aims at integrating cultural heritage into planning policies and tools, linking DRM, CCA and heritage site management, making use of the Resilience ID incremental strategy. To do so, establishing the baseline and monitoring strategy for each Open Lab in T2.2 will support the definition of the state of the art for measuring the success of adequate CCA and DRM policies and strategies, and their integration with spatial planning strategies.
- **WP5** (Data-Driven Platform): the indicators developed in the hereby described task will support the diagnosis, decision making and monitoring methodologies that will be supported in the platform.
- **WP6** (Community-based approach and resilience financing) will establish the framework for the community approach and resilience financing to be implemented in the Open Labs. The first task of WP (T6.1) identified the user requirements from a GLOCAL perspective, one of them was "Resilience indicator assessment to map CH correctly due to vulnerability and resilience. More specifically, T6.6 will generate a methodology for the assessment of CH losses. This task will benefit from the definition of indicators regarding loss and damages in the recovery phase.
- In **WP7,** Open Labs are functioning as knowledge generator and evaluation frameworks, demonstration sites, long-term thinking transition labs and learning environments. Task 2.2 has worked closely with OL to define a tailored strategy for resilience assessment and monitoring.

2.3 Report structure

The document is structured as follows:

- **Section 2** establishes the purpose of the deliverable and the links with other work packages and tasks of SHELTER project
- **Section 3** describes the methodology followed to develop the indicators
- **Section 4** describes the state of the art regarding the hazard dependant indicators
- **Section 5** describes the state of the art regarding the non-hazard dependant indicators
- **Section 6** describes the inclusion of Sendai framework
- **Section 7** describes the final list of indicators
- **Section 8** describes the integration of collaborative early warning systems
- **Section 9** describes the tailored monitoring strategy for each Open Labs
- **Section 10** concludes and describe future work

2.4 Contribution of partners

The following table (Table 1) details the contribution of each partner:

Partner	Contribution
TEC	Responsible for the coordination of the task and deliverable. Responsible for definition of the methodology. Drafting of Section 1, 2, 3, 5, 6 and 8. Responsible for sections and indicators related to Wildfire and Floods. Responsible for 4.2.2. Contributions and evaluation of the longlist and shortlist of indicators and corresponding factsheets.
UNIBO	Responsible for sections and indicators related to Earthquakes and Subsidence. Contributions and evaluation of the longlist and shortlist of indicators and corresponding factsheets.
UPV/EHU	Responsible for sections and indicators related to Heat waves. Contributions and evaluation of the longlist and shortlist of indicators and corresponding factsheets.
IHED	Contributions and evaluation of the longlist and shortlist of indicators and corresponding factsheets. Coordination with Open Labs.
CRCM	Responsible for sections and indicators related to Storms. Contributions and evaluation of the longlist and shortlist of indicators and corresponding factsheets.

Table 1: Contribution of partners

3 Methodology

The development of the framework for the indicators has followed a logical sequence. It has been established taking advantage of the results of the first stage of the SHELTER: the conceptual base defined in D2.1[2] and the knowledge base developed in D1.1[3] and D1.2[4]. This coordination has allowed using already existing indicators frameworks and models to provide an integrated approach. The review of literature has provided a long list of indicators covering all the considered hazards (heat waves, earthquakes, floods, subsidence and wildfires) but also indicators to measure a more generalised resilience (including indicators to measure the coping, adaptive and transformative capacities of a community). This list had 433 indicators. The identification of the measuring objectives for the indicators together with the RACER methodology allowed to reduce (and complete) the list to a shortlist of 261 indicators that will ultimately represent the replicable SHELTER Resilience Indicators, including the SHELTER monitoring indicators (i.e., indicators that can measure the strategies, tools and solutions developed by SHELTER). From these two lists, Open Labs (OL) have prioritised to build their own tailored monitoring strategies.

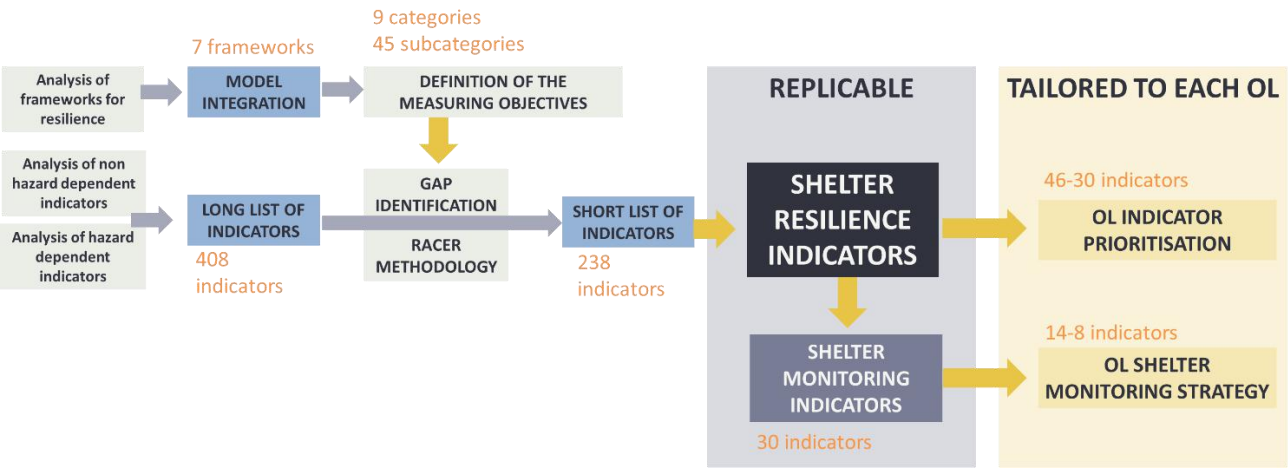

Figure 2: Overview of the methodology and the number of indicators in each step

The steps of the methodology are the following:

1. Model integration to develop SHELTER framework
2. Development of the long list of indicators
3. Development of the shortlist of indicators: Shelter Resilience indicators
4. Prioritisation from OL

[2] SHELTER deliverable "D2.1: HA Resilience structure". Available in https://shelter-project.com/documents/scientific-publications-and-deliverables/
[3] SHELTER deliverable "D1.1: Data sources and Knowledge".
[4] SHELTER deliverable "D1.2: Building of best/next practices observatory".

5. Development of SHELTER monitoring indicators and the co-monitoring strategy for each OL

3.1 Model integration, SHELTER framework and identification of the objectives of the indicators

A useful framework for SHELTER should be compliant with the requirements identified in the early stage of the project[5]:

- The framework should include both general and specified resilience. Specified resilience or hazard-dependant resilience is when the socio-ecological system is addressing problems arising from particular hazards affecting specific components and generalised resilience or non-hazard dependant resilience is when resilience to all kinds of shocks and disturbances (including unknown ones) want to be addressed [5]. In order to keep the focus in both perspectives, a first hypothesis was proposed in the model integration regarding the elements that were considered in both categories. It can be seen in Table 3 the categories that have been considered hazard-dependent (highlighted in light yellow) and the ones that have been considered to be not hazard-dependent (highlighted in orange).
- The framework has to be cross-scalar, applying from artefact/building scale to urban or transregional HA.
- Consider the multidimensionality of resilience (physical, social, economic, institutional and cultural)
- Acknowledge resilience, vulnerability and adaptive capacity as nested concepts

In that stage, it was reviewed also different frameworks for resilience trying to operationalise resilience and identify their useful outputs for the project[6]. Based on that work, in this task, the most promising models were selected, and their elements compared in order to build the framework for SHELTER indicators. In Table 2 the identified frameworks are described:

MODEL	DESCRIPTION
SPRC	Source-Pathway-Receptor-Consequence (S-P-R-C) is a "*simple conceptual model for representing systems and processes that lead to a particular consequence*". The idea is that a hazard does not have to automatically have a harmful outcome, as the consequences depend on the exposure and vulnerability of the receptor [6]
SPRC EXT.	In the work of Rumson et al. the SPRC model is extended with a broader notion of resilience that includes risk-reducing measures and the recovery phase [7]

[5] SHELTER deliverable "D2.1: HA Resilience structure". Available in https://shelter-project.com/documents/scientific-publications-and-deliverables/
[6] Ibid 5

IPCC/ SREX	This model is the result of the common work of the Working Group I (The Physical Science Basis) and Working Group II (Impacts, Adaptation and Vulnerability) of IPCC. The "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)" focuses on "*the relationship between climate change and extreme weather and climate events, the impacts of such events, and the strategies to manage the associated risks*", framing the challenge of decision making under uncertainty in the context of DRM. [8]
DPSIR	The Driver-Pressure-State-Impact-Response (DPSIR) framework is a tool developed by the Organization of Economic Cooperation and Development and the European Environment Agency [9] According to this model "*there is a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritisation, target setting, indicators)*" [10]
DRIB	The DRIB Index aims to provide a tool to support the assessment of different levels of exposure, vulnerability and risk. Although originally focused in Brasil, the interest of this model lays in its comprehensive conception of risk. Based on the structure of the World Risk Index framework and conceptually linked to vulnerability assessment holistic frameworks to understand response capabilities. The model aims to measure four major components exposure to natural hazards; susceptibility of the exposed communities; coping capacities and adaptive capacities [11]
PAR	Natural hazards are in one of the sides of the Pressure and Release (PAR) Model and apply pressure to vulnerable people and resources. But, on the other side the root causes, dynamic pressures, and unsafe conditions also put pressure [12]
EEA	This model aims to support cities towards their adaptation and transformation into attractive, climate-resilient and sustainable places [13]

Table 2: Resilience frameworks

In D2.1 four assessment quadrants were identified depending on the scale and the certainty regarding the hazard (see Figure 3

- QA- specific hazards and object/building scale
- QB- specific hazards and urban/territorial scale
- QC- non-specific hazards and object/building scale
- QD- non-specific hazards and urban/territorial scale

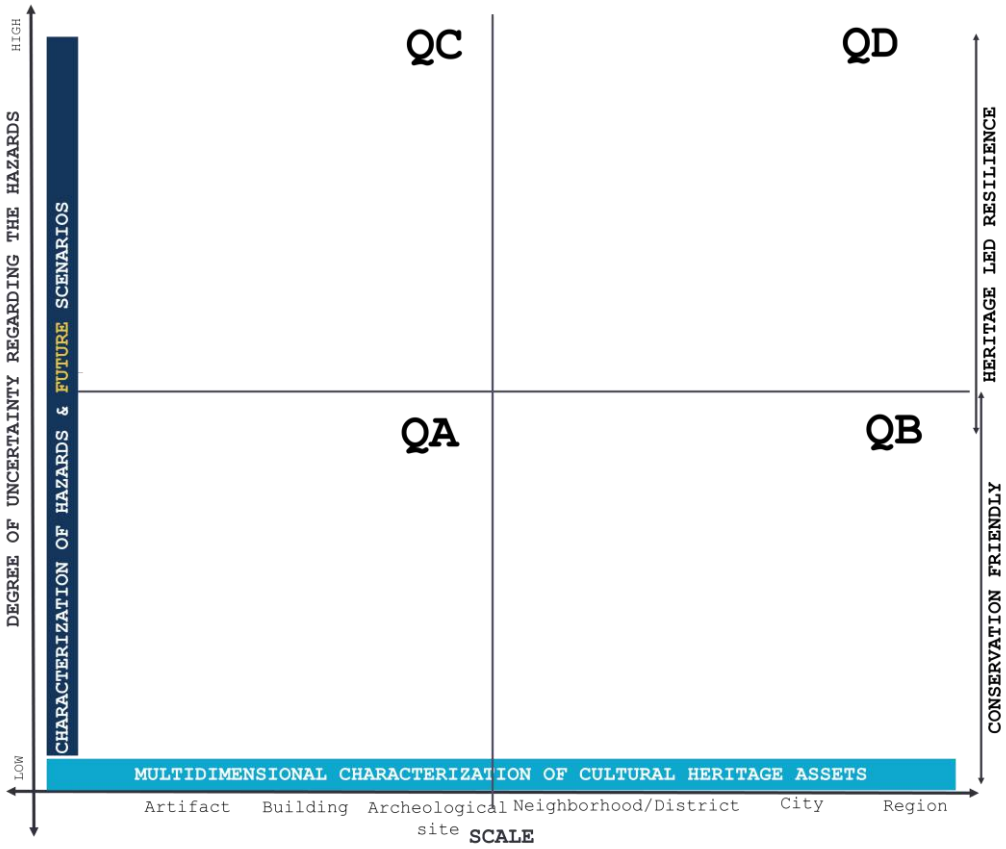

Figure 3: Frame for assessment strategy in SHELTER (Source D2.1)

The literature showed that the QC quadrant was marginal, and SHELTER will not considerate it. In quadrant **QA**, the approach is the one used by IPCC considering risk as a function of exposure, vulnerability and hazards [3] as it can be seen in the following figure (see Figure 4):

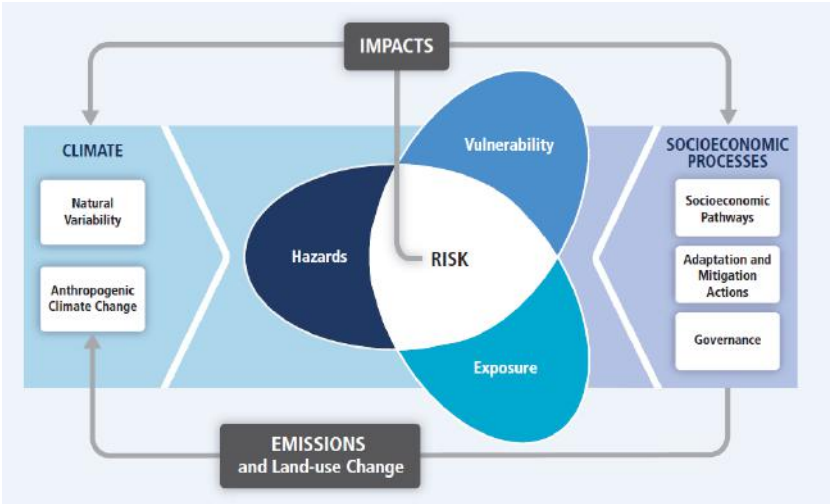

Figure 4 Illustration of the core concepts of the WGII AR5 [3]

The **quadrant QD** is where the generalised strategy is addressed in its full multidimensional nature. The following figure describes the whole strategy (see Figure 5):

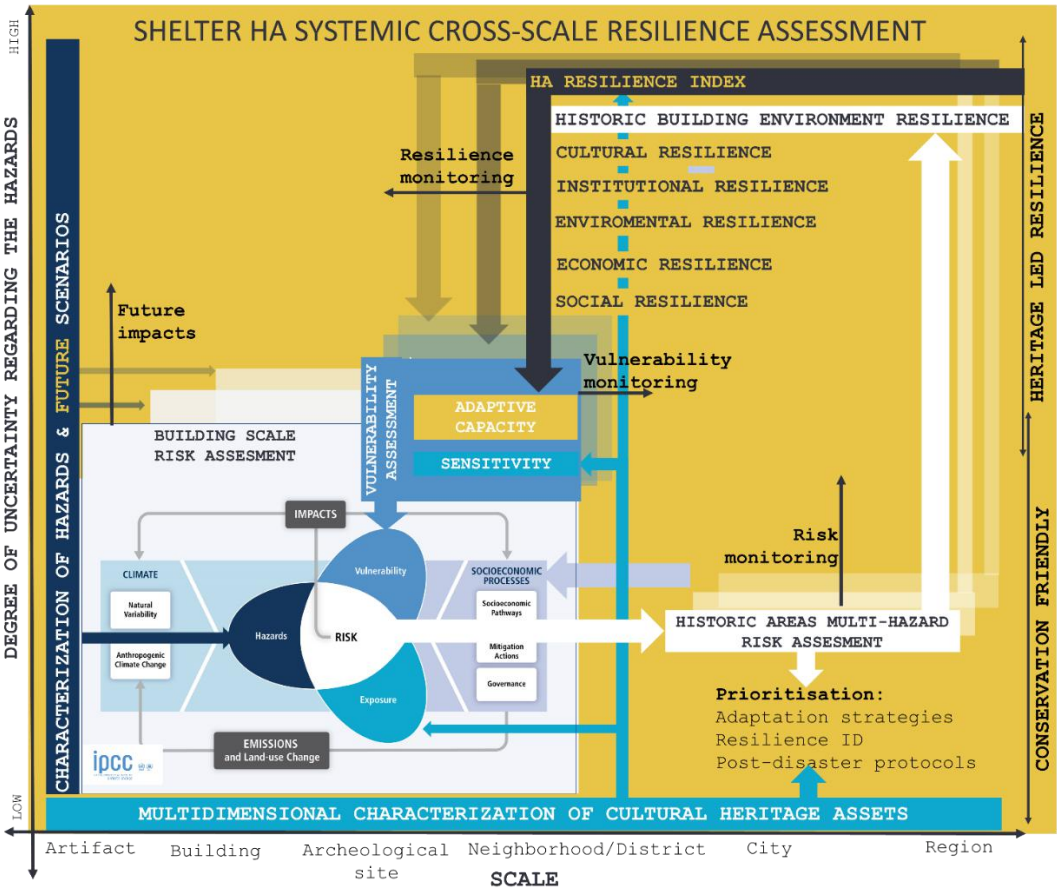

Figure 5: SHELTER resilience assessment strategy[7]

In this structure, the time scale is represented in the Z axis and considers future impacts and resilience and risk monitoring.

Considering these insights provided by the first phase of the research, the integrated framework has to consider elements as:

- Risk as a function of exposure, vulnerability and hazards
- Vulnerability is a function of sensitivity, coping capacity, adaptative capacity and transformative capacity. In the case of HA, this transformative capacity can be translated by the inherent resilience of HA to historically use the disruption to transform their systems.
- The inclusion of the possible measure that can improve resilience is necessary in order to build decision support systems.

Table 3 shows the result of this model integration that includes the following elements:

- HAZARD or SOURCE including:
  - frequency
  - magnitude
  - duration

[7] Ibid 5

- EXPOSURE or PATHWAY including:
  - individuals
  - community
  - processes
  - activities
  - object/
  - buildings/infrastructure
  - ecosystems
- SENSITIVITY including:
  - social/demography characteristics
  - economic characteristics
  - Building/infrastructure
  - environmental sensitivity
- COPING CAPACITY including:
  - awareness/information
  - networks/solidarity/Community preparedness
  - insurance/
  - funds
  - DRM
  - social memory
  - shelter capacity
  - protection of natural resources
  - adaptative capacity
  - human capital/education
  - social capital/learning
  - economic capital
  - institutional capital/
  - governance
  - cultural capital/identity
  - built capital/infrastructure
  - natural capital
- ADAPTATIVE CAPACITY including:
  - human capital/education
  - social capital/learning
  - economic capital
  - institutional capital/
  - governance
  - cultural capital/identity
  - built capital/infrastructure
  - natural capital
- TRANSFORMATIVE CAPACITY (INHERENT RESILIENCE of HA) including:
  - social memory/Living with uncertainty/
  - self-organisation, reflective and shared learning
  - resourcefulness/Efficiency/i
  - collaboration/inclusive/diversity/intersectionality

    - innovation
    - robustness/Strength/appropriately connected
    - coupled with local natural capital
- MEASURES including:
    - reducing exposure
    - reducing sensitivity
    - increasing coping capacity
    - increasing adaptive capacity
    - increasing transformative capacity
- CONSEQUENCES including:
    - casualties
    - indirect loss
    - economic loss
    - indirect loss
    - damages in buildings/infrastructure/objects
    - ecosystems
- RECOVERY including:
    - recovery rate
    - reparability

SOURCE		ELEMENTS OF RESILIENCE								
SPRC	[6]	source	pathway	receptor					consequences	
SPRC EXT.	[7]	source	pathway	receptor			measures		consequences	recovery
IPCC/ SREX	[8]	RISK					DEVELOPMENT			
		Hazard	exposure	vulnerability			DRM	CCA		
				SENSITIVITY	adaptative capacity					
			Environmental dimension (including Urban environment)							
			Social dimensions (incl. Demography, education, governance, cultural...)							
			Economic dimension							
DPSIR	[9]	SOURCE							IMPACTS	RESPONSE
DRIB	[11]		EXPOSURE	VULNERABILITY						
				SUSCEPTIBILITY	coping capacity	adaptative capacity				
PAR	[12]	RISK								
		HAZARD	VULNERABILITY							
			root causes	dynamic pressures	unsafe conditions					
EEA	[13]				Coping	Incremental adaptation	Transformational adaptation			
SHELTER		RISK					MEASURES		CONSEQUENCES	RECOVERY
				VULNERABILITY			DRM	CCA / CHM	Casualties	Recovery rate
		HAZARD/ SOURCE	EXPOSURE/ PATHAWAY	SENSITIVITY	COPING CAPACITY	ADAPTATIVE CAPACITY	TRANSFORMATIVE CAPACITY /INHERENT RESILIENCE	Reducing exposure	Indirect loss	Reparability
		Frequency	Individuals	Social/demography characteristics	Awareness/information	Human capital/education	Social memory/Living with uncertainty/	Reducing sensitivity	Economic loss	
		Magnitude	Community	Economic characteristics	Networks/solidarity/Community preparedness	Social capital/learning	Self-organisation, reflective and shared learning	Increasing coping capacity	Indirect loss	
		Duration	Processes	Building /infrastructure	Insurance/ Funds	Economic capital	Resourcefulness/Efficiency/¡	Increasing adaptive capacity	Damages in buildings/infrastructure/objects	
			Activities	Environmental sensitivity	DRM	Institutional capital/ Governance	Collaboration/inclusive/diversity/intersectoriality	Increasing transformative capacity	Ecosystems	
			Object/ Buildings/infrastructure		Social memory	Cultural capital/identity	Innovation			
			Ecosystems		Shelter capacity	Built capital/infrastructure	Robustness/Strength/appropriately connected			
					Protection of natural resources	Natural capital	Coupled with Local Natural Capital			

Table 3: Model integration in SHELTER

The process of creating the SHELTER framework allowed identifying the objectives of the indicators ("measuring objectives") within the project (see Table 4). This is an important step to identify the gaps in the long list. This task is focused on the measuring objectives regarding Prevention/adaptation and Recovery as the other two DRM phases (Preparedness and Response) are addressed specifically by other tasks in SHELTER.

PREVENTION/ADAPTATION				PREPAREDNESS	RESPONSE		RECOVERY	
CURRENT SITUATION		POTENTIAL SITUATION	MEASURES					
measuring trends source/hazards	frequency magnitude duration	measuring risk	compare strategies/measures (CCA, DRM, CHM)	monitoring/early warning Alarm systems	Alarm systems			measuring actual effectiveness of measures
measuring exposure	individuals community processes activities object/buildings/infrastructure ecosystems			information/awareness	rapid damage assessment/ prioritization	consequences	casualties indirect loss economic loss indirect loss damages in buildings/infrastructure/ objects damage in ecosystems	
measuring sensitivity	social/demography characteristics economic characteristics building/infrastructure characteristics environmental sensitivity				information/ awareness			
measuring coping capacity	awareness/information networks/solidarity/Community preparedness insurance/funds DRM social memory shelter capacity protection of natural resources							
measuring adaptative capacity	human capital/education social capital/learning economic capital institutional capital/governance						recovery rate/reparability	

	cultural capital/identity built capital/infrastructure natural capital						
measuring transformative capacity/inherent resilience	Social memory/Living with uncertainty/ Self-organisation, reflective and shared learning Resourcefulness/Efficiency/ Collaboration/inclusive/diversity/intersectoriality Innovation Robustness/Strength/appropriately connected Coupled with Local Natural Capital						
		developing scenarios/probability/ risk prediction potential damage/impacts/losses	measuring shelter measures performance	scenario identification			
comparing HA						informing Sendai monitoring	

Table 4: Role of the indicators in SHELTER (measuring objectives)

3.2 Development of the long list of indicators

A detailed review of the literature was carried out to complete an initial long list of 433 indicators. Each indicator was characterised according to the parameters in the following table (see Table 5).

Indicators ID	A number that has been unique for each selected indicator to keep traceability	
Scientific common denomination	Commonly used denomination of the indicator in the scientific community	
Dimensions of resilience	Historic building environment resilience	
	Cultural resilience	
	Social resilience	
	Governance and institutional resilience	
	Economic resilience	
	Environmental resilience	
Hazard	Floods	
	Fire	
	Earthquake	
	Heat waves	
	Storms	
	Subsidence	
Scale	A= Artefact	
	B= Building	
	U= District/ Urban	
	R= Regional	
Risk component	Hazard characterization	
	Exposure to hazard	
	Sensitivity (a component of vulnerability)	
	The capacity of response (a component of vulnerability)	
Metrics: Parameters of monitoring and evaluation	The variable used to measure the indicator	e.g. Air Temperature
Metrics: Unit of monitoring and evaluation	The unit of measure is the way to express the parameter,	e.g. degrees of Celsius/Fahrenheit or Kelvin for the parameter "air T°".
Values	The variable in which resilience is evaluated	
Type of indicator	Early warning	
	Prevention	
	Response	
	Recovery	
	Reconstruction	
Monitoring time frame	Identifies time frames in which monitoring has been carried out e.g. hourly, weekly, etc	
Time scale	Identifies the time horizon (number of years) over which results are considered	

Table 5: Characterisation of the long list of indicators.

3.3 Development of a shortlist: RACER methodology and gap detection

In order to reduce the generated long list, this was first checked in terms of the objectives identified in the previous steps. In Table 6 it can be seen as an intermediate step where some gaps regarding some hazards were identified, i.e. some measuring objectives did not have any indicator to measure them (in red). In the gaps from hazard-dependant categories, it was studied if the gap was reasonable within the specific tasks. In the gaps from non-hazard dependant categories, specific indicators were searched.

OBJECTIVE	CATEGORY	Earthquake	Wildfire	Heat waves	Storms	Floods	Subsidence	
PREPAREDNESS/ADAPTATION								
Measuring trends source/hazards	Frequency	1	1	1	2	3	1	4
	Magnitude	4	23	19	11	6	2	48
	Duration	0	0	2	1	1	0	3
	Intensity	0	0	0	3	6	0	7
	Intensity, duration and frequency	0	0	0	1	1	0	1
Measuring exposure	People	1	1	1	1	1	1	1
	Activities	1	1	1	1	1	1	1
	Object/buildings/infrastructure	4	3	4	3	3	4	6
	Ecosystems	1	1	0	1	1	1	2
Measuring sensitivity	Social/demography characteristics	8	8	8	8	8	8	8
	Economic characteristics	5	5	5	5	5	5	5
	Infrastructure characteristics	6	7	7	8	8	8	8
	Building characteristics	10	7	5	6	16	8	37
	Environmental sensitivity	2	22	3	3	1	4	27
Measuring coping capacity	Awareness/information	4	4	4	5	4	4	5
	Networks/solidarity/Community preparedness	1	1	1	1	1	1	1
	Insurance/funds	4	4	4	4	4	4	4
	DRM	17	17	16	17	17	17	17
	Social memory	0	0	0	0	0	0	0
	Shelter capacity	1	1	1	1	1	1	1
	Protection of natural resources	2	4	3	4	4	4	5
Measuring adaptative capacity	Human capital/education	3	3	3	3	3	3	3
	Social capital/learning	6	6	6	6	6	6	6
	Economic capital	1	1	1	1	1	1	1
	Institutional capital/governance	3	3	3	3	3	3	3
	Cultural capital/identity	2	2	2	2	2	2	2
	Built capital/infrastructure	5	5	5	5	5	5	5
	Natural capital	1	1	1	1	1	1	1
Measuring transformative capacity/inherent resilience	Social memory	1	1	1	1	1	1	1
	Living with uncertainty/improvising	1	1	1	1	1	1	1
	Self-organisation, reflective and shared learning	1	1	1	1	1	1	1

	Resourcefulness/efficiency/	1	1	1	1	1	1	1
	Collaboration/inclusive/diversity/intersectoriality	1	1	1	1	1	1	1
	Innovation	1	1	1	1	1	1	1
	Robustness/Strength/appropriately connected	1	1	1	1	1	1	1
	Coupled with Local Natural Capital	1	1	1	1	1	1	1
RECOVERY								
Casualties	Casualties	2	2	2	2	2	2	2
Loss	Indirect loss	2	2	2	2	2	2	4
	Economic loss	4	4	4	4	4	4	4
Damages	Damages in buildings	2	2	1	2	2	2	2
	Damages in infrastructure	2	2	2	2	2	2	2
	Damages in objects	2	2	2	2	2	2	2
	Damage in ecosystems	2	2	2	3	2	1	3
	Recovery rate	2	2	1	3	2	2	3
	Reparability	1	1	1	1	1	1	1
		120	158	131	136	140	121	243

Table 6: Gap detection

In order to select the most suitable indicators, the RACER framework was selected, which is an evaluation framework developed to assess the value of scientific tools for use in policymaking. The acronym RACER means:

Relevant	= closely linked to the objectives to be reached
Accepted	= by staff, stakeholders, and other users
Credible	= accessible to non-experts, unambiguous and easy to interpret
Easy	= feasible to monitor and collect data at reasonable cost
Robust	= not easily manipulated

Table 7: RACER criteria framework (source [14]**)**

The RACER framework was adapted to SHELTER purposes. For each criterion, certain sub-criteria were evaluated through a score:

- The subcriteria for **relevancy:**
  - Is it a MEANINGFUL indicator?
  - Is it COMPARABLE?
- The subcriteria for **acceptancy:**
  - Has it been PREVIOUSLY USED?
  - Is it a STANDARD?

- The subcriteria for **credibility:**
  - Is it UNANBIGOUS?
  - Has it a CLEAR METHODOLOGY to be calculated?
- The subcriteria for **easiness:**
  - Are the data for calculating it AVAILABLE?
  - Is it EASY TO CALCULATE?
- The subcriteria for **robustness:**
  - Does the calculation use real data or estimations? (Higher score if it uses real data)
  - Is it APPLICABLE TO SIMILAR CASES?
  - Is it APPLICABLE IN ALL EUROPE AND SHELTER COUNTRIES (including Turkey)?

The score was the following:

- 0= DOES NOT MEET THE CRITERIA AT ALL
- 1= SOMEHOW MEETS THE CRITERIA
- 2= ALMOST MEETS THE CRITERIA
- 3= MEETS THE CRITERIA TOTALLY

The average score for each criterion was calculated. Then the final score was calculated with the following formula:

Final score= (3*Relevancy +Acceptance + Credibility + Easiness + Robustness)/7

All the indicators with a final score higher than 2 were selected.

3.4 Selection from OL

Of the 262 indicators collected from the literature review and prioritized by the RACER methodology, stakeholders were asked to rate the meaningfulness of each indicator as well as their feasibility in terms of data availability. The objective of the exercise was to reduce the initial list of indicators into a manageable number of entries for each Open Lab, without compromising the coverage of key issues.

3.5 Development of co-monitoring strategy: the selection of SHELTER indicators

The co-monitoring strategy refers to the indicators that have been selected by the Open Labs and are valid for the SHELTER project monitoring. This means indicators that can contribute to the improvement of resilience through the SHELTER implementation and are therefore useful to monitor results impact on each Open Lab. The monitoring strategy has been validated during Open Labs workshops and agreed among stakeholders.

4 Hazard dependent indicators: hazard, exposure and sensitivity

This section gives an overall vision regarding the considered hazards and their indicators. As explained before (see 3.1) in the hazard-dependant risk SHELTER follows the IPCC approach were risk is as a function of exposure, vulnerability and hazards. For each hazard (earthquakes, wildfires, heatwaves, storm, floods and subsidence) these aspects are studied. Some of the useful data sources are mentioned but further data sources are described on the Data Mapping Form[8].

4.1 Earthquakes

An Earthquake is a sudden violent shaking of the ground caused by an abrupt release of energy accumulated inside the Earth, in an ideal point called hypocentre. On the surface of the Earth, it is possible to detect the epicentre, whose distance from a place explains the intensity of the seismic event in that area. Earthquakes are unpredictable and their impact could affect irreparably the built heritage and increase the mortality rate of the area. For this reason, it is important to be aware of the seismic hazard, studying the characteristic of sites and buildings for the management of the risk.

The seismic risk is a combination of the seismic hazard (related to the site), of the vulnerability (characteristic of each building) and the exposure (activities carried out inside the building). Cultural and monumental heritage are particularly prone to this type of risk due to their typical high vulnerability and specific exposure.

4.1.1 Hazard characterization

An earthquake is characterized by its intensity, that can be defined through magnitude and **Modified Mercalli scale (KPI #356)**, which is based on earthquake effects on buildings [15]. Also, the main event (primary shock) lasts from 30 to 60 seconds, while secondary shocks keep happening during the following weeks and/or months. In terms of hazard, an important role is played by the expected Peak Ground Acceleration (**PGA**) **(KPI #354)** and the type of soil. Based on PGA values registered during decades by national seismological institutes, it is possible to map the territory through the definition of seismic zones by the level of seismic risk [16] [17].

4.1.2 Exposure

In terms of exposure, a seismic event can be mainly affected by the type of soil, possibly magnifying the seismic effect. Also, geomorphology is a physical factor that can affect the spread of the seismic wave, which can be numerically expressed through the topographic coefficient of the site [18]. It is also necessary to be aware of the possible **presence of critical facilities (KPI #212)**, **productive activities (KPI #213)** and,

[8] SHELTER deliverable "D1.1: Data sources and Knowledge".

primarily, of **major-accident risk factories (KPI #360)**, whose damage related to earthquake effects could cause an environmental catastrophe.

4.1.3 Sensitivity

The characterization of the seismic vulnerability can be accomplished through a wide knowledge of the built heritage, mainly related to its period of construction, the structural technology, **buildings alignment rate (KPI #178)**, maintenance level and materials conservation. Therefore, if the building satisfies earthquake engineering requirements, it is more likely to comply with the hazard, leading to lower risk in the seismic area. In these terms, degradation is one of the main factors that affect the structural response of the building, because a degraded material causes a heavy drop of the mechanical capacity (and an increase of vulnerability).

Especially in the case of masonry, its degradation can be extremely accelerated by the strong presence of moisture, e.g. induced by floods events; correspondingly, a periodic occurrence of floods can increase the seismic risk. A similar scenario can happen in case of subsidence phenomena, which can produce a diffuse cracking pattern throughout the masonry structural system, thus increasing also the seismic vulnerability [18].

On the other hand, buildings or part of them located inside archaeological areas, like the present case study, are often characterized by unconventional boundary conditions and geometric irregularities, like lack of horizontal diaphragms (slabs) or different levels of excavation; for this reason, proper knowledge of the structural/geometrical irregularity is fundamental.

Finally, in the recovery phase, the characterization of the severity of the seismic event is strictly related to the identification of the **number of collapsed or heavily damaged buildings (KPI #206)**, such as the number of slight or moderate damaged buildings.

4.1.3 Useful data sources

Useful sources of data on earthquake in Europe:

- EPOS European Plate Observing System https://www.epos-ip.org/tcs/seismology
- EMSC-CSME European Mediterranean Seismological Centre https://www.emsc-csem.org/#2
- EFEHR European Facilities for Earthquake Hazard and Risk http://www.efehr.org/en/home/
- ORFEUS Observatories & Research Facilities for European Seismology https://www.orfeus-eu.org/

4.2 Wildfire

Although forest fires are a central part of the shaping of forest ecosystems and essential for forest renewal, and they contribute to the control of insect and disease damage [19], forest fires also threaten ecosystems services, biodiversity, landscape, human health and

surveillance of economic activities, are a significant cause of land degradation worldwide and are increasing due to climate change.

Forest fires increase health and mortality risks due to direct and indirect health hazards resulted from air pollution. They can burn residential, commercial and public buildings, and damage transport infrastructure and block roads and railways. The economic damages can further increase if the fire reaches agricultural fields and damages crops and trees. Indirect economic losses can also occur through job losses and lower incomes, especially in areas that rely on offering tourist products that are based on natural and cultural beauty. The register economic losses in Europe are estimated to be above EUR 9.5 billion in 2015 prices [20].

4.2.1 Hazard characterization

The main determinants of wildfire spread and intensity are climate variables and fuel accumulation [20] **(KPIs from #19 to #37, #39, #40, #229).**

Air temperature rise, heat waves, and decreasing precipitation during the summer months contribute to increased ignition probability and fire propagation for many parts of Europe, but especially for the Mediterranean areas[9].

- Air temperature does play a significant role in fire behaviour. It influences the temperature of the fuel to be burnt thus also influencing the quantity of energy required to raise the fuel to the ignition point.
- Rainfall affects the moisture content of the fuel and thus the ignition.
- Relative humidity if high reduces the risk of fire due to enough moisture content in the fuel.
- Severe drought. The fires feed off high temperatures and low soil moisture. The worst years for Europe in terms of areas burnt were 2002, 2003, and 2012 [19]. Besides, these climate change-induced factors increase fire danger in south-western Europe and expand the fire-prone areas in higher latitude and altitude[10].

The topography includes elements of slope, steepness, aspect, elevation, and configuration of the land. Although topography may not change with time, it affects how fuel and weather change. In the past decades, fire frequency and extent have changed as well as the burning patterns, and fire seasons have lengthened as a consequence of land-use changes, longer seasonal droughts, and proliferation of human activities and environmental disturbances[11]. This has led to more forest fires, which are bigger in terms of size and severity.

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[9] EEA (2016). Map book Urban vulnerability to climate change: Forest fires [online] Available at: http://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/climatic-threats/forest-fires [Accessed 19 Apr. 2018]

[10] Ibid 9

[11] Ibid 9

4.2.2 Exposure

Climate change will affect forest fire incidents, since, in a warmer climate, harsher weather conditions, expansion of fire-prone areas, and longer fire seasons are likely to occur in various parts of Europe. As projections suggest, warmer weather and increased number of droughts, heatwaves, and dry spells will likely prevail across southern Europe, which will increase the severity and length of the fire season, the area at risk, and the probability of large forest fires. Moreover, in the central and northern countries of Europe, temperature increases and fire danger conditions could expand the areas prone to forest fires northwards [21]. Indicators related to the exposure of object, buildings, infrastructure, ecosystem as well as people are **KPIs #17, #57, #209 to #213 and #360.**

4.2.3 Sensitivity

Fire ignition parameters are elevation, slope, and aspect, proximity to roads, water bodies and area of human activities, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and vegetation type. The vulnerability of forests to fire is affected by topography and vegetation type and litter data. The density of vegetation thus indicates the amount of biomass available for burning.

Still one of the most relevant drivers of forest fires are obsolete and irresponsible agroforestry practices alongside the lack of resources/budget and very often the lack of coordination between the procedures and organizations involved in fire prevention and extinction.

Maps from the European Environment Agency (EEA) show that a high percentage of residential areas of all Portuguese and Spanish cities have a high direct risk of forest fires and the same pattern is followed by cities in southern France and Greece as well as some cities in southern Italy[12]. Figure 6 shows the percentage of urban areas prone to forest fires in 2006 and the average meteorological forest fire danger between 1981 and 2010 in Europe.

There are many methods of fire risk modelling, of which one will be the best for a region for the selected parameters. In general, for every domain expert knowledge plays an integral role in giving inputs for modelling and developing new algorithms. Expert knowledge improves the quality of produced data for all fields in general and in the field of forest fire vulnerable zones in particular. The most commonly used fire risk modelling methods include linear regression and logistic regression, multi-criteria decision analysis, weighted overlay methods.

Sensitivity to wildfires is expressed by several indicators and consider both the cultural as well as the natural heritage: **KPIs #38, #56, #58, #62, #63, #69,** from **#70 t**o **#77, #80, #83, #84, #89, #91, #92, #93, #95, #105, #106, #108, #109, #111,**

[12] Ibid 9

#114, #124, #126, #129, #130, #138, #140, #144, #146, #148, #149, #150, #151, #153, #156, #158, #161, #165, #166, #169, #170, #172, #174, #180, #188, #218, #223, #226, #241, #242, #245, #248, #250, #278, #287, #299, #310, #311, #312, #313, #315, #316, from **#319** to **#331,** from **#363 to #384, #389, #390,** from **#397** to **#401, #409,** from **#416** to **#422, #427, #428, #429.**

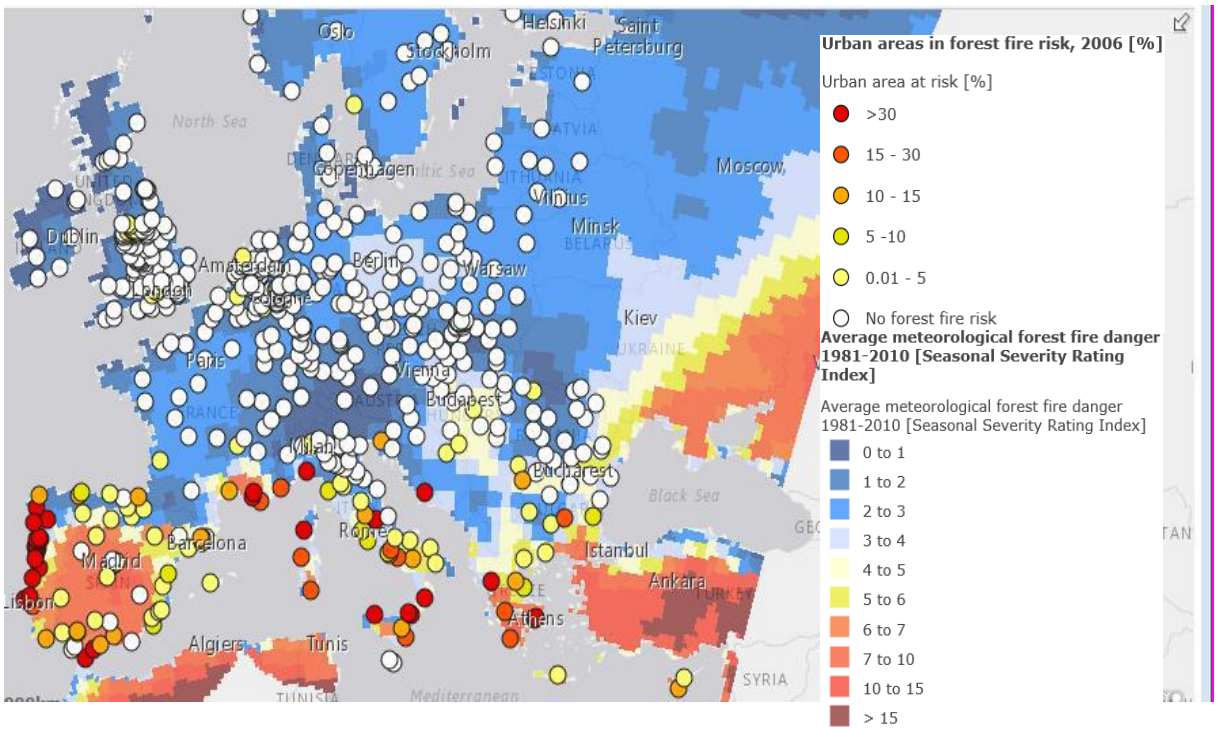

Figure 6: Urban areas in forest fire risk and average meteorological forest fire danger [13]

4.2.4 Key factors for the analysis, related to fire risk, in the natural environment (and its relationship with built environments)

The severity is associated with the loss of biodiversity and landscape values, and with the danger to houses in settlements and population centres near the forest masses. The elements of analysis are mainly:

- Historic data on fire episodes in the past.
- The orientation of forests, with respect to the sun (southern slopes with more risk than northern slopes) and with respect to the winds (prevailing winds in the direction of populations).
- Edaphology and plant species, more or less combustible, both trees and shrubs, grasses and herbs.
- Existence of firebreaks and security strips between the forest and the houses or the facility to establish them.
- Existence of a forest plan that includes fire risk, management, cleaning and maintenance of wooded areas, etc.

[13] Ibid 9

- Existence of alternative evacuation routes (or ease of creating them), especially for the evacuation of populations and homes surrounded by wooded masses (there must be at least two alternative escape routes).
- Possibility of establishing networks of hydrants around populations surrounded by forest masses.
- Existence of evacuation plans for population centres and early warning systems.
- Land use ownership structure of the natural territory (easier management of the communal forest).

4.2.5 Useful data sources

The deliverable D1.1[14] studied in the Copernicus Programme and Services, but in this section, some resources available and datasets in Copernicus to assess wildfire risk are described. The European Forest Fire Information System (EFFIS) by the Joint Research Centre (JRC) supports the services in charge of the protection of forests against fires in the EU countries and provides the European Commission (EC) services and the European Parliament with updated and reliable information on wildland fires in Europe. Several specific applications are available through EFFIS https://effis.jrc.ec.europa.eu/

Fire Weather Index: Fire weather indices are used for warning, to increase surveillance and stop management operations that can initiate fire. Nowadays Copernicus has subcontracted a European tourism Sectoral Information System (SIS) to develop different datasets (i.e. Mountain Tourism Meteorology and Snow Indicators (MTMSI), Lake Surface Water Temperature (LSWT), Climate Suitability for Tourism (CST)) and one focused on **Fire Weather Index (FWI)**.

All datasets cover different scales (from observations and reanalysis products), short term (from Copernicus Climate Change Service (C3S) seasonal forecasts) and long-term (from climate projections).

Palmer Drought Severity Index (PDSI): Influenced by the combined effect **of temperature and precipitation**. The Palmer Drought Index (PDI) (1965) was developed as an index "to measure moisture deficiency". It is based on the concept of demand-water supply, taking into account the deficit between the actual precipitation and the precipitation necessary to maintain normal or climatic humidity conditions. The calculation procedure requires as input data:

- Potential Evapotranspiration
- monthly precipitation
- useful water content of the soil

Soil moisture: Monitoring soil moisture is becoming very important for predicting and monitoring possible disasters. Nowadays, synergies between different satellite systems enable us to monitor soil moisture at an unprecedented regularity and scale. In this aspect, the Copernicus programme plays a crucial role. Soil moisture is a key variable

[14] SHELTER deliverable "D1.1: Data sources and Knowledge".

regulating the exchange of water, energy, and carbon cycles between the land and the atmosphere. Soil moisture data is therefore essential for various environmental studies, including hydrology, climatology, meteorology, agriculture, water resource management and climate change. This is why soil moisture is recognized as one of the Essential Climate Variables (ECV) defined by the Global Climate Observing System (GCOS), which assesses the status of global climate observations and produces guidance for its improvement. Several in-situ techniques have been developed over the past decades to measure soil moisture. However, they are restricted to specific area measurements and do not represent soil moisture distribution over larger areas, as soil moisture is highly variable in both space and time. Fortunately, current technological advances in satellite remote sensing have offered an alternative to field measurements and have enabled us to monitor it at higher temporal and spatial resolutions and at a considerably lower cost and time. The Copernicus programme is a frontrunner in this field.

Near-real time soil moisture information, based on the state-of-the-art "ESA CCI SM" algorithm, can be downloaded from the Copernicus Climate Data Store. There are three products available: the active dataset (based on active scatterometer data), the passive dataset (based on passive radiometer data) or a combined product, based on a combination of both active and passive datasets. When the data is not self-explanatory, one can count on the Copernicus Global Land Service, which is part of the Copernicus Land Monitoring Service. It provides a series of bio-geophysical products that are used to monitor vegetation, water cycle, the energy budget and the terrestrial cryosphere, based on Sentinel-1 data.

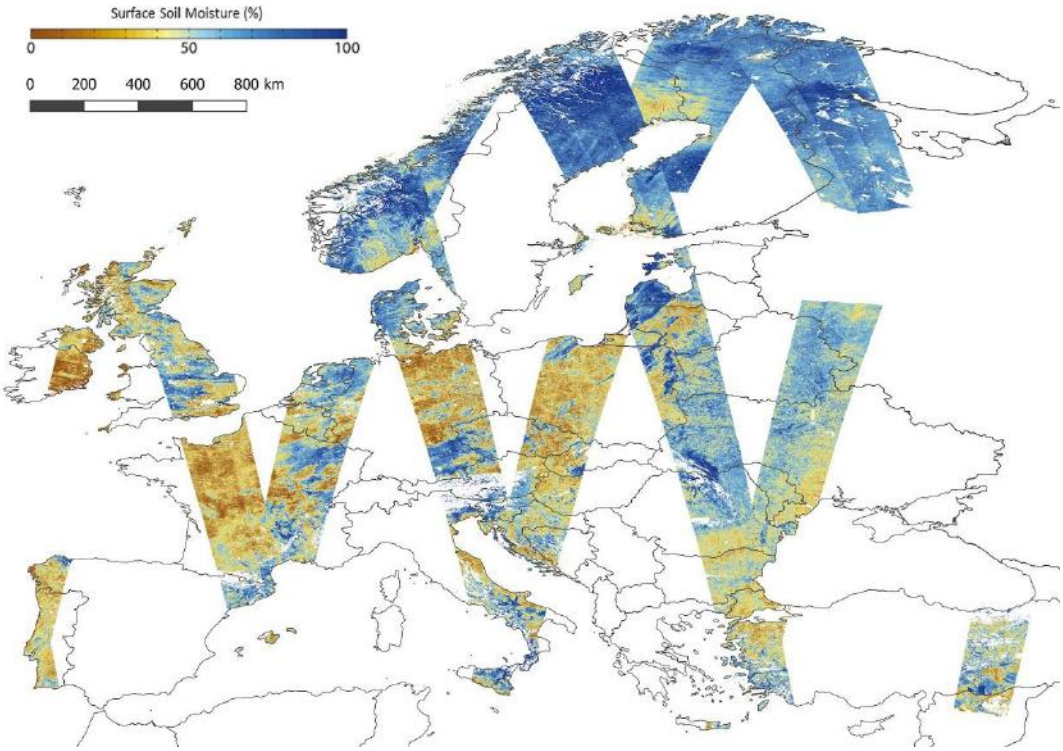

Figure 7: Copernicus Global Land service, Daily Surface Soil Moisture based on Sentinel 1 over Europe, 24 Aug 2018

One of their products, Surface Soil Moisture, shows the relative water content in the top few centimetres of soil (usually up to 5 or 7 cm). The top layer is crucially important, as it provides water supply for vegetation, and directly affects local air temperature and humidity. Another useful tool is the Soil Water Index (SWI). It quantifies moisture based on the Surface Soil Moisture, presenting it at various soil depths. The added value comes from combining it with the scatterometer satellite sensor ASCAT on the MetOp EUMETSAT meteorological satellite. It is provided at 1km resolution over Europe, and 0.1 degree, or 12.5 km resolution, at the global scale, on a daily basis, in near-real-time.

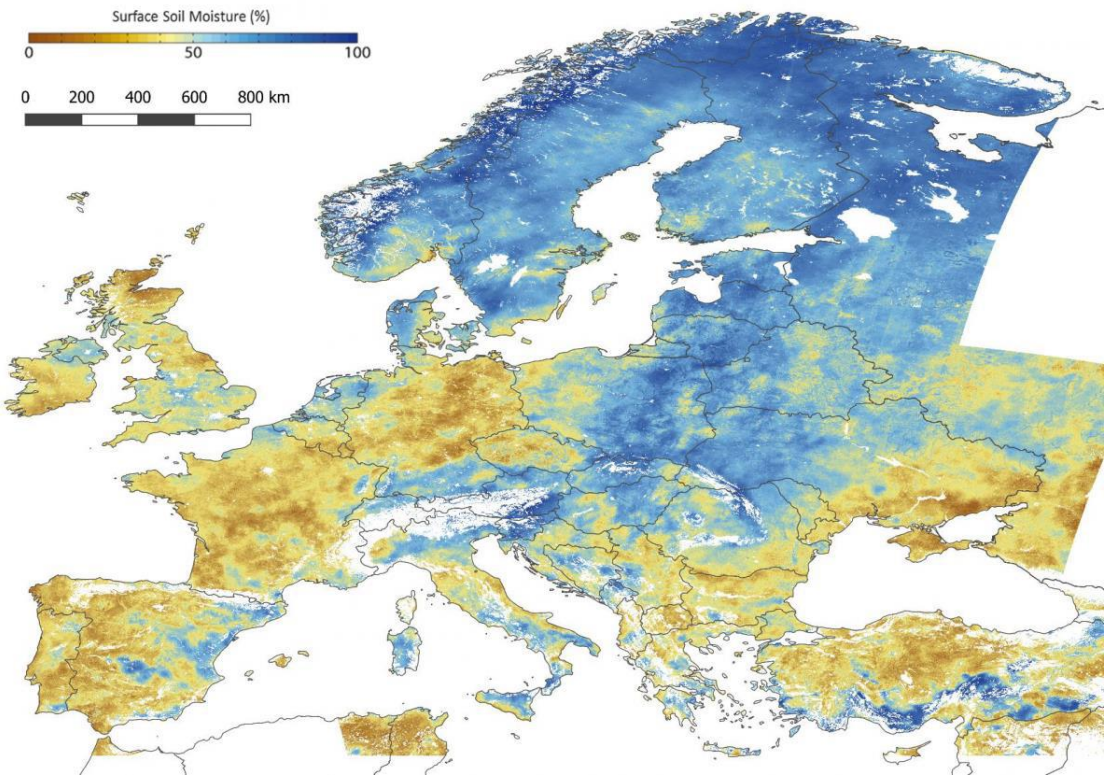

Figure 8: Copernicus Global Land service, Soil Water Index product over Europe in August 2018

4.3 Heat waves

Heat waves (HW) are one of the most threatening natural hazards that can adversely affect human health, ecosystems, biodiversity, natural heritage, infrastructure and urban areas [22]. Population in urban areas are very vulnerable to extremes in heat and relative humidity and HW events can have important consequences in human health and increase mortality rates. Numerous studies indicate that climate change is expected to aggravate HW events, becoming more frequent and increasing their duration and intensity [3]. Although there is no standard definition of the HW, it can be referred to a period of consecutive days of abnormally high temperature. The World Meteorological Organization (WMO) guidance on heat-health warning [23] defines heatwaves as periods of unusually hot and dry or hot and humid weather that have a subtle onset and

cessation, a duration of at least two to three days and a discernible impact on human activities [24]. Therefore, the main indicators to characterize HW are temperature **(KPI #43)** and Relative Humidity (RH) **(KPI #46)**; with levels of RH defining if it is a dry heat wave or a humid heat wave [25] [23].

These extreme heat events are becoming a growing concern for cities and urban areas because high temperatures reached during heat waves are often exacerbated due to specific urban phenomenon called the Urban Heat Island (UHI) effect [26]. UHI are the observed characteristic of urban areas to have higher temperatures than their surrounding rural areas [27]. This is due to the way urban geometry and materials influence wind flow, energy absorption, and the ability of surfaces to emit long wave radiation back to space.

This extremes in heat and low or high humidity and their combination can have an impact on Cultural Heritage (CH), both when considering the singularities of Historic Areas and the characteristics of traditional construction materials. When addressing the state of the art for the impact of HW and UHI on Cultural Heritage a search on Web of Science (WOS) determines that there is a lack of specific research on this area:

	Key words	Results
WoS	Heat wave + Heritage	27 results - 3 of which related to the topic, none of them specific about heat waves (just addresses them in a climate change related hazards overview)
	Heat wave + Historic area	12 results - only 1 related to the topic and not specific about heat waves
	Urban heat island + Heritage	24 results - 2 relevant results (both case studies)
	Urban heat island + Historic area	23 results - 3 relevant results (all case studies)

Table 8: Systematic search results using WoS

As a result, research for indicators on HW and their impact on CH follows three lines: hazard characterization, KPIs to determine magnitude and characteristics of HW, exposure indicators, regarding specifically the urban form and characteristics linked to UHI, and sensitivity indicators, for the characterization of CH assets.

4.3.1 Hazard characterization

As mentioned, HWs are characterized using temperature and RH. The threshold for a HW varies depending on the location and each country/region has its definition depending on their specific climate. Basic characterization of a HW would need, therefore, as indicators, daily mean temperature **(KPI #43)** and RH **(KPI #46)**. As a further characterization of the intensity of the hazard and its possible implications for population and CH, other indicators must be considered [28]. Additional variables that influence HW characterization are the ones that determine the fluctuations on temperature and RH on

a daily basis, such as daily RH cycle shocks **(KPI #47)**, humidity cycles that surpass 75% RH **(KPI #48)**, and thermal shocks **(KPI #44)**. Another parameter that can have an important determination in the characterization of the intensity and effects of HW is the number of daily sun hours **(KPI #45)**, that considers the amount of solar radiation that an area has received in a day. All of these indicators characterize the risk of HW in historic areas due to their effect on the weathering of traditional construction materials [29].

4.3.2 Exposure

The exposure is related to an assets location, urban form and possible UHI characteristics

As stated by Oke (1987), the formation of the UHI phenomenon can be ascribed to some main characteristics of urban areas related to materials (reduced albedo, less vegetation, increased thermal admittance), urban form (increased density, urban canyons) and urban characteristics (noise pollution, air quality) [30]. These modifications to the natural landscape have as an outcome a series of atmospheric and thermophysical changes that favour heat storage in cities [31]. This is very relevant when addressing Historic Urban Areas, due to their specific characteristics and their tendency to be situated in the centre of cities.

When addressing the urban form, the main indicators found in the literature are the sky view factor **(KPI #54)**, that determines the proportion of an urban space related to heat storage [32] and that can led to a phenomenon known as Urban Canyon [33] and Hillshade **(KPI #50-51)**, that indicates the areas of a building that receive direct sunlight [34].

As previously mentioned, the thermophysical characteristics of urban materials have a big impact on heat storage in cities. The most relevant indicators used in literature are the albedo **(KPI #52)** [35], the thermal diffusivity **(KPI #53)** [27] and the solar reflectance index **(KPI #55)** [36].

Other urban characteristics that are linked in the literature to interact with HW, and that are intrinsic characteristics of urban areas, are the tropospheric Ozone (O3) levels **(KPI #57)** and the acoustic pollution **(KPI #59)**. Abundant research shows that the ozone levels can increase under specific meteorological conditions such as high temperature, intense solar radiations, and long sunshine hours, all characteristics of heatwaves [37], and can have a big impact on the health of the urban population [38]. Concerning acoustic pollution, studies have shown that people living in high street noise areas, tend to either ventilate less, consequently increasing heat storage inside the building [39] [40] or suffer health consequences due to the high dB levels of acoustic pollution [41].

4.3.3 Sensitivity

Sensitivity parameters are related to the characteristics of buildings and assets located in HA. The sensitivity of CH assets to heat waves can be divided into two lines of indicators, identification of traditional materials that are prone to increase weathering

and degradation under HW conditions, and typological characteristics of assets that made them less capable of coping with the hazard.

Research and studies are abundant regarding the behaviour of historic and traditional materials under the impacts of Climate Change, including several European Projects [42] or diverse studies on specific materials [43]. Based on an analysis of the literature, indicators of the envelope materials (façade and roof) **(KPI #71)** and structural materials **(KPI #70)** are considered essential for the characterization of CH assets and their sensitivity to HW.

The typology of the building is addressed on the indicator list, based on their characteristics to cope with HW conditions. In this regard, general indicators such as year of construction **(KPI #62)**, state of conservation **(KPI #63)** and level of protection **(KPI #69)** or listing have been included, with other more specific such as the existence of insolation on buildings **(KPI #67)** [40].

4.4 Storm

Extreme meteorological events such as storms carry the potential for considerable damage to property and environment and thus affect society as well as its CH [44] [45]. Intense storms affect Central Europe regularly such as storm Kyrill in January 2007 [46] and storm Xynthia in February 2010.

In future simulations, the intensity of cyclones causing storms in Central Europe is predicted as increased especially over the eastern Atlantic and the North Sea, on average by about 10%. Wind speeds during storm events are also increased significantly by about 5%. The analysis of extreme wind speeds and the associated loss potentials shows higher speed values and also loss risks over the northern parts of Central and Western Europe, while they decrease significantly over Southern Europe and the Mediterranean region [47] [48].

The average annual wind speed (measured at 10 m above ground) has decreased by 10% in the past 30 years [15] . This is due in equal parts to an increase in surface roughness (land-use change, non-urban) and a change in atmospheric circulation. Long series of stations indicate a long-term decrease since about 1960. The higher percentiles, i.e. the high wind speeds, also show this decreasing trend – in contrast to the average annual wind speed on the 850-hPa pressure area (at about 1500 m above sea level) and above in Western and Northern Europe as well as North America. Here, the evaluation of radiosonde ascents shows a slight increase in wind speeds [49] [50] [47].

Storms usually impact large areas, which contributes to the large loss amounts caused by those events, accounting for several billion Euros related to individual storms. For

[15] Zentralanstalt für Meteorologie und Geodynamik. https://www.zamg.ac.at/cms/de/klima/informationsportal-klimawandel/klimazukunft/europa/stuerme

example, in Germany, 53% of economic (insured) losses owing to natural hazards are caused by severe winter storms [51]

4.4.1 Hazard characterization

Extreme wind events have a negative impact on human safety, aviation, maritime transport and the integrity of infrastructures (IPCC, 2012 149pp). Therefore, the indicators for storms are **wind speed (KPI #274)**, **gust strength (KPI #337)** and **air pressure (KPI #281)**. Especially gusts can cause high damage to buildings as well as to CH due to higher dynamical **wind pressure (KPI #335)**[51]. For the wind speed, the categorisation of the Beaufort scale is used as a standard parameter[16].

Rapid change of **air pressure (KPI #281)** is also an indicator for weather situation and a higher possibility of a storm event as well as **gust strength (KPI #337)** and air temperature, for example, **the daily maximum temperature of more than 5 consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1961–1990 (KPI #337)**.

The **lifted index (KPI #332)** and the **Cape index (KPI #284)** are used as standardized indicators for the strengths of a thunderstorm[17]. Heavy precipitation due to **heavy rain (KPI#334)** may have a huge impact on infrastructure and cause flooding, crop failure or interruption of lifelines [52] [8] [53]. To identify the economic loss, the total of **insurance claims (KPI #347)** due to storm events are a useful tool [51].

For characterization on a lower scale (urban level), there are additional indicators in use, which were identified based on the expertise of the researcher also in combination with an early warning system. These indicators are:

- **Storm duration (KPI #343):** It is important to clarify whether the duration of storm events is increasing or decreasing as well as when the events take place (not only season, maybe daytime is necessary). This is important for the early warning system.
- **Number of storms per month (KPI #344):** similar to the indicator above (storm duration).
- **Minor damages to buildings (KPI #348):** In case the data are available, the economic loss, as well as the reconstruction time and staff requirements, can be identified very quickly.
- **Variance of the average wind speed in defined area per year (KPI #350):** This indicator allows the identification of areas and timing of increased wind speeds. This is important for the early warning system.
- **Variance of average gust speeds in defined area per year (KPI #351):** This indicator allows the identification of areas and timing of increased gust speeds.

[16] Deutscher Wetterdienst, Wetter und Klima aus einer Hand. https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?nn=103346&lv2=100310&lv3=100390

[17] Deutscher Wetterdienst, Wetter und Klima au seiner Hand. https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?lv2=101518&lv3=101590

This is important for the early warning system. In case it is possible to identify this indicator on a lower scale level (e.g. building) the risk mitigation measures can be done in time.

- **Operating hours due to storm events (KPI #352):** This indicator is used by first responder units to describe the effort. This indicator is not useful for economic estimations.
- **Count of missions due to storm events (KPI #353):** This indicator is used by first responder dispatchers or headquarters to structure the mission trigger. This indicator is part of the decision-making of further planning (education, equipment, etc.).

4.4.2 Exposure

Indicators for the exposure are related to the location of an asset as well as the dimension and possible pre-damages of infrastructures [18]. A distinction is made between wind effect on buildings due to **wind pressure (KPI #335)** (e.g. infrastructures) and wind forces on natural structures (e.g. wood) [19]. Changes in the landslide (e.g. construction measures) may cause wind channels (strong wind zones) which increase the **wind pressure (KPI #335)** (Werth, 2019) with the effect of heavy damages. For identification of the damages of forests due to storms (natural structures), a **windthrow indicator (KPI #349)** is relevant and necessary[20].

Most building insurances cover damage from a wind force of 62 km/h and higher (Uniqa, 2015) and have very good databases and information available.

For exposure on a lower scale (urban level), there are additional indicators in use, which were identified based on the expertise of the researcher also in combination with an early warning system. These indicators are:

- **Reduced working capacity (KPI #277):** How many days a person stays off duty due to a storm event.
- **Reported insurance claims (KPI #347):** Number of claims due to storm event in a specific time (yearly, seasonal or event-specific).
- **Slight or moderate damaged buildings (KPI #348):** Number of buildings due to storm event. Therefore a dispatcher-, first responder- or municipality database is necessary.

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[18] Anwalt.de. Rechtstipps. https://www.anwalt.de/rechtstipps/sturm-und-sturmschaeden-einige-unterschiede-und-probleme-in-den-versicherungssparten_117135.html; Versicherungsverband Österreich. https://www.vvo.at/vvo/vvo.nsf/033bc38c04cb4a8bc12574dc005de1e4/6ea8221cc4ac13f4c1257cde005163ce?OpenDocument

[19] Karlsruher Institut für Technologie. Laboratorium für Gebäude- und Umweltaerodynamikund Forschungsgruppe Strömungsmesstechnik. http://www.ifh.uni-karlsruhe.de/science/aerodyn/forschungsschwerpunkte.htm

[20] holzkurier.de. https://www.holzkurier.com/blog/groesste-windwuerfe.html?gclid=EAIaIQobChMImoiX-42a6QIVU_hRCh2kHQ2kEAAYASAAEgIqCPD_BwE

4.4.3 Sensitivity

The IPCC WG II Report (2014)presents 'vulnerability' as a pre-existing characteristic property of a system exposed to a hazard like a storm [45]. Accordingly, storm-related indicators for 'sensitivity' and 'adaptive capacity', which are internal properties of a system, are employed to assess it.

An important component of vulnerability is the sensitivity of property regarding for example storms. According to IPCC [54], sensitivity is the "degree to which a system or species is affected, either adversely or beneficially by climate variability or change. The effect may be direct (e.g., change in crop yield in response to a change in the mean, range, or variability of temperature [or an increase of the weathering of surfaces of historic structures]) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise [or by an increase of the frequency of heavy storms or an increase of the average wind speed of heavy storms with **Variance of the average wind speed in defined area per year (KPI #350)** and **Variance of average gust speeds in defined area per year (KPI #351)**)".

According to this definition, sensitivity is the "degree to which a system or species is affected…" or to which a property is affected (i.e., the cultural property of any kind). Therefore, the indicator **RMI: Reinforcement and retrofitting of public and private assets (KPI #320)** is useful.

Jagmohan Sharma and Nijavalli H Ravindranath [55] therefore conclude: "this implies that sensitivity of a system operationalizes through a 'cause-effect' or 'dose-response' mechanism. While cause (dose) is exposure to a hazard, effect (response) is sensitivity. However, sensitivity considered in the vulnerability construct is only the first-order impact caused by a dose of exposure to hazard. Such a first-order impact is countered and reduced by the adaptive capacity of a system, and the manifested impact is lesser. Vulnerability is equal to this reduced impact."

For sensitivity at the urban level, for example, there are additional indicators in use, which were identified based on the expertise of the researcher also in combination with an early warning system. These indicators are:

- **Compared mortality (KPI #271):** This indicator gives an overview of the event-based mortality in a specific area and time scale.
- **Increased hospitalization (KPI #272):** This indicator allows an overview of the hospitalization situation. In case the indicator is part of an early warning system the utilization can be identified in advance.
- **Stays in hospital (KPI #273):** With this indicator, the economic loss of a storm event can be identified. This can be used to justify risk mitigation measures.
- **Media observation (KPI #278):** The indicator is a benchmark about the public awareness and perception of the storm event as well as the risk management. In case the data are available in real-time (hourly or shorter) the indicator is also good for the early warning system.

4.5 Floods

Flooding is perhaps Europe's most high-profile climate change hazard due to the visible and damaging impacts that it creates. Floods and storms are two weather-related hazards that cause some of the highest economic losses in Europe [56]. Except for economic losses, floods can severely affect society and the environment at large.

Although climate change is a key driving force, other factors including land-use change and urbanization will also influence flood hazards over the coming decades. There are several main types of flooding that affect Europe, including flooding from rivers and streams (or fluvial flooding), surface water flooding (or pluvial flooding), groundwater flooding and snowmelt flooding.

In SHELTER project the focus is principally on fluvial and pluvial floods, which are underpinned by sustained and/or intense rainfall events.

4.5.1 Hazard characterization

Climate projections suggest a significant change in the pattern of rainfall across Europe, with implications for flooding. Most future scenarios anticipate an increase in rainfall in the north and west, particularly during the winter months. Across the continent, even in southern Europe where rainfall volumes are declining, extreme downpours are projected to become more common. Forecasting changes to future flood hazards is complex, particularly at finer spatial scales.

Despite this, there is some agreement between climate models that certain locations, particularly north-western Europe during the winter months, will see an increase in fluvial flood hazard frequency. In other regions, for example around the Baltic sea, central Spain and parts of northern Europe where snowmelt flooding is projected to decline, reductions in fluvial flood hazard frequency are anticipated.

Data on the nature and extent of flood hazards, from a European perspective, is expanding. The European Floods Directive (FD) 2007/60/EC[21] required the Member States, by 2013, to draw up maps showing areas exposed to sources of flooding including from rivers, surface water, groundwater and coastal flooding. Flood hazard maps combine flood probability, under three different scenarios, with the exposure characteristics of the receiving area [57]. Most Member States have now produced flood hazard maps [58]. Mapping the effect of climate change on flood hazards is now required under the second cycle of the Floods Directive.

Data on projected changes to precipitation patterns across Europe shows how this will influence the frequency and severity of fluvial and pluvial floods. Seasonal variations are a key feature of this data, as are the contrasting projections for different European sub-regions. It is important to note that changing precipitation patterns within different

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32007L0060

countries is not always the dominant factor influencing the severity of fluvial flood hazards locally. In the Netherlands, for example, this is dependent on precipitation patterns in the Alps and central France. Often working with climate projections produced by the IPCC and within programmes such as ClimateCost and ENSEMBLES, research projects have produced additional spatial data on future flooding prospects. In most European sub-regions, patterns of future change in fluvial flood hazard risk differ according to the model used and emissions scenario chosen [59]. This variability between the outputs of different climate models is more pronounced for precipitation projections than for average changes in temperature [60]. Feyen et al [61] find that this diversity of future fluvial flood hazard forecasts becomes even more pronounced at finer spatial scales emphasising the challenges associated with projecting changes to flood hazards locally.

At the scale of individual river basins, using a different combination of climate models or assuming a different emission scenario sometimes results in a very different or even opposite climate change signal in flood hazard [61]. Despite this uncertainty, there is agreement on certain locations where changes are projected to future fluvial flood hazards and also patterns of heavy rainfall events.

The factors that determine the hazard include the region's climatology (KPIs from #1 to #5, #405), local geography and morphology (KPI#11, #196, #406, #407), river basin characterisation (KPIs from #12 to #15), as well as hazard frequency (KPI #229) and flood characterization (KPIs from #6 to #10).

The most common metrics that measure flood events are severity and magnitude. Severity measures how rare or unusual the flooding event is, while the magnitude is estimated by a function that involves the severity, the duration of the flood, and its regional scope.

Projected changes in the frequency and severity of heavy rainfall events have the potential to influence the severity of pluvial and fluvial floods. Although not the only source, heavy precipitation is the principal factor that causes fluvial and pluvial floods. The term heavy precipitation includes both high-intensity short-duration events and low-intensity extended-duration events (wet spells). Finding clear trends for heavy precipitation events is challenging. However, climate models agree that on average such events are becoming more intense and more frequent in Europe, especially in central and eastern Europe during the winter. Instances of extreme precipitation events have increased in northern Europe and decreased in southern Europe. Their length and intensity have increased in the north and north-east Europe and decreased in south-western Europe. Modelling projections suggest that global warming will make dry regions drier and wet regions wetter. Extreme precipitation events will most likely increase in both regions. As a result, this increase in heavy precipitation instances is expected to increase both river and surface water flooding.

4.5.2 Exposure

Exposure is related to assets, services and population **(KPI#209 and #210)** located in flood-prone areas, such as physical infrastructures **(KPI#17)**, including buildings **(KPI#211),** primary assets **(KPI#212),** productive activities **(KPI#213)** and major-accident risk factories **(KPI #360).** Exposure is determined by different return periods for different projections including climate change scenarios. Information related to elements exposed to flood risk is determinant in all phases of the disaster risk management, being the assessment useful for decision making in prevention, preparedness, early warning, response and recovery.

4.5.3 Sensitivity

Sensitivity to flood risk is evaluated using the characterization of what is exposed. This characterization includes a large number of indicators (see annexes) that indicates the nature of what is exposed and how it could be impacted and damaged if an event occurs. **(KPI #58, #62, #63, #65, #69, #70, #71, #72, #77, #83, #84, #89, #91, #92, #93, #95, #105, #106, #108, #109, #111, #114, #124, #126, #129, #130, #138, #140, #144, #145, #146, #148, #149, #150, #151, #153, #156, #158, #161, #165, #166, #169, #170, #172, #174, #180, #183, #186, #188, #218, #223, #226, #228, #241, #242, #245, #248, #250, #256, #257, #259, #263, #264, #265, #266, #267, #278, #287, #299, #310, #311, #312, #313, #315, #316, #319, #320, #321, #322, #323, #324, #326, #327, #328, #329, #330, #331, #363, #384, #389, #390, #397, #398, #399, #400, #401, #409).**

In the following paragraphs, we address fluvial and pluvial flooding separately since different indicators and metrics are used to evaluate sensitivity.

4.5.4 Fluvial flooding

River floods (or fluvial floods) are natural phenomena that contribute to the shaping of floodplains and riparian zones. However, riparian zones and floodplains in Europe and globally have been significantly altered from their natural state by human activities, leading to an increased risk of flooding [20]. According to EEA, river floods are mostly a result of heavy precipitation but are also often caused by snow-melting and tidal-related influences [20].

Soil, vegetation cover, land use, and other ground conditions have a direct effect on the generation of run-off, which causes flooding when it exceeds the local river flow capacities. Usually, the river's level rises slowly, and once flooded the subsequent period of retreat of the flood is particularly long, especially in relatively flat areas and river deltas. River flood trends can be analysed either by the number of events or by assessing the resulting economic loses[20].

Spring snowmelt is a key driver of fluvial flooding in some areas of northern Europe. Due to a projected reduction in snow accumulation and subsequent snowmelt volumes, projections suggest a decrease in future flood hazard for eastern Germany, Poland,

southern Sweden and the Baltic countries [59] [61]. However, in the 2020s, the risk of fluvial flooding during the winter months increases in northern Europe, as snowmelt shifts to winter from spring as temperatures warm [62].

Increases in fluvial floods magnitude and return period, accounting for climate change, are projected for north-western and central Europe, including specific areas such as the British Isles, northern Italy and the upper Danube. This is mainly as a result of increases in extreme rainfall [59] [63] [64][61].

In northern, north-western and north-eastern Europe, an increase in the annual mean number of days with heavy rainfall is projected [65]. Frei et al. [66] add that over large parts of northern Europe above the 45° parallel, extreme precipitation events are projected to become more frequent, particularly during the winter months.

A decline in the annual mean number of heavy rainfall days (or extreme precipitation events) is anticipated in southern and southern central Europe [65][66]. Although the summer months are projected to become drier across much of Europe, an increase in extreme downpours is nevertheless very likely over many areas [67], with notable exceptions including locations on the Iberian Peninsula and the Balkans [68].

As a rough estimate, about 20% of European cities with over 100,000 inhabitants are classified as vulnerable to river flooding (i.e., more than 40% of the urban area would be flooded if a river rises by one metre) [69]. Similarly, the EEA Urban Vulnerability Map Book shows that in the period 1961-1990, about 21% of the 574 cities included in the map book had at least 10% of their urban area at risk of river flooding in case of a one-in-a-century flood event [22].

The highest share of cities with a high percentage of their areas potentially threatened by river floods is found along big European rivers, such as the Danube, Rhine, Rhone, Moldau-Elbe, Po and Vistula [23]. From 2000 to 2014, Europe has experienced hundreds of major floods that resulted in thousands of deaths and affected many millions of people[24]. Catastrophic floods affect some areas more than others. Between 1998 and 2005, north-western Romania, south-eastern France, northern Italy, central and southern Germany, and eastern England experienced the highest concentration of repeated flooding. Moreover, major floods occurred in Europe in 2005, 2007 and 2010. The highest number of floods in a year was reported in 2010 when 27 European countries were affected by 321 floods mainly in central Europe. Figure 5 presents the number of floods per country from 1980 to 2010.

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[22] Urban area potentially affected by river flooding, period 1961-1990. Dataset available for download at http://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/my-adaptation

[23] EEA (2017). Map book urban vulnerability to climate change – Factsheets. EEA working paper. Available at: http://climate-adapt.eea.europa.eu/repository/fact-sheets-final-27_06_2017.pdf

[24] EEA (2007). Floods [online] Available at: https://www.eea.europa.eu/themes/water/water-resources/floods [Accessed 19 Apr. 2018]

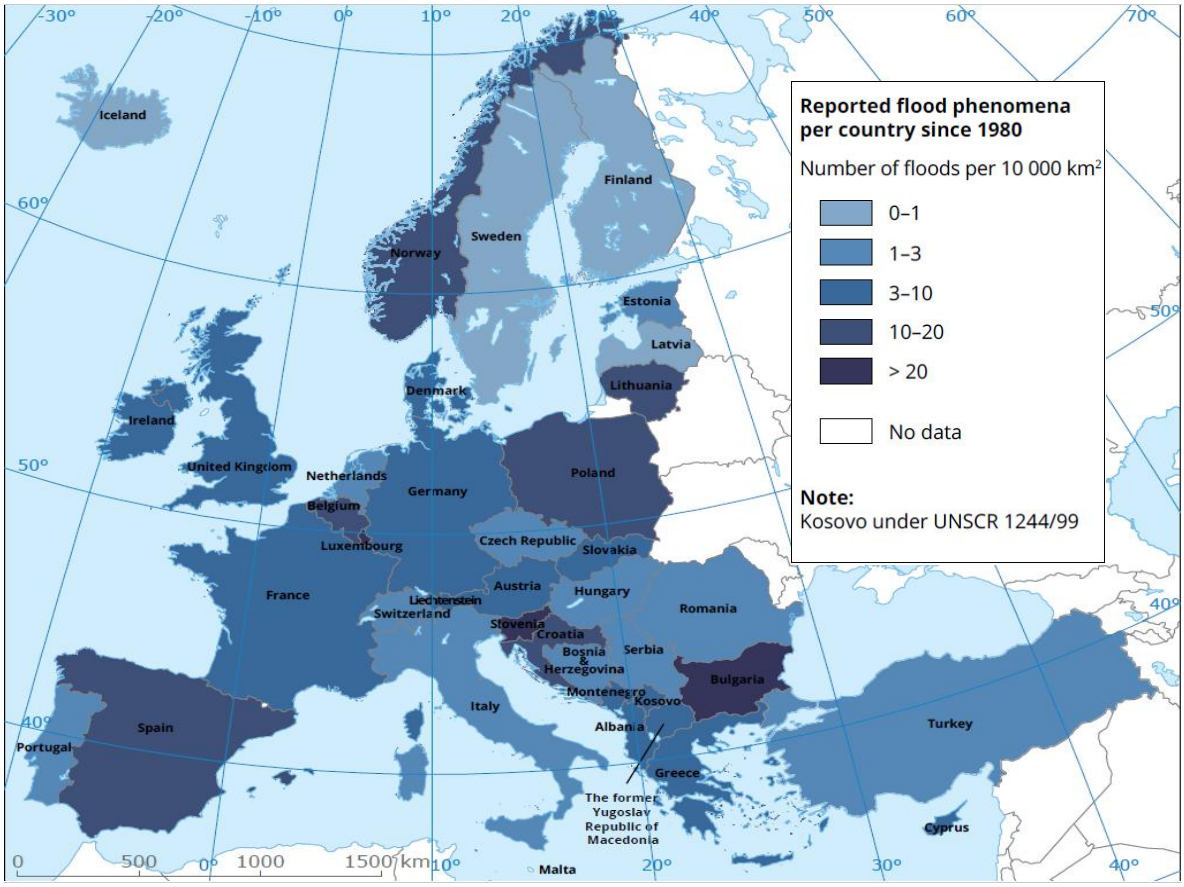

Figure 9: Reported flood phenomena (number of floods per 10.000 sq. km) per country (1980-2010)[25]

In the EU, river flooding is estimated to have caused annual average economic losses of around EUR 4.9 billion in the 2000-2012 period, but the economic losses from a single flooding event can be as high as the 2013 flood losses, which amounted to EUR 12 billion affecting nine central and eastern European countries [70].

4.5.5 Key factors for the analysis, relative to river flooding (by avenues), in urban areas.

The severity of fluvial flooding is related to the possible loss of human life and impact on human health and environmental quality, as well as economic losses (due to direct and indirect material damage: e.g., impact on the proper functioning of infrastructures and services, productivity) and is proportional to the flood spot and the existence of sensitive elements (dwellings) within that spot, the depth that the river can reach and the speed of the flood. As elements of analysis it is convenient to resort to:

- Hydrographic network, including all elements, not only rivers, but also regattas and ravines, or ditches.
- Identification of possible hidden channels under the urbanization.

[25] Source: EEA (2016). Flood risk and environmental vulnerability — Exploring the synergies between floodplain restoration, water policies and thematic priorities, EEA Report 1/2016, European Environment Agency.

- The rainfall history in the locality (frequency and severity of flood episodes).
- The existence of hydraulic models. For certain sections of the main rivers of Navarra region, models represented by flood curves are available (accessible from the websites of the Ministry of Ecological Transition, the Hydrographic Confederations of Andalusia of the spatial data infrastructure of Andalusia) but not all the channels are included, neither there are studies of regattas and ravines. However, technical approaches based on experience could be made.
- The existence of gauging records, as well as possible early warning systems, which in combination make it possible to foresee the avenues well in advance and facilitate evacuation (avoiding human and material losses).
- The absorption capacity of the land included within the flood patch, as it is more or less permeable (forests, parks) or is specially designed as a laminating pool.
- The possibilities of action in riverbeds or the most delicate sections of them (existence of buildings and sensitive uses, sensitive infrastructures such as treatment plants or historical infrastructures, such as Romanesque bridges, with limited drainage capacity and risk of breakage).

4.5.6 Pluvial flooding

Pluvial flooding is becoming increasingly prominent in European urban areas, although comprehensive modelling and mapping work is yet limited. Surface water flooding, caused by excessive rainwater runoff above the capacity of drainage systems, is becoming an increasing threat to European cities and urban areas. Indeed, surface water flooding (and groundwater flooding) accounted for the highest number of recent flood events occurring since 2000 in Europe's Member States and nine have produced maps for current exposure to this hazard, as reported under the Floods Directive [58].

The socio-economic impacts resulting from floods do not differ substantially among the different types of floods. They can cause deaths, environmental damages, social problems (displacement) and significant economic losses due to damages in infrastructure, property and agricultural land, and indirect losses [71]. Although according to EEA (2017), fatalities from floods are not as high as other natural hazards (i.e., climatological and geophysical events) [71], the resulted economic losses are substantially high. In terms of the material impacts, residential, commercial and public buildings and assets as well as public utility objects and networks can be severely damaged and lead to exceptionally high costs [71]. Furthermore, the destruction of transport infrastructure and vulnerable objects, such as petrol stations, might cause significant economic losses and social disruption. The impacts that floods can have on the economy can be particularly detrimental with long-term effects, including the destruction of agricultural and market products as well as the disruption of all sorts of business and productive activities. Finally, flooding causes both direct and indirect health effects. The direct health impacts involve injuries and drownings and illnesses due to polluted water, and the indirect ones include illnesses due to damp and fungi resulted from flooded residential areas and post-traumatic stress due to dislocation and loss [71].

Projections of river floods are subject to the highest levels of uncertainty, as they often depend on changes in single extreme events [56]. However, since heavy daily precipitation is the predominant factor that is correlated with flooding events and that is projected to increase in frequency by up to 35% in most parts of Europe during the 21st century [56], the risk of river floods can be expected to increase as well.

4.5.7 Key factors for the analysis, relative to rain flooding (overflow of networks), in urban areas.

The severity is in relation to the material damage that can occur, both in the water evacuation networks themselves and in sensitive buildings (humidity in ground floors can cause or aggravate pathologies) or urbanizations (electrical installations, communication), besides of being able to accuse hygiene or pollution problems (rivers and water supply). Questions to be analysed, to guide decisions, must be:

- Rainfall history and network flooding episodes throughout the network or at certain points.
- The capacity of the rainwater network, in relation to current and potential torrential rain events.
- The existence of separate or communicated rainwater and sanitation networks, making it necessary to schedule the replacement of networks that are not separate.
- The capacity and location of water treatment plants and their possible overflow resulting in contamination of water and riverbeds.

4.5.8 Useful data sources

Useful sources of data on flood hazards in Europe include:

- The European Floods Awareness System (EFAS), which provides free flood forecasts to partnering national and/or regional authorities responsible for flood forecasting: www.efas.eu
- Examples of flood hazard maps including links to online flood hazard mapping tools, available from the European Commission: http://ec.europa.eu/environment/water/flood_risk/pdf/MS%20examples.pdf
- The RAMSES project, which developed projections for future fluvial and pluvial flood hazards for 571 European cities covered by the Urban Audit: http://www.ramses-cities.eu
- The RESIN project- on climate change adaptation: https://resin-cities.eu/fileadmin/user_upload/D1_1_SOTAHazards_UNIMAN_2015-11-30.pdf
- The ESPON TITAN Territorial impacts of Natural Disasters: https://www.espon.eu/natural-disasters

4.6 Subsidence

Land subsidence is here intended as the gradual settling of the ground surface on a regional scale. Generally speaking, the term land subsidence includes not only gradual settling but also the sudden sinking of the Earth's surface due to removal or displacement of subsurface earth materials. The principal causes of land subsidence include:

- aquifer-system compaction associated with groundwater withdrawals;
- drainage of organic soils;
- underground mining;
- liquefaction;
- natural compaction or collapse, such as with sinkholes or thawing permafrost

The land subsidence phenomenon discussed in this chapter includes only regional land subsidence, herein also referred to as subsidence for shortness.

Land Subsidence can have natural as well as anthropogenic causes. Natural causes have geologic roots that include tectonics, glacial isostatic adjustment and natural sediment compaction. Subsidence from anthropogenic causes occurs as a result of compression of deeper layers generated by the extraction of resources such as oil, gas, coal, salt and groundwater [72].

The possible effects of land subsidence include:

- damage to buildings and infrastructures (direct effects);
- changes in relative water levels, both groundwater levels and surface water levels (indirect effects);
- increased flood risk in low-lying areas, and lasting damage to groundwater aquifers and aquatic ecosystems.

Figure 10 shows the current subsidence problems related to socio-economic development and climate change [73].

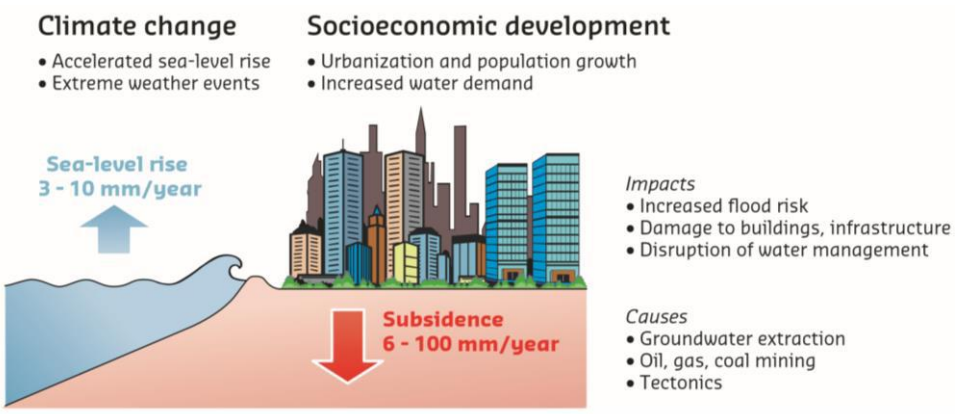

Figure 10: Land subsidence from a multi-sectoral perspective (Source [73]**)**

4.6.1 Hazard characterization

A widespread land subsidence process, of both natural and anthropogenic origin, affects many coastal and delta cities all over the world, where land subsidence exceeds absolute sea-level rise up to a factor of ten. Increased flooding and other widespread impacts of land subsidence result in damage totalling billions of dollars per year. A major cause of severe land subsidence is excessive groundwater extraction due to rapid urbanization and population growth, while the effect of natural subsidence tends to be exiguous.

A significant deterioration to the urban as well as to the natural environments affected by land subsidence became evident in the city centres, where ancient monuments and the basement of old buildings can be permanently flooded. Furthermore, the coast may experience an increased frequency of flooding during severe sea-storms. At the same time, in the countryside, a dense net of channels and water pumping plants must be built along with the rising of the river embankments to keep the farmland drained. In many coastal areas, a continuous sequence of pine forest, dating back to the Middle Age, lagoons, and marshes located behind the dune ridges was jeopardized by increasing salinization of the phreatic aquifer. Often local groundwater level must be artificially kept low by dewatering, becoming a source of maintenance problems and current critical issues.

Some major potential impacts of subsidence, which in many sites could be aggravated in the long term by climate change (e.g., sea-level rise, increased storm surges and changes in precipitation) are:

- Increased flood risk (frequency, severity and duration of inundation) and more frequent rainfall-induced floods due to ineffective drainage systems;
- Increased need for pumping;
- Damage to buildings, foundations and subsurface structures (e.g., drainage system, etc.).

The entity of land subsidence is usually quantified through a parameter known as **subsidence rate** (**KPI #196**), which is defined as trend of settlements with time, in mm/year, typically represented using maps of isolines of total settlement and isokinetics (with annual subsidence rate). In order to measure land subsidence rates, accurate measuring techniques are required, as traditional systematic optical levelling, GPS surveys, LIDAR and INSAR remote sensing techniques.

4.6.2 Exposure

In the context of land subsidence, exposure should be carefully evaluated, since the nature of this hazard is different from that of other natural disasters, such as floods, earthquakes, etc... Indeed, land subsidence is a continuous phenomenon. It is not hazardous if it generates homogeneous settlements over large areas and if these areas are sufficiently elevated concerning the groundwater level. On the contrary, it could trigger hazardous phenomena in case of a variable rate of subsidence in limited size sites, causing differential settlement of the buildings located in the investigated area. It

also negatively impacts on those sites where ground level and local groundwater level are close, as in low-lying areas. These are the cases where, the progressively increased need for pumping due to subsidence creates maintenance problems and other critical issues, like increased risk of flooding.

4.6.3 Sensitivity

In SHELTER the effect of subsidence is evaluated through its potential consequences on the built environment. Damage to buildings and infrastructures can be measured through the **deflection ratio** (**KPI #396)**, a non-dimensional parameter given by the ratio of the differential settlement between two points of the structure and their relative distance. It can be deduced from field maps (i.e., maps of isolines of the total settlement, cited above). The effect of differential settlements on structure stability depends on the type of structure or infrastructure involved at the ground surface.

In terms of increased flood risk, the impact of subsidence is more significant in low-lying areas, characterized by modest or even negative values of **elevation above sea level (m) (KPI #228)**.

5 Hazard non-dependent indicators

The hazard non-dependent indicators are aimed to quantify generalised resilience. These indicators help to understand and improve community resilience, quantifying the cultural and socio-demographic context and the coping, adaptive and transformative capacities of the socio-ecological systems.

The literature analysis of the indicators for hazard non-dependent categories used as a starting point the comprehensive work of Edgemon et al. "Community Resilience Indicator Analysis: County-Level Analysis of Commonly Used Indicators from Peer-Reviewed Research" [74]. The authors studied recent meta-analyses of peer-reviewed community resilience assessment methodologies selecting six relevant meta-analyses: Cutter (2015)[75], Koliou et al. (2018) [76], Lavelle et al. (2015) [77], Ostadtaghizadeh et al. [78], Sharifi et al. (2016) [2] and Winderl (2014)[1] and 27 methodologies were identified.

In order to identify useful indicators, these 27 methodologies were narrowed down to 11, selecting the ones with the following criteria:

- The ones focused on the following categories: food security, humanitarian, water scarcity, poverty, health and drought.
- The ones that could be applied at the community level
- The ones with quantitative indicators
- The ones with public data sources

CODE	NAME	DATE	SOURCE	Number of selected indicators
BRIC	Baseline Resilience Indicators for Communities (BRIC)	2014	[79]	25
CDRI	Community Disaster Resilience Index	2010	[80]	9
CDRI-I	Community Disaster Resilience Index (Italy)	2019	[81]	8
CR-E	Community Resilience in Disaster Prone Districts	2015	[82]	3
CRI2	Community Resilience Index	2010	[83]	1
DROP	Disaster Resilience of Place	2010	[84]	6
ODI	Overseas Development Inst.	2013	[85]	11
PVI	Prevalent Vulnerability Index	2011	[86]	12
ResilUS	Resilience Institute	2011	[87]	6
SVI	Social Vulnerability Index	2011	[88]	4
TNC	The Nature Conservancy Coastal Resilience Mapping Tool	2015	[89]	5

Table 9: Selected resilience indicators frameworks

The indicators from these frameworks were categorised in the following groups:

- Education
- Demographic
- Transport/ Access
- Communication
- Economic
- Infrastructure
- Housing
- Urban
- Employment & business
- Immigration
- Political
- Social capital
- Institutional
- Mortality & Losses
- Operational/ recovery
- Exposure
- Index

From all the similar indicators from de different frameworks, the indicator that was best suited for HA context was then selected. The gap detection process explained in Section 3.3 identified the measuring objectives that were missing. A literature review was conducted again focused on the indicators that were missing. It is worth mentioning that the results of EMBRACE project[26] ("Building resilience amongst communities in Europe", FP7) were very useful in this step [90].

[26] https://sites.google.com/site/embracehandbook/. Accessed 27/09/2020

6 SENDAI framework

SHELTER can contribute to the implementation of Sendai Framework, supporting Regions in the process of "Avoiding generation of new risks and mitigating existing ones" and "Building Back Better". On 17 June 2016, the EC published an Action Plan [91] on the Sendai Framework. Covering five years, the Plan provides for a more systematic disaster-risk-informed approach in EU policy-making. One of the implementation priorities concerns the development of good practice regarding the essential integration of CH in National Disaster Risk Reduction (DRR) strategies to be developed by the EU Member States. The execution of the SHELTER project will support the implementation of the EU adaptation strategy[27]. The Sendai Framework Monitor (March 2018) is based on a set of 38 indicators that will track progress in implementing the Sendai Framework's seven targets. It has been identified that SHELTER will inform specifically the C-6 indicator (Direct economic loss to cultural heritage damaged or destroyed attributed to disasters) including it in the short-list (**KPI #383**).

[27] http://ec.europa.eu/clima/policies/adaptation/index_en.htm

7 Final list of indicators

The final list of indicators can be found here. The list has the following information regarding each indicator:

INDICATOR SPECIFICATIONS	
ID	Identification number of the indicator
PHASE	Phase to which the indicator applies: Prevention/adaptation or Recovery
OBJECTIVE	Risk component the indicator is measuring
SUB-OBJECTIVE	Specification of the aspect of the risk component
SUBCATEGORY	Characterisation/ description of the indicator scope
INDICATOR	Denomination of the indicator
PARAMETER	The variable used to measure the indicator
UNIT	The unit of measure
VALUE	The variable in which resilience is evaluated
APPLICABILITY OF SHELTER	
SH INDICATOR	Identifies if Shelter results will impact on the indicator: yes/no.
HAZARD, SCALE & FREQUENCY	
HAZARD	Identifies the hazards related to the indicator: Earthquake, flood, storm, heatwave, wildfire, subsidence
SCALE	Identifies the scale(s) related to the indicator: Artefact, building, district/urban, regional
FREQUENCY	Identifies how often the indicator should be measured
OPEN LABS VALIDATION	
OL NAME	Identifies the name of the Open Lab
MEANINGFULNESS	Identifies the meaningfulness of the indicator for the Open Lab and its hazard. 0= Not at all important/Not a priority 1 = Moderately important to very important/ medium to high priority 2 = Extremely important/Essential
FEASIBLE	Identifies if the indicator is feasible in terms of data availability and timely data collection, thus obtainable with reasonable and affordable effort in the Open Lab 1= feasible 0.5 = not feasible

Table 10: Structure and information available in the indicators list

A factsheet for each indicator can be found in annexes to facilitate their application in the OLs. Each factsheet has the following information:

DESCRIPTION	
ID	Identification number of the indicator
NAME	Denomination of the indicator
PHASE	Phase to which the indicator applies: Prevention/adaptation or Recovery
HAZARD	Identifies the hazards related to the indicator: Earthquake, flood, storm, heatwave, wildfire, subsidence
OBJECTIVE	Risk component the indicator is measuring
TYPE	Descriptive/Assessment/Monitoring
SCALE	Artefact/Building/ Urban/ District/Regional
DEFINITION	Definition of the indicator
FOCUS/OBJECTIVES	Sub-category
CH SINGULARITY	Is it an indicator specifically for CNH?
NOTES	
DATA AND MEASUREMENT	
REQUIRED DATA	Required data for the calculation of the indicator
COMPLEXITY LEVEL	• Easy to calculate and requires few data; • Easy to calculate but requires data; • Medium calculation difficulty and required data; • Medium calculation difficulty but requires a lot of data • High calculation and requires few data; High calculation difficulty and requires a lot of data
INPUT TYPE	Quantitative/quantitative
DATA SOURCE	Data sources for the calculation
FREQUENCY	How often to use this indicator (hourly, daily, monthly, seasonal, yearly…)
MEASUREMENT UNIT	Professionals
REQUIRED TOOL	If specific tools/software are needed for the calculation of the indicator
CALCULATION METHOD	How the indicator is calculated through a formula or a detailed description on how to obtain it
OUTPUT TYPE	Quantitative/Qualitative
EXAMPLES	
LINKS AND REFERENCES	
KEYWORDS	
REFERENCES	

Table 11: Structure and information available in the factsheets

8 Integration of collaborative early warning systems

Early warning systems are a special type of information system that signal possible dangers to the user(s) in advance.[28] Their special feature is that they are suitable:

- to perceive and analyse relevant phenomena in observed areas as indicators (indications) of possible hazards at an early stage,
- to forward specific early warning information to the user(s) of the system in the event of changes in relevant phenomena that deviate from the specified limits or developments that are considered permissible, and thus
- to enable users to have sufficient time for taking appropriate measures to avoid or reduce hazards.

In general, all identified indicators that are assigned to Prevention and Recovery phases of DRM are consultable for the early warning system. Besides, some indicators which are assigned to the preparedness phase may also be relevant for the early warning system.

In this chapter, the result of a first analysis for possible indicators for the SHELTER early warning system is shown. A suggestion for the next step in the following T3.1 (Multi-hazard early warning systems) would be to bring the identified indicators in a timeline. An early warning system shall inform before the impact of the event takes place or better before the event starts. Therefore it is necessary to know this time for each indicator. The impact of an event for the CH and the measures to reduce or avoid these impact as well as the time for the effective implementation of the measures may be for example a guideline for the usability of the identified indicators.

In the framework of early warning systems, it is worth to mention the Copernicus Emergency Management Service (EMS) mapping, which is able to provide immediate data and start with data collection before a hazardous event has occurred.

8.1 Possible multi-hazard indicators for early warning systems

The following indicators are identified as multihazard indicators which can be used for the early warning system. Especially the RMI-indicators (#310 to #331) can be used for the calibration of a common early warning system.

Number	Indicator	Description and/or parameter
17	Road and traffic disturbance	Vehicles: for road disruption, the water level should be considered.
58	Population density	Habitants
83	Percent of people with disasters preparedness education	No. of people/total
84	% of the population with access to risk information	No. of people/total

[28] http://geb.uni-giessen.de/geb/volltexte/2013/9841/pdf/GU_12_1979_2_S_21_32.pdf (25.07.2020)

105	Distance to service centres	Km
106	Distance to fire brigades	Km
129	Hospital beds per 10,000 persons	Number
138	% of buildings complying with hazard-resistant building codes and/or standards	No. hazard retrofitted buildings/tot. Buildings
166	Red Cross volunteers per 10,000 persons	Number
210	Population in the hazard area	Number of population
211	Buildings in the hazard area	Number of buildings
212	Critical facilities in the hazard area	Number of facilities
310	RMI: Hazard monitoring and forecasting (Risk Identification Indicator)	The Risk Management Index brings together a group of indicators that measure a country's risk management performance. These indicators reflect the organizational, development, capacity and institutional actions taken to reduce vulnerability and losses, to prepare for crisis and to recover efficiently from disasters. Each RMI indicator is evaluated for a defined timescale of 5 years for the last 20 years. For each Indicator Type/category (RI, RR, DM, GF) it is also possible to weigh the indicators in the type but not mandatory. Five-degree scale: 1.Minimum and deficient instrumentation of some important phenomena. 2.Basic instrumentation networks with problems of updated technology and continuous maintenance. 3.Some networks with advanced technology at the national level or in particular areas; improved prognostics and information protocols established for principal hazards. 4.Good and progressive instrumentation cover at the national level, advanced research in the matter on the majority of hazards, and some automatic warning systems working. 5.Wide coverage of station and sensor networks for all types of hazard in all parts of the territory; permanent and opportunity analysis of information and automatic early warning systems working continuously at the local, regional and national levels.
321	RMI: Organization and coordination of emergency operations. (Disaster Management Indicator)	Same as 310.Five-degree scale: 1.Different organizations attend emergencies but lack resources and various operate only with voluntary personnel. 2.Specific legislation defines an institutional structure, roles for operational entities and coordination of emergency commissions throughout the country.

		3.Considerable coordination exists in some cities, between organizations in preparedness, communications, search and rescue, emergency networks, and management of temporary shelters. 4.Permanent coordination for response between operational organizations, public services, local authorities and civil society organizations in the majority of cities. 5.Advanced levels of interinstitutional organization between public, private and community-based bodies. Adequate protocols exist for horizontal and vertical coordination at all territorial levels.
322	RMI: Emergency response planning and implementation of warning systems (Disaster Management Indicator)	Same as 310. Five-degree scale: 1.Basic emergency and contingency plans exist with checklists and information on available personnel. 2.Legal regulations exist that establish the obligatory nature of emergency plans. Some cities have operational plans and articulation exists with technical information providers at the national level. 3.Protocols and operational procedures are well defined at the national and sub-national levels and in the main cities. Various prognosis and warning centres operate continuously. 4.Emergency and contingency plans are complete and associated with information and warning systems in the majority of cities. 5.Response preparedness based on analysis
323	RMI: Supply of equipment, tools and infrastructure. (Disaster Management Indicator)	Same as 310. Five-degree scale: 1.Basic supply and inventory of resources only in the operational organizations and emergency commissions. 2.Centre with reserves and specialized equipment for emergencies at the national level and in some cities. Inventory of resources in other public and private organizations. 3.Emergency Operations Centre which is well stocked with communication equipment and adequate registry systems. Specialized equipment and reserve centres exist in various cities. 4.EOCs are well equipped and systematized in the majority of cities. Progressive complimentary stocking of operational organizations. 5.Interinstitutional support networks between reserve centres and EOCs are working permanently. Wide-ranging communications, transport and supply facilities exist in case of emergency.
324	RMI: Simulation, updating and testing of inter-institutional response	Same as 310. Five-degree scale:

	capability. (Disaster Management Indicator)	1.Some internal and joint institutional simulations between operational organizations exist in some cities. 2.Sporadic simulation exercises for emergency situations and institutional response exist with all operational organizations. 3.Desk and operational simulations with the additional participation of public service entities and local administrations in various cities. 4.Coordination of simulations with community, private sector and media at the national level, and in some cities. 5.Testing of emergency and contingency plans and updating of operational procedures based on frequent simulation exercises in the majority of cities.
326	RMI: Rehabilitation and reconstruction planning. (Disaster Management Indicator)	Same as 310. Five-degree scale: 1.Design and implementation of rehabilitation and reconstruction plan only after important disasters. 2.Planning of some provisional recovery measures by public service institutions and those responsible for damage evaluation in some cities 3.Diagnostic procedures, reestablishment and repairing of infrastructure and production projects for community recovery are available at the national level and in various cities. 4.Ex ante undertaking of recovery plans and programs to support social recovery, sources of employment and productive means for communities in the majority of cities. 5.Generalized development of detailed reconstruction plans dealing with physical damage and social recovery based on risk scenarios. Specific legislation exists and anticipated measures for reactivation.
327	RMI: Decentralized organizational units, inter-institutional and multisector coordination (Governance and Financial Protection Indicator)	Same as 310. Five-degree scale: 1.Basic organizations at the national level arranged in commissions, principally with an emergency response approach. 2.Legislation that establishes decentralized, interinstitutional and multisectoral organization for the integral management of risk and the formulation of a general risk management plan. 3.Interinstitutional risk management systems active at the local level in various cities. Inter-ministerial work at the national level in the design of public policies for vulnerability reduction. 4.Continuous implementation of risk management projects associated with programs of adaptation to climate change, environmental protection, energy, sanitation and poverty reduction. 5.Expert personnel with wide experience incorporating risk management in sustainable

		human development planning in major cities. High technology information systems are available.
328	RMI: Availability of resources for institutional strengthening (Governance and Financial Protection Indicator)	Same as 310. Five-degree scale: 1.Existence of a national disaster fund and some local funds in some cities. 2.Regulation of existing reserve funds or creation of new sources to co-finance local level risk management projects. 3.National economic support and search for international funds for institutional development and strengthening of risk management in the whole country. 4.Progressive creation of reserve funds at the municipal level to co-finance projects, institutional strengthening and recovery in times of disaster. 5.Financial engineering for the design of retention and risk transfer instruments at the national level. Reserve funds operating in the majority of cities.
329	RMI: Budget allocation and mobilization (Governance and Financial Protection Indicator)	Same as 310. Five-degree scale: 1.Limited allocation of the national budget to competent institutions for emergency response. 2.Legal norms establishing budgetary allocations to national level organizations with risk management objectives. 3.Legally specified specific allocations for risk management at the local level and the frequent undertaking of interadministrative agreements for the execution of prevention projects. 4.Progressive allocation of discretionary expenses at the national and municipal level for vulnerability reduction, the creation of incentives and rates of environmental protection and security. 5.National orientation and support for loans requested by municipalities and subnational and local organizations from multilateral loan organizations.
330	RMI: Existence of social safety nets and funds (Governance and Financial Protection Indicator)	Same as 301. Five-degree scale: 1.Sporadic subsidies to communities affected by disasters or in critical risk situations. 2.Permanent social investment funds created to support vulnerable communities focusing on the poorest socio-economic groups. 3.Social networks for the self-protection of means of subsistence of communities at risk and undertaking of post-disaster rehabilitation and reconstruction production projects. 4.Regular micro-credit programs and gender-oriented activities oriented to the reduction of human vulnerability.

		5.Generalized development of social protection and poverty reduction programs integrated with prevention and mitigation activities throughout the territory.
331	RMI: Insurance coverage and loss transfer strategies for public assets. (Governance and Financial Protection Indicator)	Same as 310. Five-degree scale: 1.Very few public buildings are insured at the national level and exceptionally at the local level. 2.Obligatory insurance of public goods. Deficient insurance of infrastructure 3.Progressive insurance of public goods and infrastructure at the national level and in some cities. 4.Design of programs for the collective insurance of buildings and publicly rented infrastructure in the majority of cities. 5.Analysis and generalized implementation of retention and transfer strategies for losses to public goods, considering reinsurance groups, risk titles, bonds, etc.
384	Number of professionals trained in post-disaster recovery and preservation of cultural heritage	Number
388	Duration of an infrastructure outage	Measured in hours

Table 12: Possible multi-hazard indicators for early warning systems

8.1.1 Possible earthquake indicators for early warning systems

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for earthquakes.

Number	Indicator	Description and/or parameter
184	Soil stability index	The capacity of the land to limit the redistribution and loss of soil resources by wind and water.
354	Peak Ground Acceleration (PGA)	Maximum ground acceleration that occurred during earthquake shaking at a location
356	Earthquake intensity (Modified Mercalli scale)	the severity of an earthquake in terms of its effects on the earth's surface and humans and their structures

Table 13: Possible earthquake indicators for early warning systems

8.1.2 Possible wildfire indicators for early warning systems

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for wildfire.

Number	Indicator	Description and/or parameter
1	Daily maximum precipitation corresponding to the return period T	Daily Maximum precipitation rates mainly relevant for fluvial flood
2	Hourly maximum precipitation for a return period (relevant for pluvial flood)	hourly Maximum precipitation rates very relevant for Pluvial Flooding (Run-off)
20	Mean Diurnal Range (Mean of monthly (max temp - min temp))	Measured in Celsius degree
38	Relative water content in the top few centimetres of soil (usually up to 5 or 7 cm). The top layer is crucially important, as it provides water supply for vegetation, and directly affects local air temperature and humidity.	Indication in %
39	Fire weather index	Nowadays Copernicus has subcontracted a European tourism Sectoral Information System (SIS) to develop it- not available yet but worth to follow-up on this one.
57	Air quality	stratospheric ozone (O3) levels
363	Soil Water Index (SWI)	It quantifies moisture based on the Surface Soil Moisture, presenting it at various soil depths

Table 14: Possible wildfire indicators for early warning systems

8.1.3 Possible heat wave indicators for early warning systems

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for heat waves.

Number	**Indicator**	**Description and/or parameter**
20	Mean Diurnal Range (Mean of monthly (max temp - min temp))	Measured in degree
38	Relative water content in the top few centimetres of soil (usually up to 5 or 7 cm). The top layer is crucially important, as it provides water supply for vegetation, and directly affects local air temperature and humidity.	Indication in %
43	Daily mean temperature	Celsius degree
44	Thermal shock [Tmax-Tmin]	Indication on Celsius degrees
45	Daily sun hours	Time
46	Mean relative humidity	Humidity

47	Daily humidity cycle shocks [RH(n)-RH(n+1)>25%]	Humidity
48	Relative humidity concentration [nRH>75%]	Humidity
57	Air quality	stratospheric ozone (O3) levels

Table 15: Possible heat waves indicators for early warning systems

8.1.4 Possible storms indicators for early warning systems

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for storms.

Number	Indicator	Description and/or parameter
1	Daily maximum precipitation corresponding to the return period T	Daily Maximum precipitation rates mainly relevant for fluvial flood
2	Hourly maximum precipitation for a return period (relevant for pluvial flood)	hourly Maximum precipitation rates very relevant for Pluvial Flooding (Run-off)
4	Torrentiality index (factor).	The Index of torrentiality expresses the relationship between the hourly precipitation intensity and corrected daily mean. Its value is determined in function of the geographical area.
274	Wind speed	Differentiation between Hurricane, violent storm, heavy storm, storm
281	Air pressure	change of barometric pressure in defined time (mins to an hour); the strong decrease is an indicator for bad weather. Sometimes combined with strong gusts and storm. When the barometric pressure falls within one hour more than 1-2hPa the probability is high for heavy wind or storm.
284	CAPE Index	CAPE stands for Convective Available Potential Energy; CAPE (the maximum available potential energy for convection) is a measure of how much an air packet can be lifted. High CAPE values (>2000 J/kg) in combination with a clearly negative Lifted Index are an indication for the occurrence of very high reaching and therefore mostly thunderstorms. Convective Available Potential Energy is a measure of the energy that can be created if there is enough heat in a cloud to give convection. The values are given in Joules per Kilogram of air as a general rule. The greater the energy that is released during convection, the greater will be the charge separation and the more lightning is liable to occur.
332	Lifted index	The Lifted Index is a measure of the stability/stability of the stratification in the atmosphere and is calculated from the

		temperature difference between an air package adiabatically lifted to a certain level and the surrounding air mass. If the index is negative (labile stratification), thunderstorms are possible, if it is positive (stable stratification), thunderstorms are unlikely. If the index is clearly negative, intensive thunderstorms are possible. The temperature on the ground is compared with the temperature at a specific pressure level. The difference between the values is the Lifted index (LI). It is therefore a dimensionless measure of instability in the atmosphere and is expressed with values between -6 and +6. The Lifted Index is mainly used for thunderstorm forecasting. A negative value indicates, for example, stronger up winds where thunderstorms can develop. On the other hand, a positive index indicates stable conditions where thunderstorms are unlikely to occur. In weather charts, LI is given as an altitude independent value. LI = (500mb T - T*) T* = temperature as the value of an air package, which is characterised by the dew point of the lowest 1000 m and the maximum forecast soil temperature, if it is raised to the condensation point dry-adiabatically and subsequently wet-adiabatically up to the 500 hPa layer The lower the value, the higher is the probability of thunderstorms (see the following parameter).
334	heavy rain	Precipitation quantity within one hour
335	wind pressure	The wind pressure or dynamic pressure of the wind on a surface perpendicular to the wind direction is an essential variable for the construction of buildings, or CH for example.
337	gust strength	A gust is a sudden strong gust of wind that lasts only briefly (between 3 and a maximum of 20 seconds). It stands out at least ten knots from the measured 10-minute average wind speed. It occurs mainly during or before a thunderstorm, in the context of rain, hail and snow or a cold front.
343	storm duration	time with high wind speeds in the defined area
353	Count of missions due to storm events	Number of alerts and missions

Table 16: Possible storms indicators for early warning systems

8.1.5 Possible floods indicators for early warning systems

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for floods.

Number	Indicator	Description and/or parameter
1	Daily maximum precipitation corresponding to the return period T	Daily Maximum precipitation rates mainly relevant for fluvial flood
2	Hourly maximum precipitation for a return period (relevant for pluvial flood)	hourly Maximum precipitation rates very relevant for Pluvial Flooding (Run-off)
3	Hyetograph	distribution of the rainfall intensity over time, corresponding to the return period T and duration of the event (e.g. less than 8 hours for pluvial flood and less than 3 days for fluvial flood)
4	Torrentiality index (factor).	The Index of torrentiality expresses the relationship between the hourly precipitation intensity and corrected daily mean. Its value is determined in function of the geographical area.
7	Flood depth	Measured in m
8	Water velocity (in the flooded area)	Measured in m/s
9	Combinations of flood depth and water velocity in the flood area	This is very relevant when evaluating people at risk
11	Surface runoff	Measured in m^3/s
145	Dam capacity	Measured in m^3/s

Table 17: Possible floods indicators for early warning system

8.1.6 Possible subsidence indicators for early warning system

Based on the indicators identified in the shortlist, the following table shows the result of the first analysis for possible indicators specific for subsidence.

Number	Indicator	Description and/or parameter
145	Dam capacity	Measured in m^3/s
184	Soil stability index	The capacity of land to limit the redistribution and loss of soil resources by wind and water.
185	Soil water content	% water by weight or volume of soil

Table 18: Possible subsidence indicators for early warning system

9 Tailored Monitoring Strategy for Open Labs

9.1 Validation of the indicators by OL

In order to determine the applicability of the indicators and to link data availability to specific locations, a validation process has been addressed during OLs Workshops to build a tailored resilience assessment for each OL, considering their type of heritage, the hazards they are facing as well as their scale. Given the wide scope of the resilience assessment, it was considered appropriate to involve broad-based participation of stakeholders with different profiles and expertise, through a Workshop exercise.

Of the 433 indicators collected from the literature review and prioritized by technical partners, stakeholders were asked to rate the meaningfulness of each indicator as well as their feasibility in terms of data availability. The objective of the exercise was to reduce the initial list of indicators into a manageable number of entries for each Open Lab, without compromising the coverage of key issues.

As a first step, a tailored list of indicators was prepared for the exercise of each Workshop by filtering hazard-dependant indicators to the hazard faced by the Open Lab. The list was circulated among stakeholders previous to the workshop, to enable them to get familiar with the spreadsheet. During the Workshop, the general framework was explained, and indicators discussed. Stakeholders were asked to answer the following questions as part of a remote exercise:

1. Please, evaluate the indicators according to their meaningfulness in measuring resilience against [*type/s of hazard*] in your historic area, by selecting the indicators with highest or lowest priorities

    - *0 Not at all important/Not a priority*
    - *1 Moderately important to very important/ medium to high priority*
    - *2 Extremely important/Essential*

2. Please, answer with a yes/no to the following questions:

    - *Is the indicator sufficiently specific by providing a clear description of what has to be measured?*
    - *Is the indicator feasible in terms of data availability and timely data collection, thus obtainable with reasonable and affordable effort?*

Respondents were also requested to suggest the inclusion of any missed but relevant indicators.

Each OL responsible was in charge of summarising the received responses and get a consensus on the final rating value, validating the final list for the related Open Lab. 25 new indicators were proposed and included in the final list, while some indicators definitions were improved according to stakeholders suggestions. The following table summarises the indicators that were considered as a medium-high priority, as essential as well as essential and available:

			SAVA			GAL			DORD			RAVENNA			SEFER		
		Shortlist	Medium-high priority	Essential	Essential & feasible	Medium-high priority	Essential	Essential & feasible	Medium-high priority	Essential	Essential & feasible	Medium-high priority	Essential	Essential & feasible	Medium-high priority	Essential	Essential & feasible
prevention/adaptation																	
measuring trends source/hazards	frecuency	5	2	1	1	1	1	1	1	2	2	0	3	3	0	0	0
	magnitude	53	3	3	3	9	13	13	3	3	3	10	21	20	7	15	14
	duration	3	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0
	intensity	7	5	1	1	0	0	0	4	2	1	3	1	1	0	0	0
	Intenstiy, duration and frequency	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0
measuring exposure	people	1	0	1	1	0	1	1	0	0	0	0	1	1	0	1	1
	activities	1	0	1	1	0	0	0	0	1	1	0	1	1	0	0	0
	object/buildings/infrastructure	8	1	2	2	1	0	0	2	0	0	0	4	4	1	5	5
	ecosystems	2	0	1	1	0	0	0	1	0	0	2	0	0	0	1	0
measuring sensitivity	social/demography characteristics	10	4	0	0	1	3	3	7	0	0	1	3	3	2	4	4
	economic characteristics	12	1	0	0	0	7	7	5	0	0	1	2	2	2	0	0
	infrastructure characteristics	8	4	1	1	2	2	2	6	0	0	4	2	0	0	4	3
	building characteristics	34	10	2	2	1	0	0	7	4	3	4	15	13	2	9	1
	environmental sensitivity	26	1	1	1	9	5	5	3	0	0	1	3	3	1	1	0
measuring coping capacity	awareness/information	6	4	1	1	0	1	0	3	0	0	1	1	0	1	2	0
	networks/solidarity/Community preparedn	1	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0
	insurance/funds	3	3	0	0	0	0	0	3	0	0	2	1	0	0	2	0
	DRM	9	0	8	6	1	4	4	2	7	6	0	4	0	3	5	2
	social memory	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	shelter capacity	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	protection of natural resources	11	2	1	1	0	4	4	3	0	0	1	0	0	0	2	0
measuring adaptative capacity	human capital/education	2	0	2	0	1	1	0	2	0	0	1	1	0	0	2	1
	social capital/learning	6	4	4	4	1	1	1	3	0	0	5	0	0	0	0	0
	economic capital	2	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
	institutional capital/governance	4	0	4	3	1	2	2	3	1	1	1	3	1	1	2	1
	cultural capital/identity	2	2	2	1	0	2	0	0	2	0	0	0	0	0	2	2
	built capital/infrastructure	5	2	5	3	1	2	2	1	3	0	3	1	1	0	1	1
	natural capital	2	0	1	1	0	2	2	1	0	0	0	0	0	0	1	1
measuring transformative capacity/inherent resilience	Social memory	1	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0
	Living with uncertainty/improvising	1	0	1	1	1	0	0	1	0	0	0	1	1	0	1	1
	Self-organisation, reflective and shared lea	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1	1
	Resourcefulness/Efficiency/	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1
	Collaboration/inclusive/diversity/intersecto	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
	Innovation	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Robustness/Strength/appropiately connect	1	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0
	Coupled with Local Natural Capital	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
recovery																	
casualties	casualties	4	2	1	1	0	2	2	4	0	0	0	2	2	0	0	0
loss	indirect loss	2	0	3	2	0	0	0	2	0	0	1	0	0	0	0	0
	economic loss	5	2	2	2	0	1	0	3	1	1	1	1	0	1	0	0
damages	damages in buildings	4	1	2	2	0	0	0	0	3	3	1	3	3	0	0	0
	damages in infrastruture	2	1	1	1	0	0	0	2	0	0	2	0	0	0	0	0
	damages in objects	2	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0
	damage in ecosystems	4	0	2	0	0	3	2	1	1	0	0	0	0	0	0	0
	recovery rate	4	1	1	0	0	2	1	0	1	0	0	1	0	0	0	0
	reparaibility	1	1	0	0	0	1	0	0	1	0	0	1	0	0	1	1
		261	**62**	**61**	**47**	**32**	**62**	**54**	**82**	**33**	**21**	**48**	**78**	**59**	**21**	**65**	**40**

Table 19 Summary of indicators that were considered as a medium-high priority, as essential as well as essential and available

9.2 Description of the co-monitoring strategy

The co-monitoring strategy refers to the indicators that have been selected by the Open Labs and that are valid for the SHELTER project monitoring. This means indicators that can contribute to the improvement of resilience through the SHELTER implementation and are therefore useful to monitor results impact on each Open Lab. The monitoring strategy has been validated during Open Labs workshops and agreed among stakeholders.

The following table shows indicators which are considered as essential for the resilience assessment, which are available, and which contribute to the project monitoring:

				SAVA		GAL		DORD		RAVENNA		SEFER	
		Shortlist	SHELTER	Essential & feasible	Essential, feasible & Shelter	Essential & feasible	Essential, feasible & Shelter	Essential & feasible	Essential, feasible & Shelter	Essential & feasible	Essential, feasible & Shelter	Essential & feasible	Essential, feasible & Shelter
prevention/adaptation													
measuring trends source/hazards	frecuency	5	0	1	0	1	0	2	0	3	0	0	0
	magnitude	53	1	3	0	13	0	3	0	20	0	14	0
	duration	3	0	0	0	1	0	0	0	0	0	0	0
	intensity	7	0	1	0	0	0	1	0	1	0	0	0
	Intenstiy, duration and frequency	1	0	0	0	0	0	0	0	0	0	0	0
measuring exposure	people	1	0	1	0	1	0	0	0	1	0	1	0
	activities	1	0	1	0	0	0	1	0	1	0	0	0
	object/buildings/infrastructure	8	0	2	0	0	0	0	0	4	0	5	0
	ecosystems	2	0	1	0	0	0	0	0	0	0	0	0
measuring sensitivity	social/demography characteristics	10	0	0	0	3	0	0	0	3	0	4	0
	economic characteristics	12	0	0	0	7	0	0	0	2	0	0	0
	infrastructure characteristics	8	0	1	0	2	0	0	0	0	0	3	0
	building characteristics	34	1	2	0	0	0	3	0	13	0	1	0
	environmental sensitivity	26	0	1	0	5	0	0	0	3	0	0	0
measuring coping capacity	awareness/information	6	3	1	1	0	0	0	0	0	0	0	0
	networks/solidarity/Community preparedn	1	1	0	0	0	0	0	0	0	0	0	0
	insurance/funds	3	1	0	0	0	0	0	0	0	0	0	0
	DRM	9	8	6	6	4	4	6	5	0	0	2	2
	social memory	0	0	0	0	0	0	0	0	0	0	0	0
	shelter capacity	1	0	0	0	0	0	0	0	0	0	0	0
	protection of natural resources	11	1	1	1	4	0	0	0	0	0	0	0
measuring adaptative capacity	human capital/education	2	2	0	0	0	0	0	0	0	0	1	1
	social capital/learning	6	0	4	0	1		0	0	0	0	0	0
	economic capital	2	0	0	0	0	0	0	0	0	0	0	0
	institutional capital/governance	4	3	3	2	2	2	1	1	1	1	1	1
	cultural capital/identity	2	2	1	0	0	0	0	0	0	0	2	2
	built capital/infrastructure	5	1	3	1	2	1	0	0	1	1	1	1
	natural capital	2	0	1	0	2	0	0	0	0	0	1	0
measuring transformative capacity/inherent resilience	Social memory	1	1	0	0	0	0	0	0	0	0	0	0
	Living with uncertainty/improvising	1	1	1	1	0	0	0	0	1	1	1	1
	Self-organisation, reflective and shared lea	1	1	1	1	0	0	0	0	0	0	1	1
	Resourcefulness/Efficiency/	1	1	0	0	0	0	0	0	0	0	1	1
	Collaboration/inclusive/diversity/intersecto	1	0	0	0	1	0	0	0	0	0	0	0
	Innovation	1	0	0	0	0	0	0	0	0	0	0	0
	Robustness/Strength/appropiately connect	1	0	1	0	0	0	0	0	0	0	0	0
	Coupled with Local Natural Capital	1	0	0	0	0	0	0	0	0	0	0	0
recovery													
casualties	casualties	4	0	1	0	2	0	0	0	2	0	0	0
loss	indirect loss	2	0	2	0	0	0	0	0	0	0	0	0
	economic loss	5	1	1	1	0	0	1	1	0	0	0	0
damages	damages in buildings	4	0	2	0	0	0	3	0	3	0	0	0
	damages in infrastruture	2	0	1	0	0	0	0	0	0	0	0	0
	damages in objects	2	0	2	0	0	0	0	0	0	0	0	0
	damage in ecosystems	4	0	0	0	2	0	0	0	0	0	0	0
	recovery rate	4	0	0	0	1	0	0	0	0	0	0	0
	reparaibility	1	0	0	0	0	0	0	0	0	0	1	0
		261	**29**	**46**	**14**	**54**	**7**	**21**	**7**	**59**	**3**	**40**	**10**

Table 20: Indicators essential for the resilience assessment, which are available, and which contribute to the project monitoring

The following table (see Table 21) shows the indicators that each OL have decided as meaningful and available from the indicator list.

ID	PHASE	OBJECTIVE	FOCUS	NAME
DORDRECHT				
248	Prevention/ Adaptation	Coping capacity	DRM	Prediction capacity
310				Hazard monitoring and forecasting
311				Hazard assessment and mapping
312				Vulnerability, risk assessment and mapping
326				Rehabilitation and reconstruction planning
329		Adaptative capacity	Institutional capital/governance	Budget allocation and mobilization
309	Recovery	Loss	Economic loss	A systematic inventory of hazard events, damages and losses
SAVA RIVER BASIN				
84	prevention/ adaptation	coping capacity	awareness/information	Percentage of population with access to risk information
310			DRM	Hazard monitoring and forecasting
311				Hazard assessment and mapping
312				Vulnerability, risk assessment and mapping
322				Emergency response planning and implementation of warning systems
326				Rehabilitation and reconstruction planning
248				Prediction capacity
316			protection of natural resources	Management of river basins and environmental protection
174		adaptative capacity	institutional capital/governance	Percentage population covered by a mitigation plan
329				Budget allocation and mobilization
250			built capital/infrastructure	Available (collective) equipment to limit damage
399		transformative capacity	living with uncertainty/improvising	Existence of a platform for information sharing and networking using tools and routines and number of unique users
327			self-organisation, reflective and shared learning	Decentralized organizational units, inter-institutional and multisector coordination
309	recovery	loss	economic loss	A systematic inventory of hazard events, damages and losses
RAVENNA				
174	prevention/ adaptation	adaptative capacity	institutional capital/governance	Percentage population covered by a mitigation plan

250			built capital/infrastructure	Available (collective) equipment to limit damage
399		transformative capacity	living with uncertainty/improvising	Existence of a platform for information sharing and networking using tools and routines and number of unique users
BAIXA LIMIA - SERRA DO XURÉS				
223	prevention/ adaptation	coping capacity	DRM	Coordination with other government bodies
248				Prediction capacity
322				Emergency response planning and implementation of warning systems
326				Rehabilitation and reconstruction planning
174		adaptative capacity	institutional capital/governance	Percentage population covered by a mitigation plan
250			built capital/infrastructure	Available (collective) equipment to limit damage
329			institutional capital/governance	Budget allocation and mobilization
SEFERIHISAR				
223	prevention/ adaptation	coping capacity	DRM	Coordination with other government bodies
326			DRM	Rehabilitation and reconstruction planning
384		adaptative capacity	human capital/education	Number of professionals trained in post-disaster recovery and preservation of cultural heritage
174			institutional capital/governance	Percentage population covered by a mitigation plan
241			cultural capital/identity	The intangible value of cultural and natural heritage
242				Presence of a traditional culture
250			built capital/infrastructure	Available (collective) equipment to limit damage
327		transformative capacity	self-organisation, reflective and shared learning	Decentralized organizational units, inter-institutional and multisector coordination
399			living with uncertainty/improvising	Existence of a platform for information sharing and networking using tools and routines and number of unique users
328			resourcefulness/Efficiency	Availability of resources for institutional strengthening

Table 21: OL monitoring strategy

10 Conclusions and future work

A solid indicator framework is a necessary tool for HAs to establish strategies to enhance resilience and improve DRM as well as for evaluating SHELTER project impacts. There is not a universally accepted method to measure resilience, although several models have tried to operationalise the concept. In SHELTER, these models have been studied to establish and develop an integrated model that could measure the SHELTER approach to resilience. An approach focused on Cultural and Natural Heritage that incorporates the intrinsic resilience of HAs, considering hazard-dependant and non-hazard dependant multidimensional resilience. An interactive methodology has allowed the fine-tuning of a replicable indicators list but also a prioritisation of these indicators to the needs and data availability of each HA.

Out of a comprehensive indicator system based on the state of the art, this document proposed a selection of indicators adapted to the HA resilience measuring objectives and based on the RACER criteria: Relevant, Accepted, Credible, Easy, Robust. This document gathers also the factsheets of each proposed indicators to facilitate its application and adoption. It constitutes a state-of-the-art reference book for multi-scale and multi-hazard resilience and risk indicators which comprises 9 measuring objectives, 45 sub-objectives and 6 hazards.

The overall indicator system will serve as a starting point for further discussion and work in WP2, WP3, WP4 and WP5. But especially, this list of indicators aims to be the basis for the risk assessment methodology and Resilience Index to be developed in T2.5 (Specific hazard risk assessment) and T2.7 (Systemic resilience assessment methodology). Developed as an initial base, it is expected that the framework of indicators will evolve with the results of other tasks and the implementation of monitoring strategy in WP7.

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