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

D.2.4. Methodology for characterisation of hazards, climate change events and impacts.

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Glossary

Acronym	Full name
BBB	Building back better
CC	Climate Change
CCA	Climate Change Adaptation
CGLS	Copernicus Global Land component of Land Service
CH	Cultural Heritage
CHM	Cultural Heritage Management
CNH	Cultural and Natural Heritage
C3S	Copernicus Climate Change Service
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSS	Decision Support System
ECMWF	European Centre for Medium-Range Weather Forecast
EC	European Commission
EEA	European Environmental Agency
EU	European Union
GCOS	Global Climate Observing System
GFCS	Global Framework Climate Services
GEM	Global Earthquake Model
GP	Good Practice
HA	Historic Area
HWDI	Heat Wave Duration Index
ICT	Information and Communications Technology
IPCC	Intergovernmental Panel of Climate Change
NUT	Nomenclature of Territorial Units for Statistics
NH	Natural Heritage
RCP	Representative Concentration Pathways
RH	Relative Humidity
R&I	Research and Innovation
UHI	Urban Heat Island
UNDRR	United Nations Office for Disaster Risk Reduction
WCRP	World Climate Research Programme
WHO	World Health Organization
WMO	World Meteorological Organization

1. Executive summary

This report presents the **methodology for the characterization of natural hazards, climate change events and potential impacts to cultural and natural heritage**, developed through the work done under Task 2.4, entitled "*Methodology for characterisation of hazards, climate change events and impacts and projections & scenarios*."[1]

The main aim of the report is to explore the key concepts and to define a generic approach for the characterization of natural hazards to be assessed in the SHELTER project, that can potentially impact Cultural and Natural Heritage (CNH). This aim is achieved by, on the one hand, enhancing the understanding of natural hazards and related issues, building on an extensive literature review and existing definitions. On the other hand, by framing how to consider and include natural hazard characterization in the wider context of risk assessment. The report, more precisely, contributes in specifying the concept and consideration of natural hazard within the overall SHELTER framework for hazard risk assessment.

The report focuses especially on six natural hazards, namely, earthquakes, storms, floods, heatwaves, wildfire and subsidence. It outlines the key variables to be taken into account when characterizing these natural hazards, including climate change scenarios, as well as identification of other non-climate factors that can be defined as drivers influencing the hazard behaviour and its consequences locally, which have been explored via the project Open Labs. In the SHELTER project, all hazards considered, but earthquakes, are climate-related physical events. Therefore, developing an understanding of current and potential future events in a climate change context is an important element of adapting and building resilience for CNH. Hence, the report includes a reflection on climate change scenarios and on the importance of the extreme events in this process. The natural hazards potentially impacting historic areas (HA) are characterized considering the three CNH macro-categories already defined in the SHELTER project (addressed in D2.3[2]): CNH at territorial scale, CNH at urban & historic city centre scale and CNH at building & site level scale. The report provides a tool for the preliminary identification of direct and in-direct impacts and consequences of natural hazards that might occur tailored for CNH at different scales, by means of the definition of **impact chains**. An impact chain describes a cause-effect relationship between a hazard and an exposed receptor leading to potential direct and in-direct impacts. In the context of SHELTER project, the impact chains would help to systematise the assessment of vulnerability and risk of CNH against a number of hazards. Impact chains are a good foundation for a vulnerability and risk assessment, and constitute one of the main contributions of this report to the SHELTER overall framework for specific hazard risk assessment.

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[1] Task 2.4 is part of the Historic Resilience Index and Key Performance Indicators for resilience monitoring, co-monitoring of the project results in Open Labs (OL) and benchmarking tool, that will be the main outcome of WP2 of SHELTER project.

[2] Full document available https://shelter-project.com/documents/deliverables/)

By delivering a common, flexible and adaptive methodology for characterizing different kind of natural hazards and their potential impacts via the impact chains, the report thus contributes in advancing in both, definitions and also application of natural hazard characterization for CNH, in the climate change context and contributing to build the SHELTER conceptual framework for specific hazard risk assessment, and providing inputs already for the future development of the SHELTER Decision Support System and Platform in next steps of the project.

2. Introduction

2.1. Aims and objectives

The main aim of the report is to present the key concepts and to define a generic approach and adaptive methodology for the characterization of natural hazards to be assessed in the SHELTER project, in a climate change context, that can potentially impact Cultural and Natural Heritage (CNH). The focus of this report is specifically on six natural hazards namely, earthquakes, storms, floods, heatwaves, wildfire and subsidence, as well as the preliminary identification of their direct and in-direct impacts on CNH. The report, more precisely, contributes in specifying the concept and consideration of natural hazard within the overall SHELTER framework for risk assessment, which was initially outlined already in report D2.2[3] but must be finally delivered in the next steps of the project in Task 2.5.

Specific objectives:

- **Objective 1**- to establish a concise review of academic literature and results from previous research projects related to different natural hazards across Europe affecting CNH.
- **Objective 2**- to explore and outline the key variables and attributes to be taken into account when characterizing the natural hazards assessed in SHELTER project, i.e. earthquakes, storms, floods, heatwaves, wildfire and subsidence.
- **Objective 3-** to provide insights about how to make use of climate change scenarios for the natural hazard characterization
- **Objectives 4**- to reflect on the importance of extreme events.
- **Objective 5-** to define impact chains per natural hazard assessed in SHELTER project, as a tool for the preliminary identification of direct and in-direct impacts and consequences of natural hazards that might occur, tailored for CNH at different scales. These impact chains are a key input for undertaking the indicator-based vulnerability and risk assessment within the SHELTER overall framework for risk assessment (in Task 2.5).
- **Objective 6-** to reflect on the importance of local drivers and non-climate stressors when characterizing the natural hazards.
- **Objective 7-** to detect key uncertainties and unresolved questions related to hazard characterization that are relevant to inform the future configuration of the SHELTER platform and decision support system (DSS).
- **Objective 8-** to contribute to reshape the definition of natural hazard by including some effects related to the concurrence of factors and local specifications (e.g. through local solutions analyses and extreme events matter).

---

[3] Full document available on https://shelter-project.com/documents/deliverables/

2.2. Relations to other activities in the project

SHELTER project has been structured in 9 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 Figure 1 below.

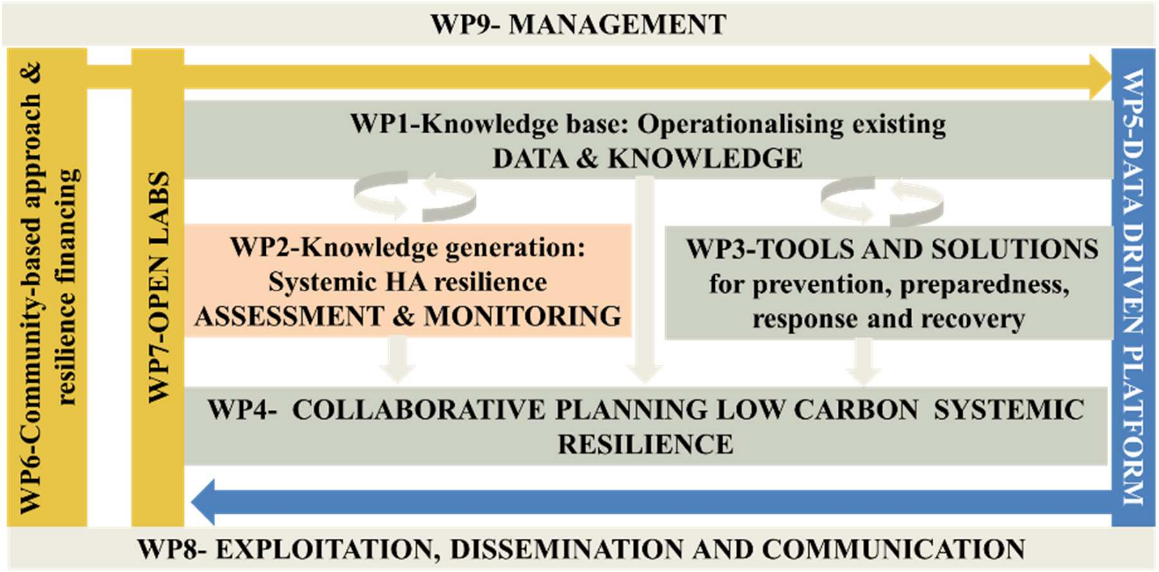
WP9- MANAGEMENT
WP6-Community-based approach & resilience financing
WP7-OPEN LABS
WP1-Knowledge base: Operationalising existing DATA & KNOWLEDGE
WP2-Knowledge generation: Systemic HA resilience ASSESSMENT & MONITORING
WP3-TOOLS AND SOLUTIONS for prevention, preparedness, response and recovery
WP4- COLLABORATIVE PLANNING LOW CARBON SYSTEMIC RESILIENCE
WP5-DATA DRIVEN PLATFORM
WP8- EXPLOITATION, DISSEMINATION AND COMMUNICATION

Figure 1. PERT chart of SHELTER

Within WP2, the work developed in Task 2.4 provides the methodology for the characterisation of natural hazards, climate change events and their potential impacts.

It builds on the CNH characterization and typologies being defined in Task 2.3 and delivered in D2.3[4]. When characterizing the natural hazards, the spatial scale matters so it is utterly important to develop a good understanding of the socio-ecological system exposed. The CNH typologies defined in T2.3 are used when defining impact chains per hazard assessed in SHELTER

The task contributes to specifying the concept and consideration of natural hazard within the overall SHELTER framework for hazard risk assessment to be delivered in T2.5 Specific hazard risk assessment and outlined already in D2.2[5].

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[4] Full document available on https://shelter-project.com/documents/deliverables/

[5] Full document available on https://shelter-project.com/documents/deliverables/

Task 2.4 has a strong relationship with a number of Work Packages and tasks in the 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. T2.4 has been drawn in line with the foundations 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 aligns with 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 exposure to natural hazards, and considering the local non-climate drivers and stressors (T2.4).

- **WP4** (Collaborative planning for building low carbon systemic resilience) aims at integrating cultural heritage into planning policies and tools, linking Disaster Risk Management (DRM), Climate Change Adaptation (CCA) and heritage site management, making use of the Resilience ID incremental strategy. To do so, establishing the diagnosis for hazard characterization and development of impact chains, will support the tailored definition of adequate DRM and CCA policies and strategies, and their mainstreaming into spatial planning strategies.

- **WP5** (Data-Driven Platform): the indicators developed in the hereby described task will contribute to the diagnosis of hazards and decision making that will be supported in the platform. The proposal for hazard characterization constitutes one of the main components in the future ÇDecision Dupport Tool to be delivered by SHELTER project.

- **In WP7** Open Labs (OL) are functioning as knowledge generator and evaluation frameworks, demonstration sites, long-term thinking transition labs and learning environments. Hazard characterization is grounded within the outputs of the SHELTER OL. Task 2.4 has worked closely with OL for identifying the non- climate drives and stressors influencing natural hazard characterization locally. The interaction with SHELTER OL allows gathering information on local context and idiosyncrasy to improve hazard characterization locally and better shape the solutions designed to cope with natural hazards in WP3.

The relations of Task 2.4 with WP and tasks within the SHELTER overall operational framework are outlined in Figure 2.

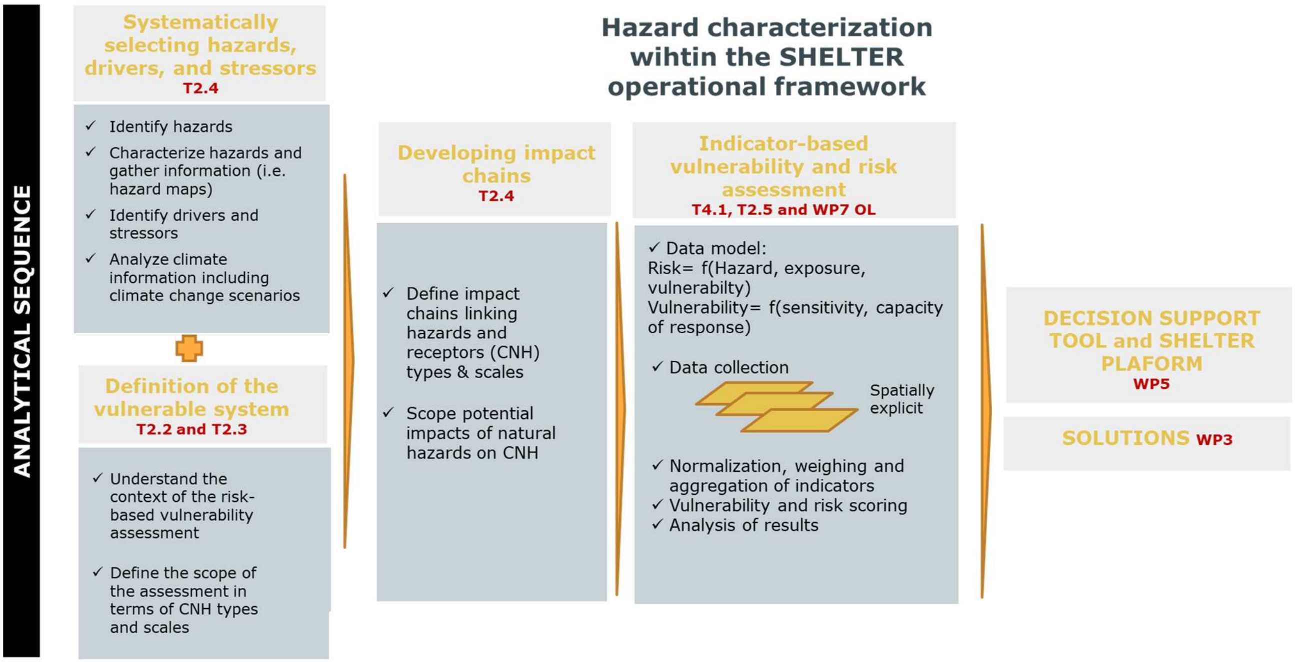
ANALYTICAL SEQUENCE
Systematically selecting hazards, drivers, and stressors
T2.4
✓ Identify hazards
✓ Characterize hazards and gather information (i.e. hazard maps)
✓ Identify drivers and stressors
✓ Analyze climate information including climate change scenarios
Definition of the vulnerable system
T2.2 and T2.3
✓ Understand the context of the risk-based vulnerability assessment
✓ Define the scope of the assessment in terms of CNH types and scales
Hazard characterization wihtin the SHELTER operational framework
Developing impact chains
T2.4
✓ Define impact chains linking hazards and receptors (CNH) types & scales
✓ Scope potential impacts of natural hazards on CNH
Indicator-based vulnerability and risk assessment
T4.1, T2.5 and WP7 OL
✓ Data model:
Risk= f(Hazard, exposure, vulnerabilty)
Vulnerability= f(sensitivity, capacity of response)
✓ Data collection
Spatially explicit
✓ Normalization, weighing and aggregation of indicators
✓ Vulnerability and risk scoring
✓ Analysis of results
DECISION SUPPORT TOOL and SHELTER PLAFORM
WP5
SOLUTIONS WP3

Figure 2. Linkages between Hazard characterization with other tasks and activities in the SHELTER project.

2.3. Report structure

The document is divided into three main parts. The first one is devoted to outlining concepts and methods. The second one is dedicated to the SHELTER project methodological proposal for hazard characterization in the overall framework for risk assessment. And the third and final one offers the conclusions and recommendations for further research.

The report is structured as follows:

- **Section 1** includes the executive summary.
- **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 define the generic approach and methodology for natural hazard characterization in the SHELTER project.
- **Section 4** describes the state of the art based on a literature review about recent projects devoted to natural hazards and links with cultural heritage.
- **Section 5** discusses the SHELTER approach, concepts and main definitions of hazard being used in different contexts and disciplines (i.e. DRM and CCA)
- **Section 6** describes the characterization of natural hazard for HA, classifying the events and listing the parameters used.
- **Section 7** provides the results for characterization per natural hazard addressed in the SHELTER project.
- **Section 8** describes the preliminary impact chains defined per hazard and CNH type and scale.

- **Section 9** explains the overarching themes in SHELTER project: climate change scenarios, importance of the extreme events and the non-climate drivers and stressors for hazard characterization.
- **Section 10** concludes and includes recommendations for further research.

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. Drafting of Section 1, 2, 3, 5, 6, 7, 8, 9 and 10. Responsible for sections and indicators related to wildfire and floods. Responsible for the definition of the methodology and preliminary delineation of the impact chains diagrams in Section 8. Responsible for Section 9 on climate change scenarios. Responsible for Section 10 on conclusions and recommendations including the identification of key uncertainties and possible gaps.
UNIBO	Responsible for state of the art on Section 4. Responsible for sections and indicators related to earthquakes and subsidence.
UPV/EHU	Responsible for sections and indicators related to heat waves.
CRCM	Responsible for the subsection on the importance of the extreme events in Section 9 Responsible for sections and indicators related to storms.
EKO	Responsible for guaranteeing the alienation and coherence of the proposal for hazard characterization with the wider context of risk assessment in T.2.5.
Open labs coordinators **(TEC, UNIBO, UNESCO, IHED, EKO)**	Facilitating inputs for section 9 on non-climate drivers and stressors influencing hazard characterization locally

Table 1 Contribution of partners to Deliverable report D.2.4.

3. Methodology

The report uses a combination of different methods, materialized in a 6 step-wise methodology, described below:

3.1. Step 1. Scientific literature review and state of the art

An extensive scientific literature review and state of the art is undertaken (Section 4) that builds on the foundation of the work being done by a number of good practices and research & innovation initiatives for hazard characterization linked with CNH, identifying gaps and challenges that are trying to be overcome by the SHELTER project.

3.2. Step 2. Contextualization of natural hazards for CNH risk assessment

Different concepts and definitions of hazards are explored (Section 5), as well as their different applications in different disciplines, in order to set the scene for hazard characterization in SHELTER project, which particularly focuses on CNH.

Hazard, in the context of SHELTER project, is defined as an unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins[6].

The characterization of natural hazards is seen as preparatory action integral to the process of a vulnerability and risk assessment, and for resilience enhancing. It is therefore understood as an essential piece of the overall framework for CNH risk assessment in the SHELTER project (T2.5 Specific hazard risk assessment).

SHELTER conceptual framework for risk assessment follows the one defined by the Intergovernmental Panel of Climate Change (IPCC) in its fifth assessment report, where risk is a function of hazard, exposure and vulnerability (see Figure 3).

The SHELTER framework for risk assessment is also consistent with the Sendai Framework for Disaster Risk Reduction 2015-2030[7] contributing, in particular, to a number of priorities for action to prevent new and reduce existing disaster risks, in particular to: i) Understanding disaster risk; ii) Enhancing disaster preparedness for effective response, and to BBB in recovery, rehabilitation and reconstruction.

Hence, the work within the present report provides a key input in the development of the SHELTER indicator-based vulnerability and risk assessment to be delivered in the following phase of the project (T2.5 Specific hazard risk assessment and T2.7 Systemic resilience assessment methodology)

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[6] https://wiki.shelter-project.cloud/en/ontology/hazard

[7] The Framework was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on March 18, 2015.

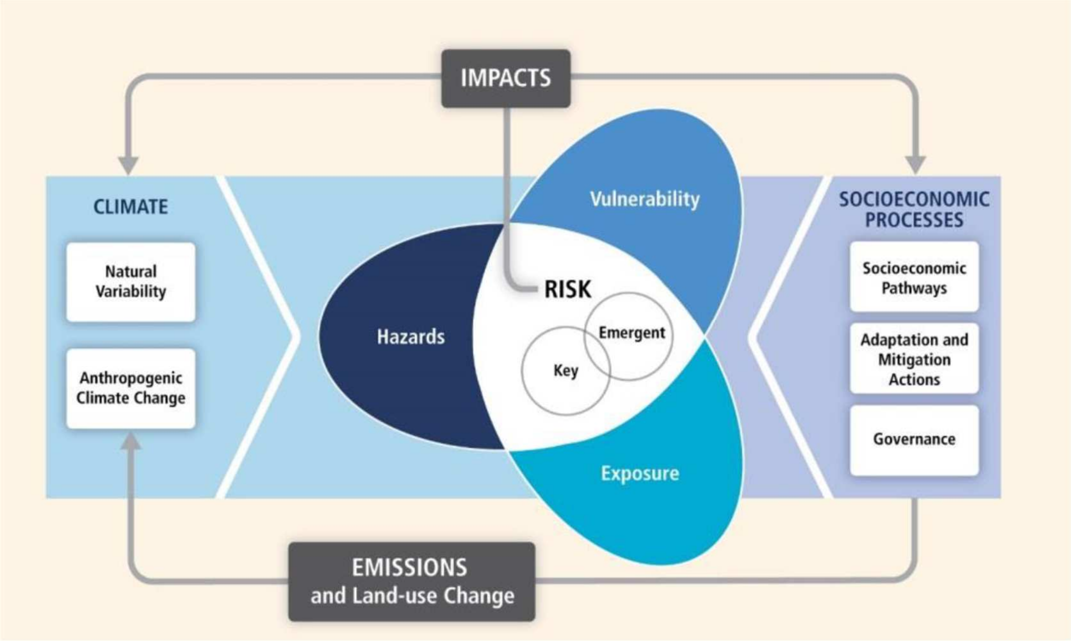
IMPACTS
CLIMATE
Natural Variability
Anthropogenic Climate Change
Vulnerability
Hazards
RISK
Emergent
Key
Exposure
SOCIOECONOMIC PROCESSES
Socioeconomic Pathways
Adaptation and Mitigation Actions
Governance
EMISSIONS and Land-use Change

Figure 3 IPCC, 2014 Technical Report, Figure [TS.1]. Source: IPCC (2014) AR5, WG-II, Ch. 19[8].

3.3. Step 3. Definition of the vulnerable CNH system

The definition of the vulnerable CNH system builds on previous results delivered by SHELTER project and includes:

a) the understanding of the indicator-based vulnerability assessment approach already addressed in D2.2[9] in which an exhaustive list of key performance indicators (KPI) attached per each component of risk (exposure and vulnerability) was delivered.

b) defining the scope of CNH assessment, addressed in D2.3[10] which offers a detailed classification of CNH under the three macro-categories and related spatial scales: i.e. territorial, urban and historic city centre, building and site level.

3.4. Step 4. Systematic classification of events

A proposal for natural hazard classification to be used in SHELTER project is shown in Section 6. The natural hazards are classified:

i) by hazard group, according to their geophysical, meteorological, climatological and hydrological nature;
ii) by their biophysical, weather and climate determinants; and
iii) by hazard type.

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[8] IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability https://www.ipcc.ch/report/ar5/wg2/

[9] Full document available on https://shelter-project.com/documents/deliverables /

[10] Full document available on https://shelter-project.com/documents/deliverables/

3.5. Step 5. Natural hazard characterization, attributes, (climate) variables and identification of non-climate drivers and stressors

The methodological identification of relevant hazards, drivers and stressors is a key element for a successful application of the risk assessment. The hazard characterization is the core focus of the present report and it builds on the characterization of the vulnerable system and CNH classification (T2.3 Anatomy of HA) and has been undertaken in parallel with the definition of the SHELTER framework for risk assessment.

The hazard characterization (Section 7) includes:

- **Information gathered about the hazards and their attributes** (i.e. variables to characterize magnitude, frequency and duration of events, hazard maps.)
- **Identify non-climate drivers and stressors influencing hazards**. End-users and stakeholders in the SHELTER project OLs were outreached for contrasting the approach and for gathering information on intrinsic features that may condition hazard characterization locally. In close collaboration with the SHELTER project OLs, an exercise was undertaken in the context of a series of workshops organized by WP3 in T3.3 during December 2020 and January 2021. It is notable that the IPCC's conceptualization of risk highlights the influence of climate and socio-economic processes on risk. Non-climate stressors and socio-economic drivers may influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (i.e. services, people/ citizens and infrastructures). Including a process to identify the non-climate stressors and drivers that may influence hazard characterization locally, is seen as a crucial element of adaptation and resilience planning. Recognizing these drivers could help to select, design and better shape the local solutions to build resilience against climate change.

Based on the literature review, the expertise of the SHELTER project partners and previous SHELTER project deliverables, a common template was designed for a consistent characterization amongst hazards. This template will be used to systematically collect data for hazard characterization in the SHELTER project platform. The completed factsheets are available as Annex 1 of the present report in an Excel format[11]. The template of the factsheet structure and the main elements that it contains are shown in Table 2.

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[11] Available at SHELTER project sharepoint https://tecnalia365.sharepoint.com/:x:/s/t.extranet/sp070767/EZvNR7MLJUJNrYlD1V43qKUBeRDHJHo7WGs8_-b2nP8O0g

DEFINITION
Brief description and definition of the natural hazard
HAZARD GROUP
Hazards classification linked to their main biophysical drivers and determinants: Geophysical Meteorological Climatological Hydrological
HAZARD TYPE
According to SHELTER proposal for hazards classification: Earthquake Subsidence Storms Heat Wave Wild Fire Flood
SPATIAL SCALE
Spatial nature of potential receptor
Refers to the SHELTER scales for CNH: Territorial level Urban and historic city centre Building/ site/ artefact level
Spatial scale of the analysis
Area of the analysis- extension
TIME DIMENSION
Time Horizon
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term
Scenarios (Climate Change)
Climate change may have affect the intensity, duration and frequency of an event For heat stress and flooding (particularly pluvial flooding) the most relevant scenarios would be: IPCC RCP4.5 Near future: 2011-2040; Mid-range century: 2041-2070; Late century: 2071-2100 IPCC RCP 8.5 Near future: 2011-2040; Mid-range century: 2041-2070; Late century: 2071-2100
THRESHOLD
The thresholds help us defining the intensity of the event the seriousness of the event.

It could be expressed for instance as follows: Above or below which conditions the event become “extreme” based on historical values. E.g: Heat Wave is defined as a consecutive period of 6 days or longer where the daily maximum temperature exceeds the calendar day daily maximum temperature 90thpercentile calculated for a 5-day window centered on each calendar day in the 1961–1990 period. (https://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_heatColdWaveIndex.pdf) The WMO uses the Heat Wave Duration Index (HWDI) to determine the occurrence of the phenomenon. It characterizes a heat wave as a sequence of more than five days in which the maximum daily temperature is at least 5ºC above the climatological average.
PARAMETERS
Magnitude and Intensity
The magnitude of a natural hazard event is related to the energy released by the event. Describes the strength of the event. Heat Stress is described by comparing the recorded Temperature index (measured or computed value) and its threshold. Another option for computing the magnitude would be to use a more complex method using additional variables.
Main variables
Relates to the minimum variables that will allow evaluating the magnitude of the event
Additional Variables
Relates to additional variables that- if available- will improve the characterization
Location and Spatial Dispersion
Location (Coordinates)
Coordinate of the locations: latitude, longitude
Spatial dispersion (Extent)
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.
Frequency
How often an event is repeated. It is expressed by the inter-event interval times For most hazards the most used concept is the return period or recurrence interval, which refers to an estimated average time between events
Duration
Time above or below a certain threshold. Eg. Persistence of conditions for a heat wave are (usually) three days
Starting date

DD-MM-YYYY
Ending date
DD-MM-YYYY
DRIVERS
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio-economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning
Environmental dimension
Environmental conditions that may influence the intensity and frequency of the hazard
Physical dimension
Physical conditions that may influence the intensity and frequency of the assessed hazard
Urban morphology
Key characteristics /determinants related to the hazard
Geomorphology
Key characteristics /determinants related to the hazard
Asset/artefact
Key characteristics /determinants related to the hazard
Planning dimension
Refers to planning elements (regulations, guidelines, etc) that may condition the hazard
Sector planning
Sector policies : water, energy, agroforestry, health, river basin planning, etc
Urban planning
Planning conditions at urban level Including instruments for disaster risk reduction and early warning systems
Spatial planning
Planning conditions at regional level
Social dimension

Particularly related to social behaviour that act as a driver to influence the hazard
Social behaviour
Mankind drivers for natural hazards. e.g wildfire ignition.
Socio-economic dimension
Socio economic development, land use distribution, mobility patterns and demography patterns
Other potential drivers

Table 2 Structure and main elements of the factsheet developed for natural hazard characterization in SHELTER.

3.6. Step 6. Developing impact chains: setting the scene for the risk assessment

As already argued, the impact chains constitute one of the key contributions of this report to the SHELTER overall risk assessment framework.

3.6.1. What is an impact chain?[12]

An impact chain is a tool that describes in a visual and simplified manner, the cause-effect relationship between a hazard and an exposed receptor leading to potential direct and indirect impacts. In the context of SHELTER project, the impact chains would help to systematise the assessment of vulnerability and risk of CNH against a number of hazards ([5] Erich et al, 2015). It is very useful tool that allows the identification of the source of a given event (hazard) and the potential consequences and effects that it may cause on a receptor or receptors exposed to that event.

In the context of the SHELTER project, we are redefining the notion of hazard impact chains by referring to CNH and, in particular, to enable the analysis of risk over different types of heritage at various scales (see D2.3 for details on the "heritage chain concept"[13]). Impact chains are developed by means of impact chain diagrams (Section 8), which make these relationships visible. An example is shown in Figure 5. Be aware that impact chains are not exhaustive, but describe the common understanding of these relationships. A major rule for elaborating impact chains is: keep it simple.

3.6.2. Why is important to characterize impact chains?

Impact chains are important in SHELTER project since they are a good foundation for the vulnerability and risk assessment, and hence resilience. It is a beneficial exercise to identify the relevant indicators that describe the system under analysis (i.e. CNH at territorial, urban and site levels) to perform the indicator-based vulnerability and risk assessment to be delivered in the next steps of project development (T2.5).

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[12] http://wiki.resin.itti.com.pl/supporting-tools/ivavia-guideline/module-2-developing-impact-chains/

[13] Full document available on https://shelter-project.com/documents/deliverables/

Based on the identified climate stimuli, that help characterizing the natural hazards affecting the territory, impact chains allow the identification of the potential direct and indirect impacts to the various HA receptors, whether they are physical or built-up assets, or functions and services provided by or associated with the HA under analysis.

In the context of SHELTER project, the impact chains will help to systematise the assessment of vulnerability and risk of CNH against several hazards.

Each hazard is characterized per CNH macro category: territorial scale, urban /historic city centre scale and building/site level scale. Also, potential impacts derived from the interaction of natural hazards on the different CNH are described in terms of three types of vulnerabilities described below. The terminology must still be agreed in the SHELTER project in the context of the overall risk assessment in T2.5:

- **Structural**: which refers to the heritage loss as well as the potential affection to the static properties and the peculiar characteristics of a CNH
- **Functional**: which refers to the potential disruptions on the functions, services and operation of use delivered or provided by the CNH
- **Social and Economic**: which refers to the potential impacts on socioecomomic activities, economic loss and characteristics of the society (inhabitants or visitors) in the HA

3.6.3. How to build impact chains?

The approach followed in SHELTER project for building impact chains, is inspired by the one suggested by the FPVII RAMSES cities project ([13] RAMSES project,2017) [14] .

The first step in building the impact chains in SHELTER project is determining the magnitude, frequency and severity of the natural hazards, by means of the analysis of the climate variables and non-climate drivers influencing hazard behaviour, including climate change scenarios whenever appropriate.

The impact chains should be able to identify the climate variables, which are non-controllable by definition, and also non-climate drivers and stressors which may be controllable (i.e. social behaviour, planning decisions, governance, early warning systems) or non-controllable and context dependant (i.e. geomorphology, land use distribution and zoning, basic infrastructure configuration).

Figure 4 shows an example of generic components of an impact chain.

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[14] https://ramses-cities.eu/home/

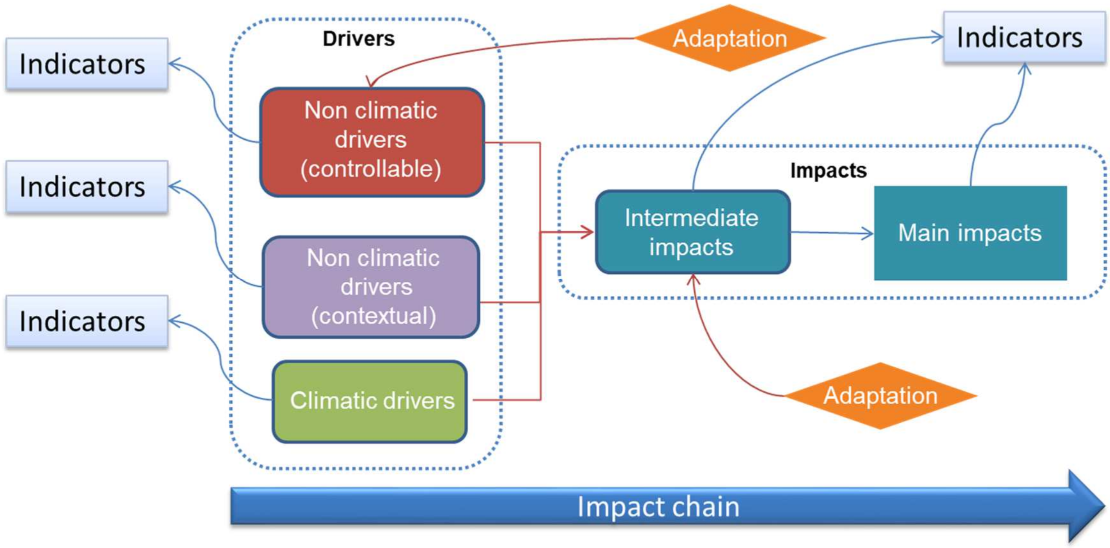
Drivers
Indicators
Indicators
Indicators
Non climatic drivers (controllable)
Non climatic drivers (contextual)
Climatic drivers
Adaptation
Indicators
Impacts
Intermediate impacts
Main impacts
Adaptation
Impact chain

Figure 4 Impact chains Source FPVII Project: RAMSES Reconciling Adaptation, Mitigation and Sustainable Development for Cities", FP7. 2012-2017

While it is very difficult, sometimes not possible, to reduce the severity of natural hazards, the main opportunity for reducing risk lies in reducing vulnerability and exposure. Reducing these two components of risk requires identifying and reducing the underlying drivers of risk, which in relation to CNH are particularly related to inefficient maintenance and governance practices, state of conservation of heritage, poor economic and urban transformation, revitalization and inertia, environmental degradation, lack of social awareness and sensitivity, loss of value and importance for local identities, and all this in a climate change context, which create and exacerbate conditions of hazard, exposure and vulnerability. Addressing these underlying risk drivers will improve decision-making processes, by anticipating impacts, reducing disaster risk, lessen the impacts of climate change and, consequently, building resilience for HA. Ideally, as a result, there will be a hazard map showing the area of influence and probability of occurrence of the events.

The second step is the identification of the potential HA exposed elements in the hazard area and its characterization under the 3 main macro-categories defined in T2.3 of the SHELTER project. It implies the identification of the inherent characteristics of the exposed heritage that explain their sensitivity and coping capacity against a particular event.

The third step is devoted to the identification of potential direct and indirect impacts that may affect the exposed receptors if an event occurs.

Figure 5 shows the conceptual flow to build impact chains and their main components in the SHELTER project. Experts on different hazards worked on defining impact chains per hazard and scale of CNH.

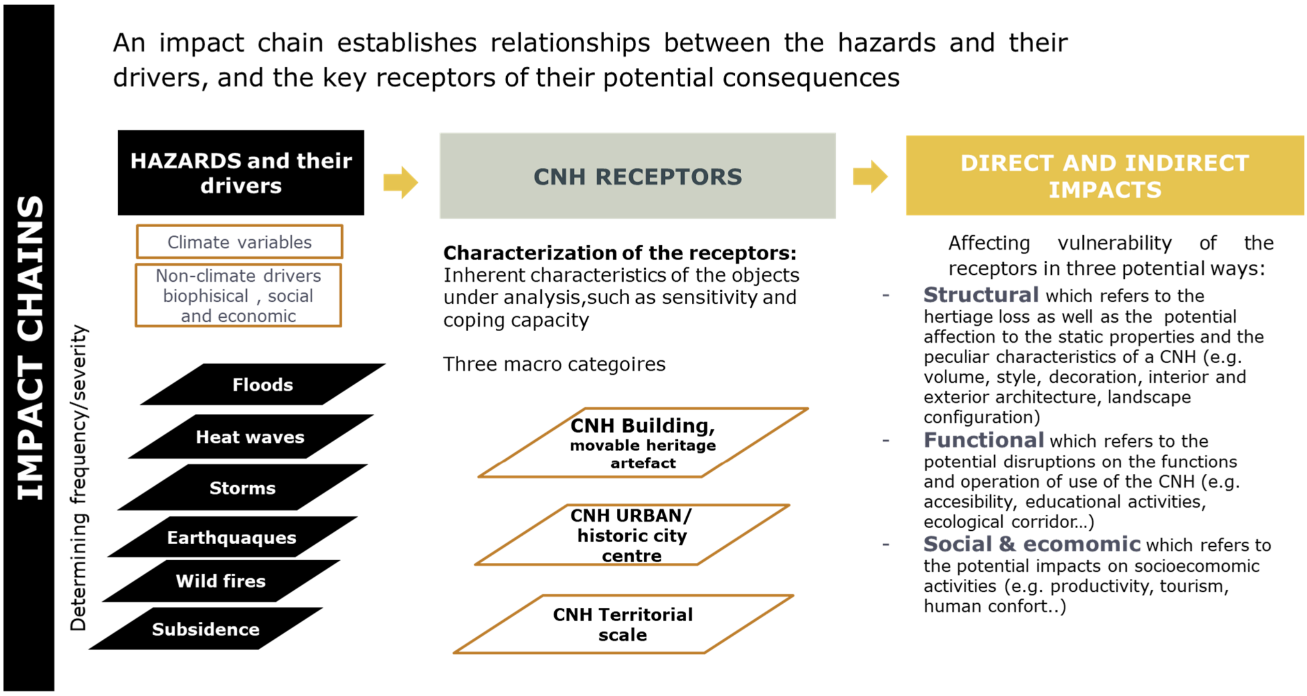
IMPACT CHAINS
An impact chain establishes relationships between the hazards and their drivers, and the key receptors of their potential consequences
HAZARDS and their drivers
Climate variables
Non-climate drivers biophisical , social and economic
Determining frequency/severity
Floods
Heat waves
Storms
Earthquaques
Wild fires
Subsidence
CNH RECEPTORS
Characterization of the receptors:
Inherent characteristics of the objects under analysis,such as sensitivity and coping capacity
Three macro categoires
CNH Building, movable heritage artefact
CNH URBAN/ historic city centre
CNH Territorial scale
DIRECT AND INDIRECT IMPACTS
Affecting vulnerability of the receptors in three potential ways:
- Structural which refers to the hertiage loss as well as the potential affection to the static properties and the peculiar characteristics of a CNH (e.g. volume, style, decoration, interior and exterior architecture, landscape configuration)
- Functional which refers to the potential disruptions on the functions and operation of use of the CNH (e.g. accesibility, educational activities, ecological corridor…)
- Social & ecomomic which refers to the potential impacts on socioecomomic activities (e.g. productivity, tourism, human confort..)

Figure 5 ¡Error! No se encuentra el origen de la referencia.

Based on the impact chains, a data model will be built matchmaking the indicators for the different components of risk (i.e. hazard, exposure and vulnerability). In SHELTER project the risk assessment does have a spatial explicit component, which is one of the added value of the project approach.

Figure 6 shows the methodology followed in the elaboration of the present deliverable report.

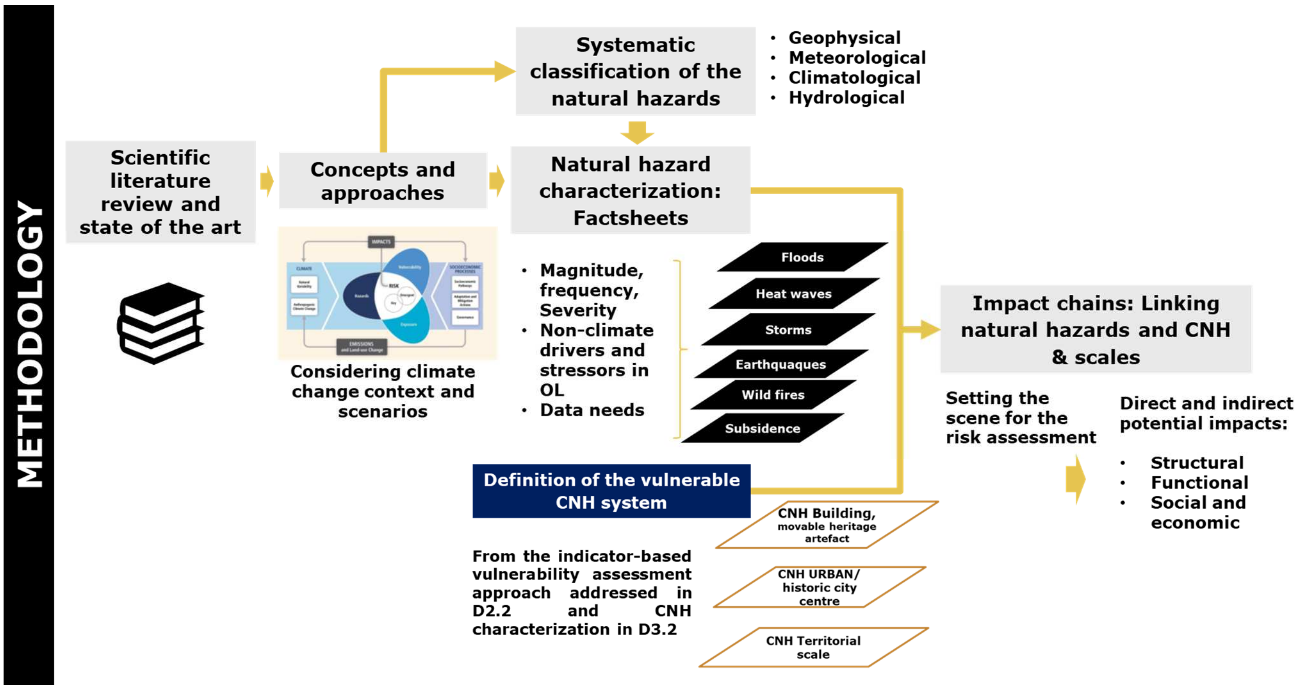
METHODOLOGY
Scientific literature review and state of the art
Concepts and approaches
Considering climate change context and scenarios
Systematic classification of the natural hazards
• Geophysical
• Meteorological
• Climatological
• Hydrological
Natural hazard characterization: Factsheets
• Magnitude, frequency, Severity
• Non-climate drivers and stressors in OL
• Data needs
Floods
Heat waves
Storms
Earthquaques
Wild fires
Subsidence
Definition of the vulnerable CNH system
From the indicator-based vulnerability assessment approach addressed in D2.2 and CNH characterization in D3.2
CNH Building, movable heritage artefact
CNH URBAN/ historic city centre
CNH Territorial scale
Impact chains: Linking natural hazards and CNH & scales
Setting the scene for the risk assessment
Direct and indirect potential impacts:
• Structural
• Functional
• Social and economic

Figure 6 Overview of the methodology applied in the delivery of the present report.

4. State of the art on hazard classification: approaches and tools

The state of the art builds the foundation of the work being undertaken for hazard characterization and the main results of the previous EU projects review described in greater detail in the D1.2[15] which overall objective was to provide an effective codification of the existing knowledge.

Through the work carried out in the Good Practice (GP) and Research and Innovation (R&I) initiative collection SHELTER related EU projects, both concluded and ongoing, were identified and classified as high/medium/low relevance for the project. The results are available in the data gathering Excel sheets[16], included in the D1.2 Annex section, which ensure an easy consultancy of the information of the lessons learned, good practices and tools developed and achieved by previous projects.

4.1. Methodology of the review

The research of good practices coming from EU projects was completed by scanning mainly the European Climate Adaptation platform (CLIMAT-Adapt)[17] and Community Research and Development Information Service (CORDIS)[18] databases. The final result is a repository of 94 good practices, of which 82 were found of medium or high relevance for SHELTER. In particular, the CLIMAT-adapt platform was relevant to retrieve information and data mainly related to climate change adaptation strategies, plans, tools and actions developed across European Countries funded not only by the EU research programmes but also at national, regional and city level. On the other hand, the CORDIS database collects the results funded by the EU's framework programmes for research and innovation (from FP1 to H2020). The set of keywords used to scan the database was defined in order to make the repository as comprehensive as possible for SHELTER further activities and is available in Section 6 of the D1.2.

The work undertaken in the framework of the T1.2 collected and analysed a repository of practices and methodologies developed within the last 20 years. This temporal framework was defined considering that prior results would probably result outdated and technically obsolete.

In regard to the tools linked to R&I initiatives, nearly 100 tools have been examined by using three databases to search for projects: CORDIS (EU), INTERREG[19] (EU) and KIRAS[20] (AT). KIRAS was used by CRCM to test the data-gathering template. The main attention was then given to CORDIS, complemented by INTERREG. As far as the data in CORDIS are concerned, R&I initiatives were identified covering the period from H2020 back to FP3 (Framework Programme 1990-1994); records on projects sponsored under

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[15] Full document accessible at Shelter web site.
[Available at: https://shelter-project.com/documents/deliverables/]

[16] Results collected in the Excel gathering sheets available in Annex II and III of the Shelter D1.2.
[Available at: https://shelter-project.com/documents/deliverables/]

[17] CLIMAT-adapt Platform. [Available at: https://climate-adapt.eea.europa.eu/]

[18] CORDIS data base. [Available at: https://cordis.europa.eu/]

[19] Interreg Europe. [Available at: https://www.interregeurope.eu/]

[20] KIRAS database. [Available at: https://www.kiras.at/index.php?id=148&L=698]

FP1 (Framework Programme 1984-1987) and FP2 (Framework Programme 1987-1991) are seemingly not available on CORDIS.

4.2. Projects reviewed

As mentioned above, the observatory developed in D1.2 is based on a critical review of the existing good practices and tools developed or collected in EU projects pilot cases. For each input, the scale of heritage the GP or R&I initiative was related to was included in the respective gathering tool created on Excel, available in the Annexes section in D1.2.

Here following a brief description of the records for GP and R&I initiatives identified as of 'high' and 'medium' relevance for the SHELTER project. The full list of collected information can be consulted in Annex II and III of Shelter D1.2[21].

4.2.1. Climate-related hazards

Within the framework of the HERACLES project[22] (H2020, 2016-2019) an **Information and Communications Technology (ICT) platform** was designed to support decision-makers in managing disaster events. The HERACLES project aimed at design and validate solutions for enhancing the resilience of urban Cultural Heritage sites against climate change in different European regions with a holistic and multidisciplinary approach (the historic town of Gubbio in central Italy and Heraklion on the Greek island of Crete). The platform collects multi-sources data and information (e.g. satellite images of heritage sites) in order to support conservation decisions and help stakeholders prioritise the interventions and investments to improve the resilience of the area. The user interface is based on geographical location allowing easy access to the collected data immediately inserted in the context of the site, while the alert system established on appropriate thresholds allows the efficient planning of operational interventions on the site. The platform generated is replicable in other scenarios, thus being able to be customized for specific cases on the basis of the basic knowledge already included, proposing both concrete solutions for the protection of CNH (preventive maintenance, conservation, restoration actions) at multiscale level and the use of materials developed customized for specific needs. The HERACLES platform was implemented and used in the project case studies but currently is not available nor accessible outside the project consortium. The work undertaken in the H2020 STORM project[23] (2016-2019) focused on the implementation of critical decision-making tools to help managers of historical centres and archaeological sites affected by climate change and natural hazards (Diocletian Baths, Rome, Italy; Mellor Heritage Project, Great Manchester, UK; Roman Ruins of Tróia, Portugal; Rethymno historical centre, Crete, Greece; Ephesus, Anatolia, Turkey). The result was a **collaborative platform[24]** to collect and enhance knowledge on CNH.

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[21] Results collected in the Excel gathering sheets available in Annex II and III of the Shelter D1.2. [Available at: https://shelter-project.com/documents/deliverables/]

[22] HERACLES - Heritage Resilience Against Climate Events on Site. [Available at: http://www.heracles-project.eu/]

[23] STORM - Safeguarding Cultural Heritage through Technical and Organisational Resources Management. [Available at: http://www.storm-project.eu/it/]

[24] STORM platform [Available at: http://www.storm-project.eu/?page_id=3111]

A set of new forecasting models and non-invasive and non-destructive investigation methods such as new sensors with different applications were developed. This allows effective environmental change predictions and easier identification of threats and conditions that could harm CNH sites at multiple scales. What's more, in the project document STORM project D2.2 *"Safeguard of Cultural Heritage recommendations in government policies"* a series of guidelines and good practices are collected from international frameworks in Europe from 2015, with a focus on cultural heritage management and climate change mitigation strategies. Among all the recommendations, the need of implementing interdisciplinary training courses and DRM programmes at the site level with all the actors operating in the area is highlighted, not only heritage professionals but also site managers, public and private administrators and citizens. It was stated also that of fundamental importance is the inclusion of emergency sectors and civil protection in local and national policies to ensure coordination among all the bodies, both emergency and managerial. In addition, the importance of defining maintenance plans and conservation interventions and integrating them in the long-term planning is stated, along with the integration of ICT platforms and digital tools in all DRM phases.

BeAWARE[25] (H2020, 2017-2019) aimed at enhancing fast and effective response to prepare communities in case of climate led emergency events. Therefore, a **communication and analysis platform** in support of decision-makers, first responders and citizens was developed. The information collected by the platform is obtained by social media, local weather forecasts, sensors and the BeAWARE mobile app. The platform serves not only as an early warning system but also as support providing real-time information and data during an ongoing disaster to first responders. In addition, the widespread of mobile app helps to raise awareness among the citizens of the hazard the area is exposed to. The project also highlighted that the implementation of new technologies and tools is not enough to be prepared for a disaster. In fact, in parallel with the development and diffusion of these tools, more and more training courses addressed to both managers and citizens should be organized in order to be efficiently prepared as soon as an event occurs. The platform was tested in the pilot cases of the project (Valencia, Spain; Thessaloniki, Greece; Vicenza, Italy) different by scale, proving it to be a valid multiscale tool.

The PLACARD project[26] (H2020, 2015-2020) aim is to enhance the integration among CCA and DRR measures, policies and research both at urban and cross-regional scale. The project produced a very exhaustive document (PLACARD project Deliverable 4.2 *"Elaborate guidelines to strengthen CCA and DRR institutional coordination and capacity"*) in which recommendations for strengthening institutional collaboration and capacity in the fight of climate changes are collected. The document recommendations are grouped according to their field of relevance, defining the 5 macro-categories, as the key steps for strengthening institutional collaboration and capacity: safeguarding sound governance, ensuring effective financing, seizing opportunities for cooperation, sharing new forms of communications, enhancing knowledge management. Each category is further investigated through questions and solutions, generating a list of recommendations, also providing an example of bringing a case study analysis for the specific issue. In addition, the PLACARD project developed the **Connectivity Hub**[27], an online database that helps to detect by keywords relevant knowledge (articles, conference results, papers) in relation to CCA and DRR issues can be detected.

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[25] BeAWARE project. [Available at: https://beaware-project.eu/]

[26] PLACARD - PLAtform for Climate Adaptation and Risk reDuction. [Available at: https://www.placard-network.eu/]

The ESPREsSO project[28] (H2020, 2016-2018) defined the six steps SHIELD Model built around the four DRM phases: Sharing Knowledge, Harmonizing Capacities, Institutionalising coordination, Engaging stakeholders, Leveraging investments, Developing communication. Under these six general groups, a series of more specific issues and consequent recommendation are presented for each chapter as support in enhancing DRM capabilities through disaster risk governance at multiple scales level. One fundamental step of the SHIELD model considers it necessary to cover the knowledge gap between science and policy. The recommendation is for local governance to develop policies and agreements with universities, corporations and research groups to be guided in actions where deep and technically advanced expertise is required.

The good practice of integrating several fields of expertise in the Disaster Risk Reduction (DRR) process is highlighted more, in general, the ENHANCE project[29] (FP7) in which it is stated the growing necessity of multi-sector partnerships, **involving the private and public sector** and the civil society organisations to be more prepared in the fight against the natural hazards at urban scale. The successful stakeholder partnerships established during the project proved that the cooperation can significantly improve DRM, especially in long-term planning. Though not specifically related to Natural and Cultural Heritage, these practices recommend a new approach to stakeholders, governance and CNH managers. The general advice is to expand the restricted group of actors usually involved in the DRM process and involve more expertise from different fields of research. The integration of all the different points of view would allow a comprehensive view of the situation to face climate-related hazards.

The importance of involving actors from several and various sectors in the DRM has progressively grown in awareness. In fact, a great number of the analysed practices insist on the necessity of engaging expertise outside municipalities and CNH managers to have a more complete view of the risks and obtain a deeper analysis of the situation. For example, a process of involving insurance companies to support climate change adaptation actions in small and medium-size enterprises was proposed and developed in the DERRIS project[30] (LIFE+, 2015-2018). The public-private partnership allowed to raise risk awareness through the insurance companies’ knowledge and to integrate climate adaptation considerations in management and operational procedures. The CLIMAbiz project[31] (LIFE+, 2010-2012) focused on integrating the financial impacts of climate change in the process of quantifying risks.

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[27] PLACARD Connectivity Hub [available at: http://connectivity-hub.placard-network.eu/?resource=false&teaser_resource=false]

[28] ESPREsSO - Enhancing Synergies for disaster PRevention in the EurOpean Union. [Available at: http://www.espressoproject.eu/]

[29] ENHANCE - Enhancing risk management partnerships for catastrophic natural disasters in Europe. [Available at: https://cordis.europa.eu/project/id/308438/it]

[30] DERRIS- DisastEr Risk Reduction InSurance . [Available at: https://climate-adapt.eea.europa.eu/help/share-your-info/general/insurance-company-supporting-adaptation-action-in-small-and-medium-size-enterprises-in-turin-italy/ - challenges_anchor]

Among the practices collected, a very broad group includes the **use of the new technologies** to be used in several phases of the DRM, underlining the different fields of applicability for these new tools. The Clim-ATIC project[32] (Interreg IIIB, 2008-2011) started its research from the assumption that nowadays almost everyone has a smartphone and can therefore access easily social media or targeted apps. This consideration allowed the consortium to test a people-centred early warning system at multiple scales, different from the more 'traditional' ones implemented directly at sites. The system worked by sending phones within a certain distance to the hazard a text and/or voice messages, allowing at the same time to initiate the evacuation more promptly and to provide citizens with guidance on the precautions. On the other hand, the CARISMAND project[33] (H2020, 2007-2018) identified strategies related to these technologies that are already active in different countries and scales that were proven helpful during the DRM phases and provided a document collecting the results. 1From the research it is clear that institutions social media channels (e.g. Facebook, Twitter, Municipality website) are a great tool to spread the alarm and reach a great number of citizens in different DRM phases. For example, the channels could be used to teach citizens good practices and behaviours even before a disaster occurs or to locate an event though people were searching for information about it. These tools should always be backed up by training course and efficient planning of the resource. A common obstacle when introducing these new technologies is the necessity of citizens having the localisation of the device enabled, agreeing in providing personal data to the authorities. At the same time, if the aim of these channels were presented transparently to citizens by institutions, they would be useful and cost-effective tools to be used in the DRM phases.

A **targeted mobile app** was developed also in the I-REACT project[34] (H2020, 2016-2019). The project validated the use of this app and of social media in emergency phases at urban scale. In fact, citizens can report events and natural hazards through the app which automatically generates initial reports for the area. The app, in line with the recommendations reported in the CARISMAND document, was designed to be as interactive and fun as possible, integrating quizzes and awards programs that guarantees the involvement and commitment of citizens, providing at the same time emergency information. What's more, the project developed the first European-wide platform. The system integrates emergency management data input from multiple sources, such as European monitoring systems, forecasts, historical information and also those provided by citizens through social media and the mobile app. Therefore, the platform produces fast and handy information, allowing DRM actors and citizens to effectively prevent and react to extreme events. The system was released as an Open Access platform and is still accessible and available through the project website[35].

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[31] CLIMAbiz project. [Available at: https://climate-adapt.eea.europa.eu/metadata/case-studies/financial-institutions-preparing-the-market-for-adapting-to-climate-change-2013-climabiz]

[32] Clim-ATIC - Climate Change - Adapting to The Impacts . [Available at: https://climate-adapt.eea.europa.eu/metadata/case-studies/multi-hazard-approach-to-early-warning-system-in-sogn-og-fjordane-norway]

[33] CARISMAND - Culture And RISkmanagement in Man-made And Natural Disasters. [Avaliable at: https://www.carismand.eu/resources.html]

[34] I-REACT- Improving Resilience to Emergencies through Advanced Cyber Technologies . [Available at: http://project.i-react.eu/dissemination/]

IPERION CNH[36] (H2020, 2014-2015) aimed at offering a unique European research infrastructure for Heritage Science in relation to the management and conservation of heritage objects, integrating national world-class facilities and research centres, universities and museums. IPERION CNH's gives heritage researchers, scholars and scientists trans-national access to three platforms bringing together knowledge of first-class facilities: MOLAB (Mobile LABoratory), for portable laboratories; FIXLAB (FIXed facilities LABoraoty), for large facilities; and ARCHLAB (ARChives LABoratory), for technical and scientific data archives. At the end of the project, it was decided to continue the work in IPERION HS[37] (H2020, 2020-2023). The project activities aim at providing **cross-border** access to **knowledge platforms** and the development of high-level scientific tools, methodologies, data and tools focused on knowledge and innovation in the study and conservation of heritage.

Furthermore, the ANYWHERE project[38] (H2020,2016-2019) developed **a pan-European** A4EU **platform** with the aim of supporting decisions related to extreme climate risks at different scales. The platform makes it possible to identify in advance disaster events that could lead to life and economic losses. It is therefore useful support at all levels of governance as well as public and private operators of critical infrastructure. The platform automatically identifies in advance the most critical areas at risk, including their location, allowing operators to respond promptly in the emergency phase[39].

CLIMATE FOR CULTURE[40](FP7) investigated the effects of climate change on European cultural heritage and searched for solutions to mitigate these effects. The achievements were reached thanks to the union of high-resolution climate modelling with building simulation tools. This allowed visualising **climate-changing effects scenarios** not only on historic buildings themselves but also on their interiors and artefacts. Different experimental monitoring techniques were used to identify the risks to heritage. To the more traditional ones (e.g. laser interferometry, investigations) techniques from previous EU projects were added to more easily determine the assessment of corrosive environments. A software algorithm was developed allowing to collect digitalised data (changing of analogue temperature and relative humidity) and a database with set of data from more than 100 historic buildings was created to identify the concept of 'generic building'. The comparison between the building's generic data and the constant monitoring of the internal conditions allows determining the changes and variations in values due to external climate change. The result is a collection of climate and risk maps that can be used to mitigate and assess the impact of climate change in Europe and around the Mediterranean. The solutions developed and validated during the project could also be replicated in areas with similar hazards and eventually extended to another field of research.

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[35] I-REACT platform [Available at: https://www.i-react.eu]
[36] IPERION-CNH Integrating Platforms for the European Research Infrastructure Cultural Natural Heritage. [Available at: http://www.iperionch.eu/]
[37] IPERION-HS Integrating Platforms for the European Research Infrastructure ON Heritage Science. [Available at: https://www.google.com/search?client=safari&rls=en&q=IPERIONHS&ie=UTF-8&oe=UTF-8]
[38] ANYWHERE - EnhANcing emergencY management and response to extreme WeatHER and climate Events . [Available at: http://anywhere-h2020.eu/]
[39] A4EU platform [Available at: http://anywhere-h2020.eu/services/multi-hazard-early-warning-platforms/a4eu/]
[40] CLIMATE FOR CULTURE project. [Available at: https://www.climateforculture.eu/]

The project ERA4CS[41] (H2020, 2016-2021) developed the SENSES toolkit dedicated to decision-makers to more easily visualise **future climate scenarios**. The open-access platform allows to visualise climate impacts, mitigations and energy strategies to make stakeholders, financial institutions and citizens are more and more aware of the global warming threat. On the platform different modules are available for every user to scan as the scenario finder, a co-production database, model-based mitigation pathways, emissions analysis and information but the main target are financial, policy and regional decision-makers.

The CRESCENDO project[42] (H2020, 2015-2010) saw the collaboration of different research teams to improve **models and tools for projections** of global climate change. The final goal was to improve the realism and capabilities of 7 European earth system modelling to increase the reliability of future projections. The project developed a set of projection of the earth system, thanks to the coupling of more earth system modelling. The result is more reliable and high-resolution versions of the projections in response to future CO^2 emissions.

Under the activities of NOAHS ARK[43] (FP6, 2004-2007) a network of tools and a **stakeholder targeted database** was created. The database serves as a support to help identify threats, allowing to run different scenarios on built cultural heritage and evaluate strategies effectiveness. The consortium developed a set of recommendations and guidelines for managers of HA to address weather phenomena on four themes: rainwater and drainage infrastructure, effects on structures, internal/external interaction and effects on building materials. A set of maps were also prepared and collected in the Vulnerability Atlas, which combined information on cultural heritage with information on weather risks.

The RESIN project[44] (H2020, 2015-2018), focusing on the urban level, developed three **tools and** one **guidebook** to help stakeholders in the DRM process: the Adaptation e-Guide (support tool in the development of adaptation strategies and plans and a guide for the other tools), the European Climate Risk Typology (interactive map allowing to visualize climate risks in Europe) and lastly the Adaptation Option Library (a searchable database storing information, adaptation measures and solutions addressing climate-related hazards). The guidebook developed by the project consortium explains the IVAVIA (Impact and Vulnerability Analysis of Vital Infrastructures and built-up Areas) methodology, a risk-based vulnerability assessment enabling stakeholders to map, analyse and communicate the impact of climate trends and weather events of the city. The tools and guidebook cover different aim and DRR process phases and are all available online open access with a very simple interface.

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[41] ERA4CS - European Research Area for Climate Services . [Available at: http://www.jpi-climate.eu/ERA4CS]
[42] CRESCENDO - Coordinated Research in Earth Systems and Climate: Experiments, kNowledge, Dissemination and Outreach. [Available at: https://www.crescendoproject.eu/]
[43] NOAHS ARK project. [Available at: http://noahsark.isac.cnr.it/]
[44] RESIN - Climate Resilient Cities and Infrastructures . [Available at: http://noahsark.isac.cnr.it/]

The H2020_Insurance project[45] (H2020, 2017-2020) focused on bringing into the increasing society resilience process the **insurance sectors** at different scales. The Oasis Loss Modelling Framework, developed by the project, allows combining climate services from several companies with loss and damage information. Thanks to the risk assessment process the system allows to identify the potential physical losses and the most vulnerable areas and also quantify the financial losses for the modelled scenarios. The open-source catastrophe modelling platform was proven so successful that the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) already adopted it to improve climate risk resilience for an international collaboration.

4.2.2. Water-related hazards (floods, storms, heavy rains)

The Protech2Save[46](Interreg Central Europe project, 2017-2020) aimed at improving the private and public sector capacities at coping with disasters and mitigating the effects of climate changes and natural hazards affecting built heritage in urban areas. The project developed both a **Good Practice manual**, a handbook collected in the GP sheet and also a decision support tool and ICT solutions (WebGis tool, inventory and maps) to support the needs of stakeholders and policymakers, involving citizens in the process, collected in the R&I Excel sheet. The *"Manual of good and bad practices for disaster resilience of cultural heritage risk assessment"* (Protech2Save project Deliverable D.T2.2.1) collects examples of practices and lessons learned from case studies in central Europe, focusing mainly on flood, heavy rain and fire due to droughts). The deliverable highlights, further than good maintenance of historic buildings to guarantee a good response to the events, the importance of generating physical and mathematical models to understand the hazards and the implementation of training and courses for stakeholders. In addition, some protection measures and warning systems to the aforementioned hazards are described in the document. The Protech2Save **WebGis tool** is designed to support decision-makers in identifying risk areas and vulnerabilities for heritage exposed to floods, droughts and heatwaves. The tools collect precipitations and climate risk indices of 2 historical periods from which 2 future 30 years risk maps scenarios were designed.

The PERICLES project[47] (H2020, 2018-2021) focuses on generating sustainable governance of CNH in coastal and maritime regions and the protection of their tangible and intangible heritage. Within the project, still ongoing, a database of references, tools, solutions and methods for understanding and preserving cultural heritage were collected and a series of templates for analysing the situation is available on the project website.

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[45] H2020_Insurance project. [Available at: https://h2020insurance.oasishub.co/]

[46] Protech2Save project. [Available at:https://www.interreg-central.eu/Content.Node/D.T2.2.1-Manual-of-good-and-bad-practices.pdf]

[47] PERICLES - PrEseRvIng and sustainably governing Cultural heritage and Landscapes in European coastal and maritime regionS. [Available at: https://www.pericles-heritage.eu/]

In addition, the project is designing an **online participatory portal** where stakeholders of coastal heritage can both search for similar case studies information and upload their data on the platform to generate maps. The work undertaken until now highlighted the importance of planning and integrating CNH policies in several levels of governance.

PERICLES was not the only project underlining the necessity of a more integrated and long-term planning as it was found to be a common good practice validated in several others. One of those was BASE[48] (FP7, 2012-2016), which validated the importance of **adaptive planning** policies in the city of Copenhagen, the case study of the project. The adaptation policies and actions foresee in the future years the integration of strong green growth and special attention on the use of nature-based solutions.

The IMPRINTS project[49] (FP7, 2009-2012) aims at the reduction of life losses and economic damage by improving preparedness and operational risk management forecasting flash floods and debris flow in historical centres of cities. The developed tools were specifically designed in support to flood risk management, responsible practitioners. The **early warning operational platform** collects forecasts for rainfall and weather radar networks to produce hydrogeological warnings. With the data collected the platform is able to provide information about the vulnerability of flooding risks, thus constituting a full early warning system.

The IMPREX project (H2020, 2015-2019) contributed to the prediction and management capabilities in relation to water-related natural hazards, developing new approaches and tools in 10 European case studies. Among the main outcomes is the production of **periodic hydrogeological risk outlook** for Europe incorporating the dynamic evolution of hydroclimatic and socio-economic processes. This analysis is obtained through dynamic model ensembles, process studies, new data assimilation techniques and high-resolution modelling leading to improve forecast skill of meteorological and hydrological extremes in Europe and their impacts which were validated during the project.

The RISC-KIT project[50] (FP7, 2013-2017) focused on hydro-meteorological event impacts in coastal areas. The project consortium developed a free open access set of tools addressed to managers of maritime areas to support mitigation measures and the prevention of storm events. The RISK-KIT tools developed are the Storm Impact Database, through which historical events can be searched along with socioeconomic and physical data. The Coastal Risk Assessment Framework allows identifying present and future vulnerable coastal areas while through the Hotspot Tool the effectiveness of DRR measures in those areas can be evaluated. The **Web-based Management Guide** contains a collection of prevention, preparedness and mitigation cost-effective and ecosystem-based DRR measures. Lastly, the Multi-Criteria Analysis Tool is designed to assess the DRR measures with stakeholders.

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[48] BASE - Bottom-up climate Adaptation Strategies for Europe [Available at: https://climate-adapt.eea.europa.eu/metadata/case-studies/realisation-of-flood-protection-measures-for-the-city-of-prague]

[49] IMPRINTS - IMproving Preparedness and RIsk maNagemenT for flash floods and debriS flow events. [Available at: http://www.crahi.upc.edu/imprints/]

[50] RISC-KIT - Resilience-Increasing Strategies for Coasts - toolKIT .[Available at: http://www.risckit.eu/np4/home.html]

The aim of SYSTEM-RISK project[51] (H2020, 2016, 2019) was to develop a system approach for large-scale flood assessment and management in coastal areas. The research developed an advanced system integrating the complete **flood risk chain** along with physical and societal interaction to reach a more realistic approach. What's more, the project investigated the time-varying nature of flood risk under different time scales in order to better understand temporal dynamics and the increasing short- and long-term learning capacities of people interacting with such hazard.

The objective of FLOOD PROBE[52] (FP7, 2009-2013) was to develop an effective and low-cost model for protection and mitigation of urban areas against floods. The project designed more accurate **vulnerability maps** of the built environment to easily assess the area risk and the critical infrastructure networks enabling to identify the interdependencies and cascading effects on facilities and city-systems. Furthermore, new **levee erosion assessment tools** and methodologies were developed using both remote sensing and geophysical technologies. The research focused also on identifying hot spots buildings (power stations, water treatment plants, control centres of public transports…) and methodologies to make them more resilient, along with a model to detect and implement flood secure shelters as immediate protection when the floods occur.

The research undertaken in the INUNDO project[53] (H2020, 2016) targeted **insurance companies** to provide them with accurate spatial information (both current and historical) for risk modelling with the objective of improving existing risk assessment processes. The aim was therefore to design natural hazard models correlated with geospatial flood information and details to enhance the accuracy of flood risk insurance related analysis.

The FLOOD-serv project[54] (H2020, 2016-2019) targeted the negative consequences of floods and focused on prevention and mitigating methodologies at different scales. The result is the open-access FLOOD-serv system designed to serve public authorities as a support in the fight against floods under different aspects. The portal is organized in six different components and tools: the Flood-serv portal serves as an introduction to the whole system and as a starting point to engage flood discussion with citizens; the Emergency Management Console is built with the objective of raising and monitoring community awareness on floods thus allowing authorities to effectively develop long term strategies and communicate with citizens during emergency phases; The FLOOD-serv Semantic Wiki is a database collecting general and specific information on floods, to be used both by authorities and citizens; the Citizens Direct Feedback is designed to enable a faster and more effective citizens-local authorities communication; the Territory Management System collects multisource analysis pictures (satellites, aeroplanes, ground-level…) which are later processed and analysed by the system able to detect relevant changes and generate reports.

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[51] SYSTEM-RISK project. [Avaliable at: https://www.system-risk.eu/]
[52] FLOODPROBE - Technologies for Flood Protection of the Built Environment . [Available at: http://www.floodprobe.eu/]
[53] INUNDO project. [Available at: https://cordis.europa.eu/project/id/729401/reporting]
[54] FLOOD-serv - Public FLOOD Emergency and Awareness SERVice. [Available at: http://www.floodserv-project.eu/]

The FRAMAB project[55] (H2020, 2015-2017) studied the exposure and capacity of masonry arch bridges heritage against floods. The project adopted a **modelling strategy** to test the structure capacities employing a nonlinear structural analysis accounting the complex geometry of the objects. The proposed strategy was validated by experiments involving both single and multi-span bridges under vertical loads and scour-induced settlements.

The FLOODCHANGE project[56] (FP7, 2012-2017) objective was to understand the relationship between the changes in land use and climate changes in relation to river floods. The research analysed the historical data and behaviours of more than 5000 river gauging station and current databases in Europe. This led to the conclusion that in the past decades floods changed both in seasonality frequency and in magnitude. The research consequently focused on a new approach for attributing observed flood changes to their drivers by evaluating the region catchments rather than the ones of a single station. Lastly, the project studied the potential long-term interactions between flood magnitude and related decision based on human-water models, reaching a step forward in the prediction of future flood changes.

The INFLATER project[57] (FP7, 2011-2014) aimed at developing a flood protection tool that used the force of water. The preliminary measures were adopted for specific sensitive locations, from industrial to urban and historic areas. The technology developed automatically reacts to the normal water level protecting the mentioned areas, activating the raising of a mobile barrier, able to protect up to one-meter water level high. The mobile flood barrier system was tested and validated in an Ireland city case study and passed static water leakage and wave tests and withstood the current tests for a considerable time period.

The MICORE project[58] (FP7, 2008-2011) aimed at producing reliable **maps of the morphological impact** of sea storms and developing related **early warning systems**. The project-transcending database OpenEarth developed within the project, allowed to store and manage data, model system and analysis tools from multiple projects and to be used later for future research, preventing future effort and economical expenditure to retrieve data. Afterwards, a WebGis system collecting useful data was developed allowing to determine storm risk mapping of the morphological impact of marine stormsand, Storm Impacts Indicators. The tool was also used to produce of early warning and information systems to support long-term disaster reduction.

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[55] FRAMAB - Flood Risk Assessment and mitigation for Masonry Arch Bridges. [Available at: https://cordis.europa.eu/project/id/657007]
[56] FLOODCHANGE project. [Available at: https://floodchange.hydro.tuwien.ac.at/home]
[57] INFLATER project. [Avaliable at: https://cordis.europa.eu/project/id/286522]
[58] MICORE- Morphological Impacts and COastal Risks induced by Extreme storm events . [Avaliable at: https://www.micore.eu/]

The research of the CENTAUR project[59] (H2020, 2015-2018) focused on the development of an autonomous system to alleviate the risk of local flooding in **urban areas**. As a result, a system was developed based on the installation of a Flow Control Device (FCD) that sends wireless communications in case of abnormal water levels. Afterwards, it can be decided whether to activate the FDC closure and store water, reducing flow and water levels at the flood-prone site, minimizing the likelihood of flooding. The communication system is solar-powered and can be connected to nearby infrastructure. Its strength is that it is very flexible and quickly deployable, being operational without the need for structural changes to the existing drainage and sewer system, unlike more common flood-related systems.

4.2.3. Heat related hazards (heatwaves, fires, wildfires)

Several projects highlighted the importance of installing **traditional early warning systems** to remotely monitor areas of archaeological and cultural interest, such as FIRESENSE[60] (FP7, 2009-2013) and CALCHAS[61] (LIFE+, 010-2013). Both projects addressed wildfire and heatwaves and use multi-source sensors and new technologies to detect environmental changes and foresee a dangerous event.

The GEO-SAFE project[62] (H2020, 2016-2020) saw the cooperation of Europe and Australia with the aim of enhancing the management of wildfires in the two regions. The project activated a network for knowledge, ideas and experience exchange for dealing efficiently with the hazard. All the data and knowledge related to wildfires are collected in the Lessons on Fire **platform**, free and open access.

The SPFireSD project[63] (H2020, 2017-2019) scope was to implement an accurate fire **forecasting system**. Usually forecasting systems are able to predict dangerous fires within ten days from their occurrence, as the Global ECMWF Fire Forecast used by the European Centre for Medium-Range Weather Forecast (ECMWF). The project developed and assessed a fire forecasting system that has a seasonal prediction capability up to one month ahead thanks to the introduction of a wide range of complementary innovative methods.

Another further project focused on wildfire management was FIRE PARADOX [64] (FP6, 2006-2010) which developed a prototype of a **system to be used by fire-fighters** during an emergency. The system simply works through a smartphone or a tablet through which field operators are able to visualise wind direction and its forecast changes, localize the others rescue teams through the GPS installed in the devices, uploading real-time photos on the maps to identify the fire extent. In addition, the system allows an easier and faster communication with base dispatchers, providing real time information and visual data. Though, this was not the only achievement of the FIRE PARADOX project. The project also designed the MOL (Multimedia OnLine), a **multimedia platform** which scope is to optimize the searching of fire related information, and a European Fuel Knowledge Platform, a library for fuel descriptions and a data source for the prediction of the behaviour of fire and wildfire. In addition, the Large-Scale Fire Simulator and the Low Scale Fire Propagation Simulator were designed, a tool that enables operators of assessing fire spread and intensity of large fires. Other tools are available on the project website: training system material, Guidelines for fire management and suppression, a set of demonstration sites, and a WebGIS tool developed as a decision support system.

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[59] CENTAUR - Cost Effective Neural Technique for Alleviation of Urban Flood Risk . [Avaliable at: https://www.sheffield.ac.uk/centaur]

[60] FIRESENSE - Fire Detection and Management through a Multi-Sensor Network for the Protection of Cultural Heritage Areas from the Risk of Fire and Extreme Weather Conditions. [Available at: https://cordis.europa.eu/project/id/244088/reporting]

[61] CALCHAS project. [Available at: https://climate-adapt.eea.europa.eu/metadata/case-studies/calchas-an-integrated-analysis-system-for-the-effective-fire-conservancy-of-forests]

[62] GEO-SAFE project. [Available at: https://geosafe.lessonsonfire.eu/]

[63] SPFireSD project. [Available at: https://www.bsc.es/research-and-development/projects/spfiresd-seasonal-prediction-fire-danger-using-statistical-and]

[64] FIRE PARADOX project. [Available at: http://www.fireparadox.org/]

A **system for early forest fire detection** and alarm was also developed within the DANTE project[65] framework. The fire ignition is firstly detected by image processing algorithms which within few seconds send the alarm to the control room. Fire fighters are then provided with all the critical information for the extinguishing of the blaze and its georeferenced coordinates. The system works as a real-time navigator, giving field operators all the information on fire progress. The researchers developed the prototype as a low-cost hardware platform, raising the attention also of insurance companies interested in monitoring high-value assets.

Furthermore, the S2IGI project[66] (H2020, 2019-2020) focused on the management of fire, with the aim of supporting operative activities. The specialised software application, ONDA, developed by the project is based on satellite technologies, with the exploitation of the already available Copernicus data and the resolution of weather patterns. The platform is able to operationally provide end-users the burned areas estimate through change detection analysis.

Drone-Hopper, developed in the homonymous project[67] (H2020, 2017), is a patented **remote-controlled aircraft** which incorporates liquids to be used for fire extinction, releasing nebulized liquids towards the land as soon as a fire is detected. When propelled, the water mist mixes with the air creating a wet air flow therefore oxygen is removed from the chemical combustion reaction. This semi-autonomous drone technology would outperform helicopters and hydroplanes currently used in fire-fighting air operation, as it would be possible to release water closer to the fire and reach the endangered areas faster.

The CIRCLE-2 project[68] (FP7, 2010-2014), focused on the study of heatwaves and wildfires, integrates traditional and new technologies in the warning process. The **alert system** monitors weather forecasts and receives data from the sensors installed in the areas and when extremely hot weather is detected the alert protocol is activated. After that, the alarm is sent and reaches citizens and authorities through different channels (social media, city homepage, mail delivery, tv news…). The system was implemented in Tatabanya, Hungary, as case study of the project. The process was proven valid as a cost-effective solution in life savings and reactiveness of citizens which directly received the alert from the selected channels. In addition, under the project framework, cycles of training courses were activated in places where most **vulnerable citizens** (children, youngsters, elderly) could be reached and educated on sun effects and personal protection measures.

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[65] DANTE - Digital Alarm Network and Tracking Equipment for forest fire detection. [Available at: https://cordis.europa.eu/project/id/807440]

[66] S2IGI - Integrated Fire Management System . [Available at: https://www.s2igi.com/]

[67] Drone-Hopper project. [Available at: https://drone-hopper.com/]

[68] CIRCLE-2 - Climate Impact Research & Response Coordination for a Larger Europe - 2nd generation. [Available at: https://cordis.europa.eu/project/id/249685]

4.2.4. Earthquake

The SMR project[69] defined the European Resilience Management Guideline, an operational framework providing guidance to the relevant stakeholders for the implementation of an **integrated management process** aimed at resilience improvement. The Guideline is composed of five tools, all available and open access through the project web site. The Resilience Maturity Model (RMM) allows decision makers to understand the city level of preparedness and resilience status. The Model provides a series of actions to be undertaken in order to lead the city to the next level of maturity. This tool helps governance to detect the most critical gaps and can be used as a support to prioritize policy implementation in the long-term planning. The Risk Seismicity Questionnaire (RSQ) is an assessment Excel tool which allows to identify the risk level of the city and the risk awareness of the possible scenarios. The Resilience Information Tool (RP) is a portal built with the scope of increasing awareness and facilitating engagement and collaboration among the key partners of resilience building. The City Resilience Dynamics Model (CRD) is a simulation game, to be seen as a training tool, to help cities visualize scenarios and explore different strategies to implement. This tool is strictly related to the RMM as it allows to identify the most effective sequence of policies implementation aligned with the Maturity Model. Lastly, the Resilience Building Policies Tool (RBP) complements all the other tools in the form of a case studies database.

The PROHITECH project[70] (FP6, 2004-2008) had as main objective the development of sustainable methodologies for the use of **reversible mixed technologies** in the seismic protection of existing constructions, with particular emphasis to buildings of historical interest (the Bagnoli area in Naples, Italy; the Mustafa Pasha Mosque in Skopje, Macedonia; the Gothic Cathedral in Fossanova, Italy; the Byzantine St. Nikola Church in Psacha, Kriva Palanka, Macedonia; the Beylerbeyi Palace in Istanbul, Turkey). Reversible mixed technologies exploit the peculiarities of innovative materials and special devices, allowing ease of removal if necessary. At the same time, the combined use of different materials and techniques yields an optimisation of the global behavior under seismic actions.

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[69] SMR - Smart Mature Resilience. [Available at: https://smr-project.eu/deliverables/]

[70] PROHITECH - Seismic Protection of Historical Buildings by Reversible Mixed Technologies. [Available at: https://cordis.europa.eu/project/id/509119/reporting]

The NIKER project[71] (FP7, 2007-2012) tackles the problem of earthquake-impact on Cultural Heritage assets. The project developed the NIKER Catalogue, a structured **database** linking earthquake induced failure mechanisms, construction typologies and materials, interventions and assessment techniques. The aim is a knowledge-based optimization of interventions and definition of main design parameters and requirements for materials and intervention techniques.

4.3. Gaps detected

The main gaps identified during the research of relevant GP and R&I initiatives are mainly related to two hazards: subsidence and heatwaves. For what concerns heatwaves, several projects addressing this hazard were encountered but the research almost entirely focused on enhancing the safety of citizens and not on heritage. Though interesting outputs, these practices were not recorded in the observatory as are not of relevance for the fields of research of SHELTER. It was found out that the studies of heatwaves related to Natural and Cultural Heritage are very few and should be for sure implemented to support the SHELTER case studies affected by this hazard.

In relation to subsidence, only one of the practices collected target this hazard. This is probably because the concept of subsidence is still quite a recent one and became subject of studies mainly since the first decades of 20th Century[72].

4.4. Conclusions

The Good Practice and R&I initiatives reviewed contributed to setting the scene of the current operational knowledge framework for Natural and Cultural Heritage resilience, also in cooperation with the other SHELTER sister projects, such as ARCH project. The practice collection allows drawing two main conclusions.

First of all, it has become increasingly recognized that it is of fundamental relevance that cities are aware of the hazards and should be ready for mitigating extreme events rather than not only focusing on preventing disasters. Extreme events are becoming more and more frequent and violent. The traditional methods that were meant to keep threats away from urban areas are no longer effective. These methods, which already had limitations before and were not always totally effective, are no longer efficient today. Researchers of the recent years has shown that the correct approach involves mitigation of effects and strategies to limit damage and consequences rather than preventing the event. There is not a unique answer, but the key point is the adoption and integration of a mix of strategies addressing all phases of risk management in planning policies.

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[71] NIKER - New Integrated Knowledge Based Approaches to the Protection of Cultural Heritage from Earthquake-Induced Risk. [Available at: http://www.niker.eu/]

[72] Riccieri, G (1992) Studi e ricerche nell'area di San Vitale, Galla Placidia e Santa Croce in Ravenna, SG Editoriali, Padova

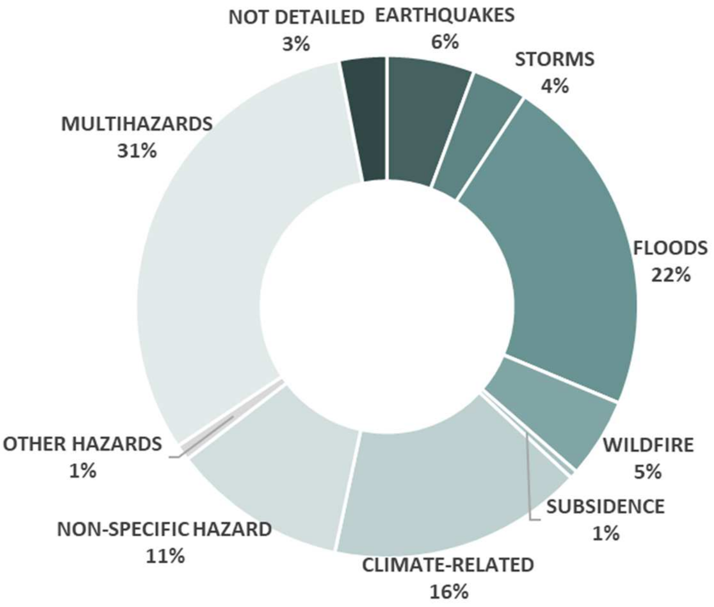

Figure 7: Graphical representation of Good Practices and Tools targeted hazards

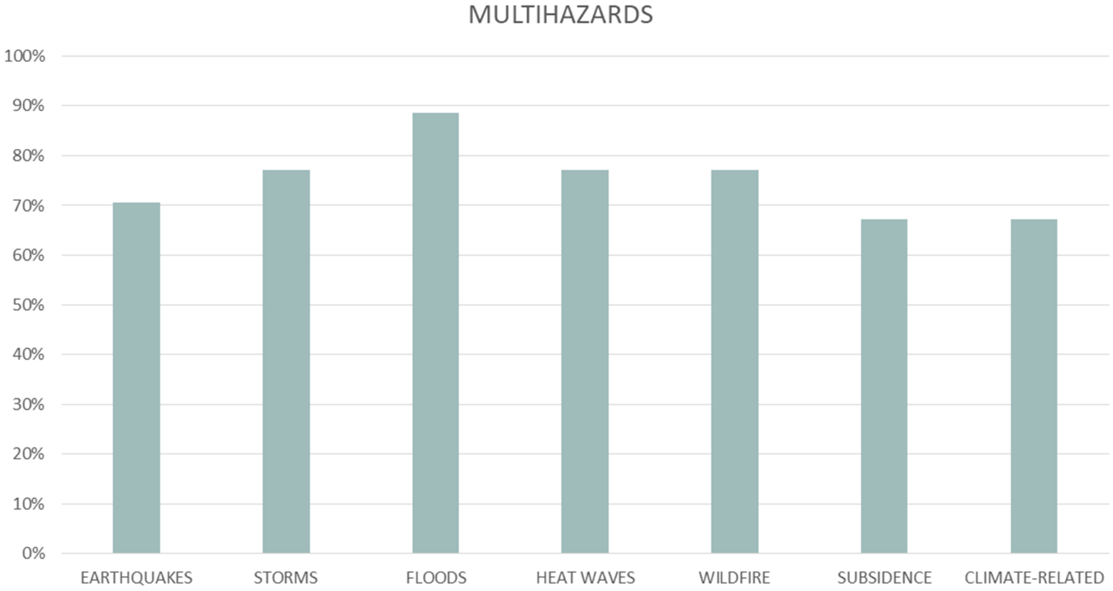

Figure 8 Specification of multi-hazard's composition of good practices and tools

The collection also showed that in recent years there has been a shift in the approach to deal with climate change. Among the projects and related pilot cases analyzed, the cities that had at disposal advanced technologies available were not necessarily the ones that responded best to the risks they faced. It became increasingly clear that what made the difference was not the availability of tools and technologies, but more importantly the methodology and readiness with which they were used. This necessarily leads to a greater focus on stakeholders, authorities, governments and their readiness to respond and even more on their level of interaction and cooperation. The advanced technologies that are available today are certainly a great contribution to urban resilience. At the same time, however, the real challenge now is to bring new actors onto the DRM scene and to educate new and old to use the capabilities that are already available.

According to the D1.2[73] research, the key factors in ensuring a good level of resilience against climate change risks are cooperation between the community, private, and public sectors; establishing targeted procedures, policies, and funds; incorporating adaptive strategies into long-term governance planning.

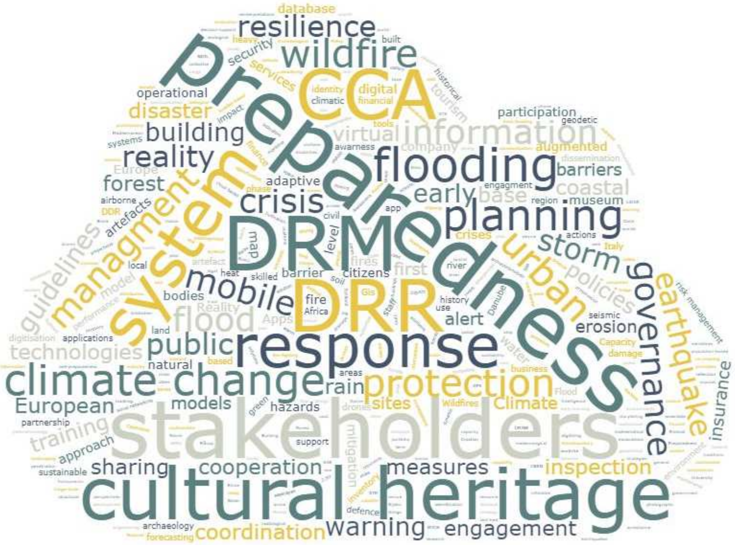
preparedness
DRM
DRR
stakeholders
cultural heritage
response
system
climate change
CCA
flooding
planning
resilience
wildfire
information
protection
governance
earthquake
urban
storm
managment
crisis
mobile
flood
public
reality
building
disaster
forest
guidelines
technologies
European
training
sharing
cooperation
measures
inspection
coordination
warning
engagement
erosion
alert
barriers
coastal
early
policies
insurance
models
hazards
rain
sites
Climate

Figure 9 Main keywords highlighted by the research

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[73] Full document available on https://shelter-project.com/documents/deliverables/

5. SHELTER project approach and concepts: contextualization of natural hazards for CNH risk assessment

5.1. Defining natural hazards

The European Environment Agency (EEA) defines hazard as

- "…*potentially damaging physical event, phenomenon or human activity characterised by its location, intensity, frequency and probability*." ([4] EEA 2012: 47)[74]

The Intergovernmental Panel of Climate Change (IPCC) defines hazard as;

- "*The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.*" ([9] IPCC 2012: 560)[75]

Generic terminology for hazard, as well as for vulnerability, are used to describe very complex processes. Although clear definitions of hazards are available, confusion remains over the use of the term in the climate change adaptation and resilience literature.

The use of the term hazard within these related concepts can further help to clarify its meaning. Definitions of risk and resilience, which include the term hazard, are given below:

- The IPCC includes hazard in the definition of risk: "*Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems.*" ([11] IPCC 2014: 3)[76]
- The United Nations Office for Disaster Risk Reduction (UNDRR) define resilience as: "*the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.*" (UNDRR 2009: 92)[77]

Events termed as hazards within the high-level international climate change reports named above, for example floods and heatwaves, are also referred to as impacts, extreme events, climate extremes, meteorological hazards and natural disasters, sometimes interchangeably within the same literature source.

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[74] EEA Report n 12/2012 Climate change, impacts and vulnerability in Europe 2012 https://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012

[75] IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/

[76] IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability https://www.ipcc.ch/report/ar5/wg2/

[77] https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction

Considering all the above, hazard in the context of SHELTER project is defined as: "*An unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins*".[78]

In SHELTER project, all hazards considered, but earthquakes, are climate-related physical events. Therefore, developing an understanding of current and potential future hazards in a climate change context is an essential element of adapting and building resilience for CNH.

5.2. Hazard characterization in the context of the SHELTER project operational framework

Hazard characterization can be conducted as stand-alone process or as component of risk assessment. In SHELTER project hazard characterization is seen as preparatory action integral to the process of a risk-based vulnerability assessment.

From the disaster risk management (DRM) perspective, risk is a function of the likelihood of an event to happen per the impact of the event. Risk analysis allows to determine, in a systematic way, the impact (i.e. extent of damage) which is to be expected if different hazardous events occur.

From the climate change adaptation (CCA) perspective, risk is understood as a function of hazard exposure and vulnerability.

SHELTER project conceptual framework for risk assessment follows the one defined by the IPCC in their fifth assessment report (AR5).The IPCC risk assessment framework is show in Figure 10.

In this conceptual framework, risk is a function of hazard, exposure and vulnerability, as shown in Table 3 below.

Risk determinants /components	*Hazard: influenced by natural variability of climate variables and anthropogenic climate change*
	Exposure to hazard
	Sensitivity (component of vulnerability)
	Capacity of response (component of vulnerability)

Risk = probability (hazard) x consequence f (exposure, vulnerability)
Vulnerability= f (sensitivity, capacity of response)

Table 3 Risk determinants according to IPCC AR5 conceptual framework

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[78] https://wiki.shelter-project.cloud/en/ontology/hazard

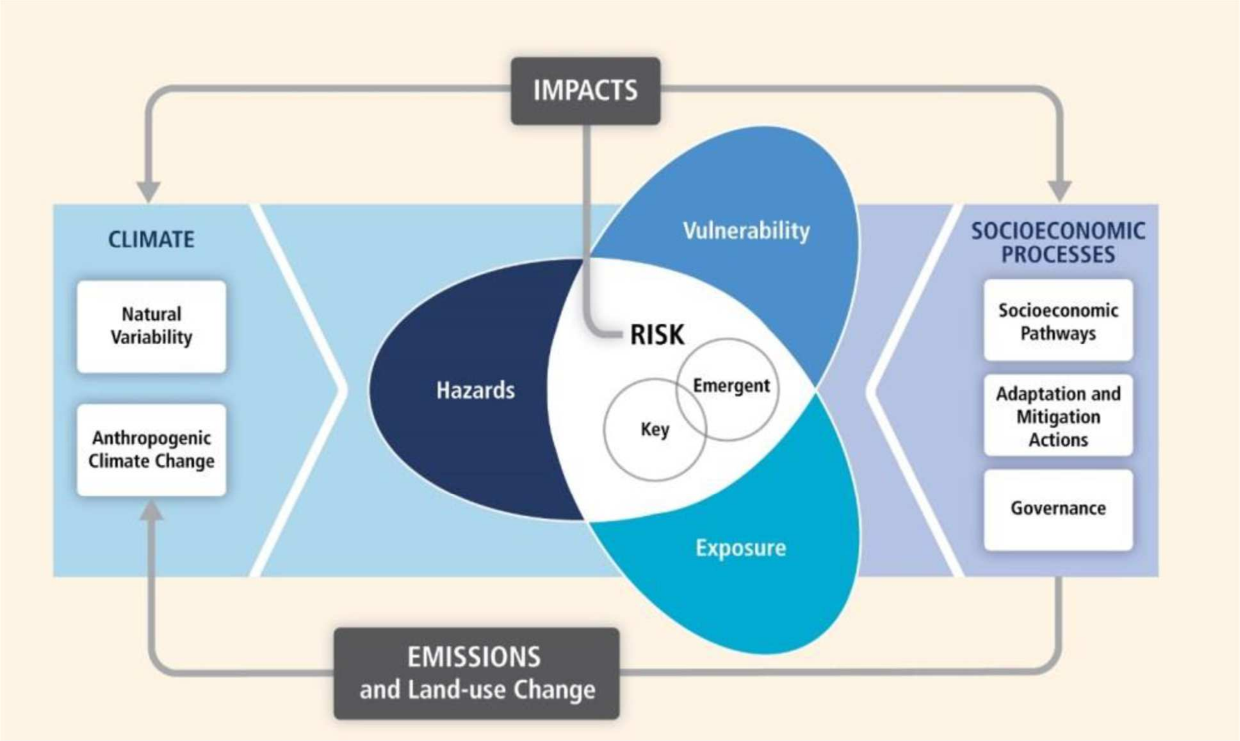
IMPACTS
CLIMATE
Natural Variability
Anthropogenic Climate Change
Vulnerability
Hazards
RISK
Emergent
Key
Exposure
SOCIOECONOMIC PROCESSES
Socioeconomic Pathways
Adaptation and Mitigation Actions
Governance
EMISSIONS and Land-use Change

Figure 10 IPCC, 2014 Technical Report, Figure [TS.1]. Source: IPCC (2014) AR5, WG-II, Ch. 19[79].

The SHELTER framework for risk assessment is also consistent with the Sendai Framework for Disaster Risk Reduction 2015-2030 ([14] UN, 2015)[80] contributing to a number of priorities for action to prevent new and reduce existing disaster risks, in particular to: i) Understanding disaster risk; ii Enhancing disaster preparedness for effective response, and to "Build Back Better" (BBB) in recovery, rehabilitation and reconstruction.

It is notable that the IPCC’s conceptualization of risk also highlights the influence of socio-economic processes on risk. The methodological identification of relevant hazards drivers, including non- climate drivers and stressors, is a key element for a successful application of the risk assessment.

It is worth mentioning that the climate change research community has not yet achieved a consistent framework for the assessment of complex climate change risks and integrated multi-hazard risk assessment. Moreover, the IPCC notion of compound risk, focuses most on the interaction of climate hazards determining a risk rather than their integrated assessment. This aligns with a growing research field on climate hazard interactions, such as heavy precipitation coinciding with a storm surge to increase likelihood of flooding, often termed compound weather or climate events. This yet unresolved challenge of multihazard risk assessment is out of the scope of the present report.

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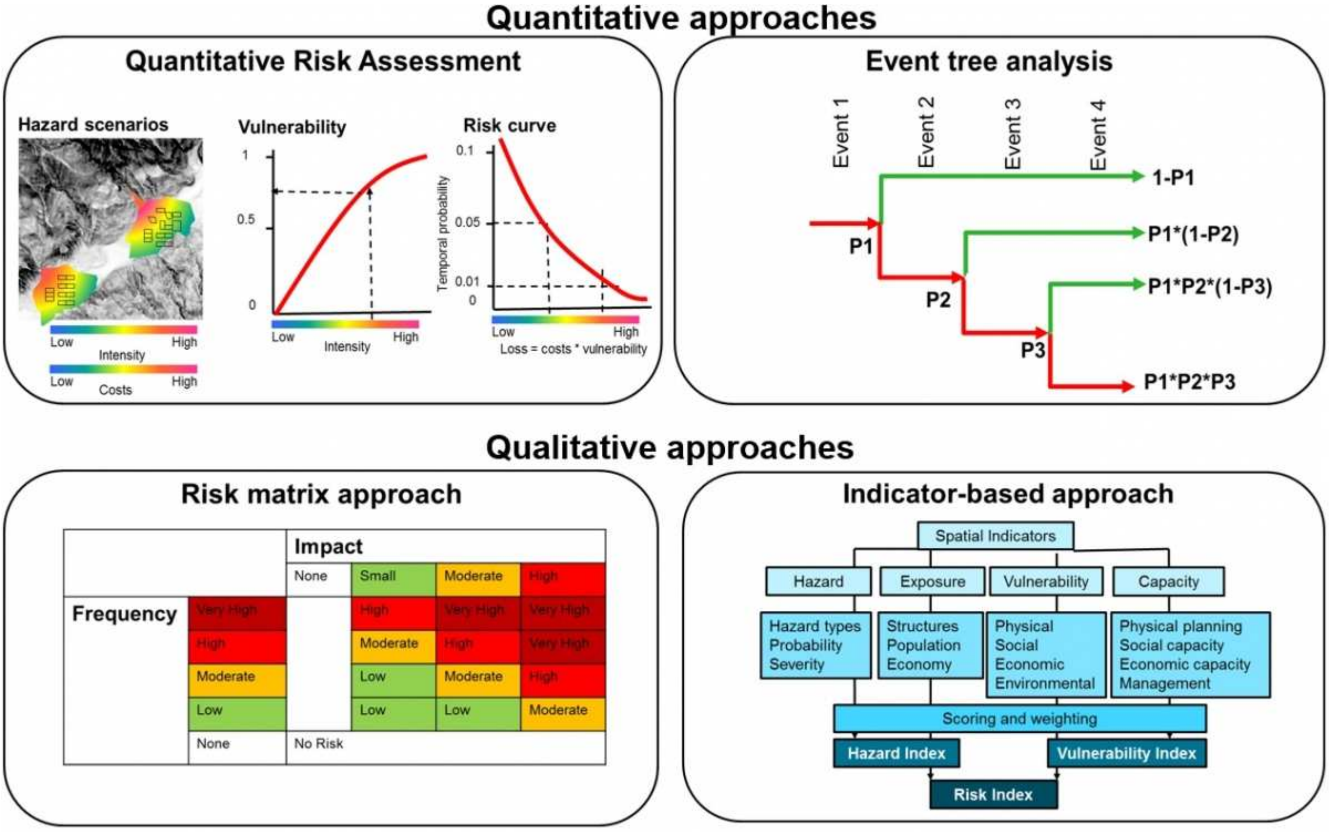
[79] IPPC AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability https://www.ipcc.ch/report/ar5/wg2/

[80] The Framework was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on March 18, 2015.

5.2.1. Different approaches and methods for risk assessment

There are different approaches and methods in the analysis of risk, which are shown in Figure 11 and described below:

- **Quantitive risk assessment**: It is a quantitative approach in which hazard scenarios and cost of elements at risk are used.
- **Event tree analysis**: It is a quantitative approach to risk where trees are defined to establish relations between different hazards and events: i.e. one hazard is the cause or driver for other hazards. .
- **Risk matrix approach**: It is a qualitative approach to risk that allows classifying risks based on expert knowledge when quantitative data is lacking or limited.
- **Indicator- based approach**: It is a semi-quantitative approach that uses indicators associated to each risk determinant/ component (i.e. hazard, exposure, vulnerability) which are then normalized, weighten and aggregated to obtain a risk scoring.


Quantitative approaches
Quantitative Risk Assessment
Hazard scenarios
Low
High
Intensity
Low
Costs
High
Vulnerability
1
0.5
0
Low
Intensity
High
Risk curve
0.1
0.05
0.01
0
Temporal probability
Low
High
Loss = costs * vulnerability
Event tree analysis
Event 1
Event 2
Event 3
Event 4
P1
P2
P3
1-P1
P1*(1-P2)
P1*P2*(1-P3)
P1*P2*P3
Qualitative approaches
Risk matrix approach
Indicator-based approach
Spatial Indicators
Hazard
Exposure
Vulnerability
Capacity
Hazard types
Probability
Severity
Structures
Population
Economy
Physical
Social
Economic
Environmental
Physical planning
Social capacity
Economic capacity
Management
Scoring and weighting
Hazard Index
Vulnerability Index
Risk Index

		Impact			
		None	Small	Moderate	High
Frequency	Very High		High	Very High	Very High
	High		Moderate	High	Very High
	Moderate		Low	Moderate	High
	Low		Low	Low	Moderate
	None	No Risk			

Figure 11 Different approaches to assess risk. Source: Caribbean Handbook on Risk Management (https://www.cdema.org/virtuallibrary/index.php/charim-hbook/what-is-charim)

¡Error! No se encuentra el origen de la referencia. shows a comparative assessment of these risk approaches and methods.

Method	Advantages	Disadvantages
Quantitative risk assessment	Provides quantitative risk information that can be used in Cost-benefit analysis of risk reduction measures.	Demands high amount and very diverse kind of data. Difficult to quantify the temporal probability, hazard intensity and vulnerability.
Event-tree analysis	Allow modelling sequences of events, and it is especially effective for the evaluation of cascading effects.	The probabilities for the different nodes are difficult to assess, and spatial implementation is very difficult since it requires huge amount of data not always available.
Risk matrix approach	Allows to express risk using risk classes instead of exact values and is a good basis for discussing strategic thinking for risk reduction measures when data and resources are limited.	The method does not give quantitative values to be used in cost-benefit analysis of risk reduction measures. The assessment of impacts and frequencies does not always provide accurate results.
Indicator-based approach	It is the only method that allows to carry out a holistic risk assessment, including social, economic and environmental vulnerability and capacity of response.	The resulting risk is expressed in relative terms not in absolute terms and does not provide information on expected losses.

Table 4 Advantages and disadvantages of risk approaches.

An indicator-based approach (see Figure 12) was already suggested in SHELTER project as operational framework for vulnerability and risk assessment in D2.2., and will be further developed in Task 2.5.

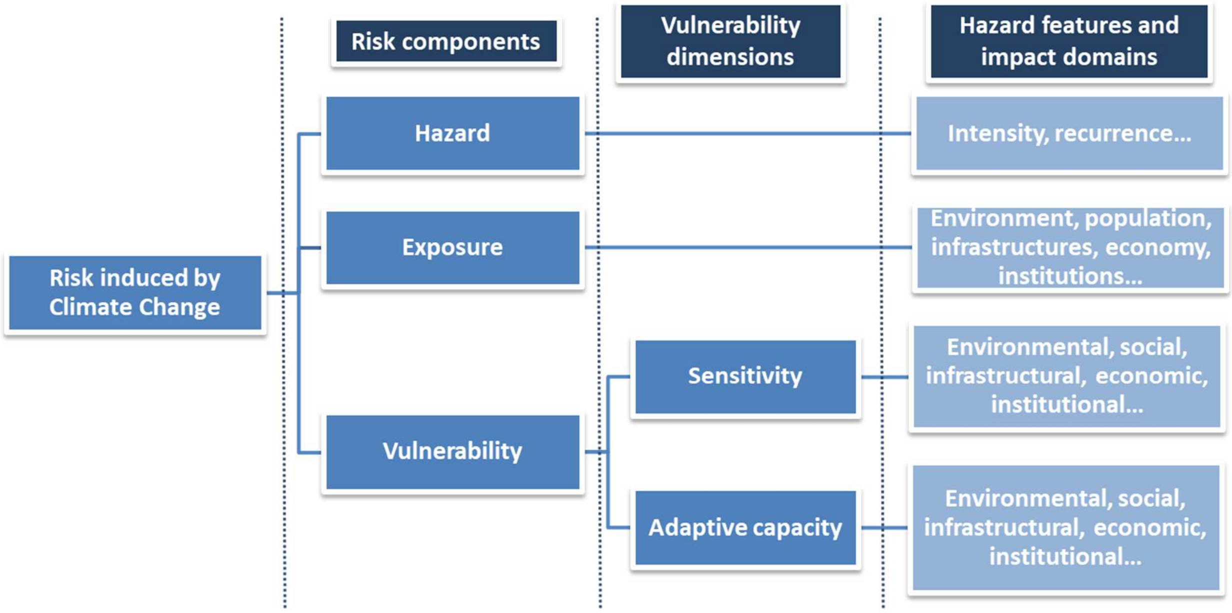

Risk components
Vulnerability dimensions
Hazard features and impact domains
Risk induced by Climate Change
Hazard
Exposure
Vulnerability
Sensitivity
Adaptive capacity
Intensity, recurrence…
Environment, population, infrastructures, economy, institutions…
Environmental, social, infrastructural, economic, institutional…
Environmental, social, infrastructural, economic, institutional…

Figure 12 SHETER operational framework for indicator-based vulnerability and risk assessment of natural hazards on CNH.

6. Systematic classification of natural hazards and events in SHELTER

Table 5 summarizes SHELTER project proposal for clustering natural hazards in line with their main physical determinants.

Hazard group	Main biophysical/weather/climate determinants	Hazard main type
Geophysical Originated from mass movement of solid earth.	Mass movement	**Earthquake**
		Landslide
		Subsidence
Meteorological Short-term or small-scale weather conditions (e.g., minutes to days).	Precipitation	Rainstorm (runoff)
	Wind	**Severe wind/storm**
	Temperature trends and patterns	**Heat wave**
		Extreme hot weather
		Cold wave
		Extreme cold weather
Climatological Long-term or large-scale atmospheric processes (e.g., intra seasonal to multi-decadal).	Water scarcity (lack of precipitation and or seasonal melt)	Drought
	Wildfire	**Forest fire and land fire**
Hydrological Mass movement of water influenced by meteorological	Flood	**Surface flood/runoff**
		River flood
		Coastal flood/ sea level rise
	Wave action	Storm surge
	Chemical change	Saltwater intrusion
		Ocean acidification
Biological Change in the way living organisms grow and thrive, which may lead to contamination and/or disease.	Insects and micro-organisms	Different diseases for humans, animals and plants anomalous growth of micro-organisms under extreme events (precipitation and extreme temperatures potentially affecting CNH structure/ materials

Table 5 Proposal for clustering hazards linked to the main biophysical drivers and determinants: *In bold Hazards addressed in Shelter

6.1. Parameters used to classify the events

Despite the differences within disciplines and the sometimes-confusing application of the term, there are certain essential features and common parameters normally used to classify the events and their corresponding characteristics:

- **Spatial nature**, location and spatial dispersion that is, that they have the potential to impact on certain areas but not others. Generally, therefore, hazards can be mapped. Scale matters and hazards must be analysed with a multi-scale approach depending on the CNH that is being analysed.
- **Magnitude and intensity** which is the severity of the natural hazard events, including extreme events.
- **Duration** of the event.
- **Frequency** how often the event is repeated.
- **Probability**. This is expressed via calculations of historic and potential future return periods, or their probability of occurrence.
  - Analysis of past and historic events could provide crucial information on the characteristics and behaviour of these events.
  - It is remarkably important also to foresee the characteristics of future events considering climate change scenarios for forwarding thinking and simulation towards resilience and risk management.
- **Time horizons.** Each natural hazard requires the definition of specific time horizons which are the timeframes and periods for undertaking the risk assessment. These time horizons could be defined in short, medium and long term. For instance, for the characterization of heat waves, short term periods are more convenient whereas earthquakes characterization may require long term time horizons. In the climate change context, the time horizons normally considered for the risk assessment are:
  - short term: present to 2030;
  - medium term: 2031- 2070;
  - long term: 2071- 2100.

  These time horizons are very relevant not only for the risk assessment but also for defining the CNH adaptation strategies.
- **Climate change** may have an affect the intensity, duration and frequency of these events.:
- **Consideration of gradual changes and extreme events**
- **Non-climate drivers and stressors**. Hazards require planned responses to reduce related risks to CNH exposed to the event, which may include structural measures, functional measures related to management plans or socio- economic related i.e. investments to increase resilience. However, it is also relevant to highlight the fact that responses to hazard and reduction of related impacts may also come from local community spontaneous actions.

  The measures are very much dependant on the spatial scale associated to CNH macro- categories: Territorial (urban/rural nexus), Urban (district, historic city centre) and Building, artefact (micro scale).

7. Natural hazard characterization in SHELTER project

This section provides an overview of the natural hazards characterized in SHELTER project. Each subsection is devoted to one natural hazard. It includes the results of the characterization undertaken using the common factsheet template designed for consistency amongst all hazards. This factsheet template will be also used to systematically collect data for hazard characterization in the SHELTER project platform.

Annex 1 of the present report includes the factsheets in EXCEL format that were elaborated for the 6 natural hazards analysed in SHELTER project with details for each of the parameters for their characterization.

7.1. Earthquakes

An earthquake could be described as a sudden violent shaking of the ground caused by a brupt release of energy accumulated inside the Earth, in an ideal point called hypocenter. The point on the surface of the Earth, placed on the vertical of the hypocenter is called epicenter. The earthquake can be classified by horizontal and vertical acceleration (PGA) recorded on the ground and its intensity defined through magnitude scale. It is one of the natural disasters with most devastating impact in terms of loss of lives and damage to structures, frequently, followed by other disasters such as fire, floods, landslides or tsunamis.

The case of L'Aquila, Abruzzo (2009, Italy) showed that only 23% of cultural heritage buildings were adequate for earthquakes.

According to the still on progress ESPON project TITAN Territorial Impacts of Natural Disasters ([6] ESPON TITAN, 2021)[81], seismic hazards affect most strongly Northern and Central Turkey, the Balkan, the Eastern Mediterranean and the Black Sea coasts, followed by a lesser hazard degree in the Western Mediterranean region, the Alps and the Carpathian mountain ranges (see Map 1). The seismic hazard must be analysed locally, and ideally the location of active faults are respected in local land use plans and building codes. It must be further considered that seismic events can cause tsunamis and information about this hazard potential should be offered in potentially affected areas.

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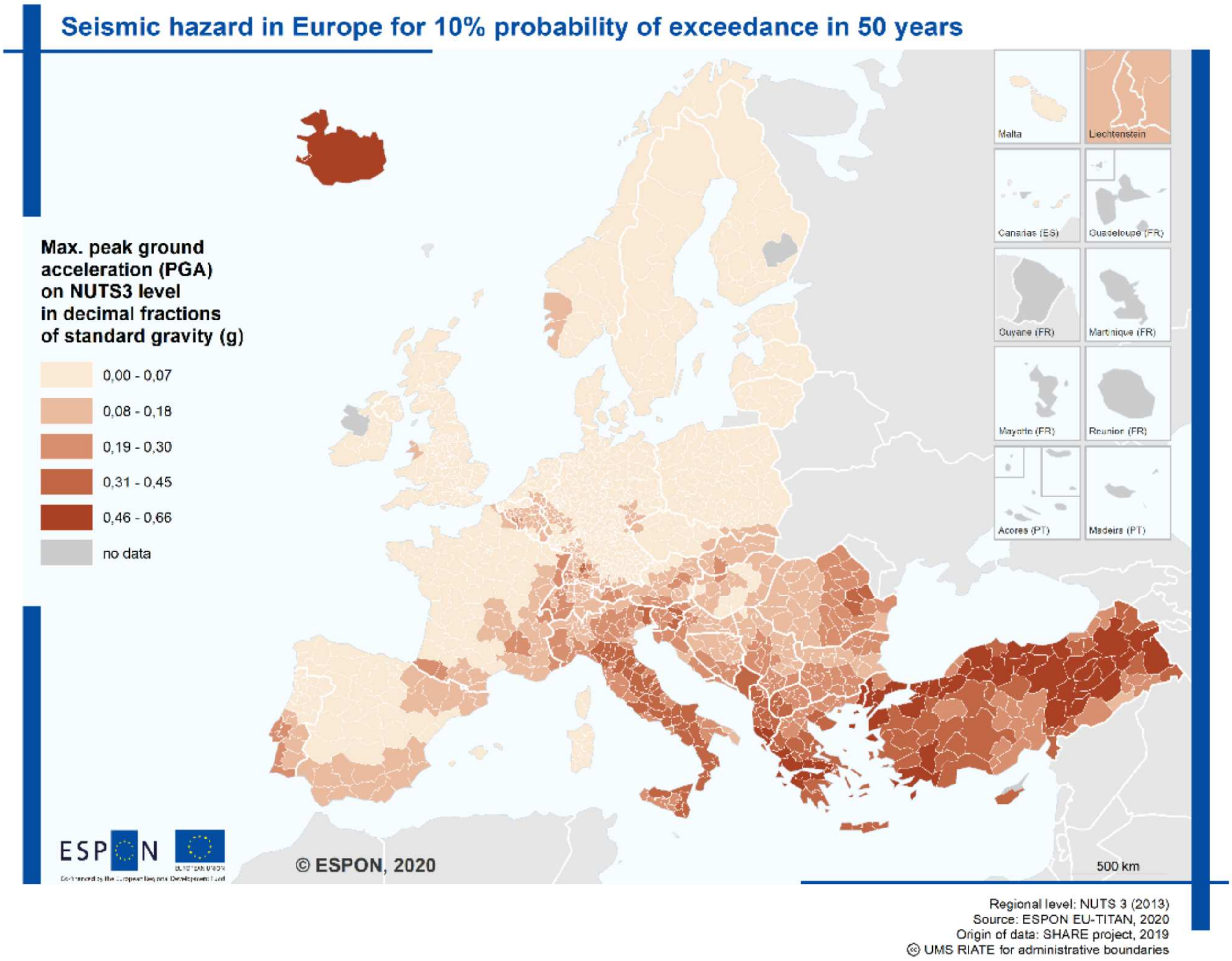
[81] ESPON TITAN overview and policy recommendations (europa.eu)


Seismic hazard in Europe for 10% probability of exceedance in 50 years
Max. peak ground acceleration (PGA) on NUTS3 level in decimal fractions of standard gravity (g)
0,00 - 0,07
0,08 - 0,18
0,19 - 0,30
0,31 - 0,45
0,46 - 0,66
no data
Malta
Liechtenstein
Canarias (ES)
Guadeloupe (FR)
Guyane (FR)
Martinique (FR)
Mayotte (FR)
Reunion (FR)
Acores (PT)
Madeira (PT)
ESPON
© ESPON, 2020
500 km

Regional level: NUTS 3 (2013)
Source: ESPON EU-TITAN, 2020
Origin of data: SHARE project, 2019
© UMS RIATE for administrative boundaries

Map 1 Earthquake hazard map (maximal peak ground acceleration in decimal fractions of standard gravity at NUTS3[82].

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[82] ESPON TITAN) Origin of data [Seismic Hazard Harmonization in Europe](http://www.share-eu.org/) http://www.share-eu.org/

EARTHQUAKES HAZARD CHARACTERIZATION

EVENT CLASSIFICATION

An Earthquake is a sudden violent shaking of the ground caused by a brupt release of energy accumulated inside the Earth, in an ideal point called hypocenter. The point on the surface of the earth, placed on the vertical of the hypocenter is called epicenter. The earthquake can be classified by horizontal and vertical acceleration (PGA) recorded on the ground and its intensity defined through Magnitude scale.

HAZARD GROUP	☑	Geophysical			☐	Meteorological			☐	Climatological	☐	Hydrological
HAZARD TYPE	☑	Earthquake	☐	Subsidence	☐	Storm	☐	Heatwave	☐	Wildfire	☐	Flooding

SPATIAL SCALE

Spatial nature of potential receptor

Refers to the SHELTER scales for CNH: Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**	**Urban and historic city centre**	**Building, site/ artefact level**

Spatial scale of the analysis

Area of the analysis- extension	<1km2	between 1km2-10km2	between 10km2-100km2	**>100km2**

TIME DIMENSION

Time Horizon

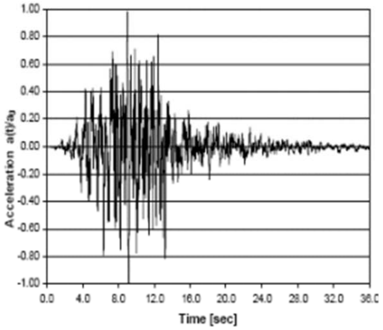
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short** Eartquake lasts from 20 to 60 seconds. The observation of secondary shock events is extended for the following weeks to months.	**Medium**	Long

Scenarios (Climate Change)

Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5**	**short 2000-2030**	**RCP 4.5**	**medium 2031-2070**	RCP 4.5	long term 2071- 2100
	RCP 8.5	**short 2000-2030**	**RCP 8.5**	**medium 2031-2070**	RCP 8.5	long term 2071- 2100

THRESHOLD

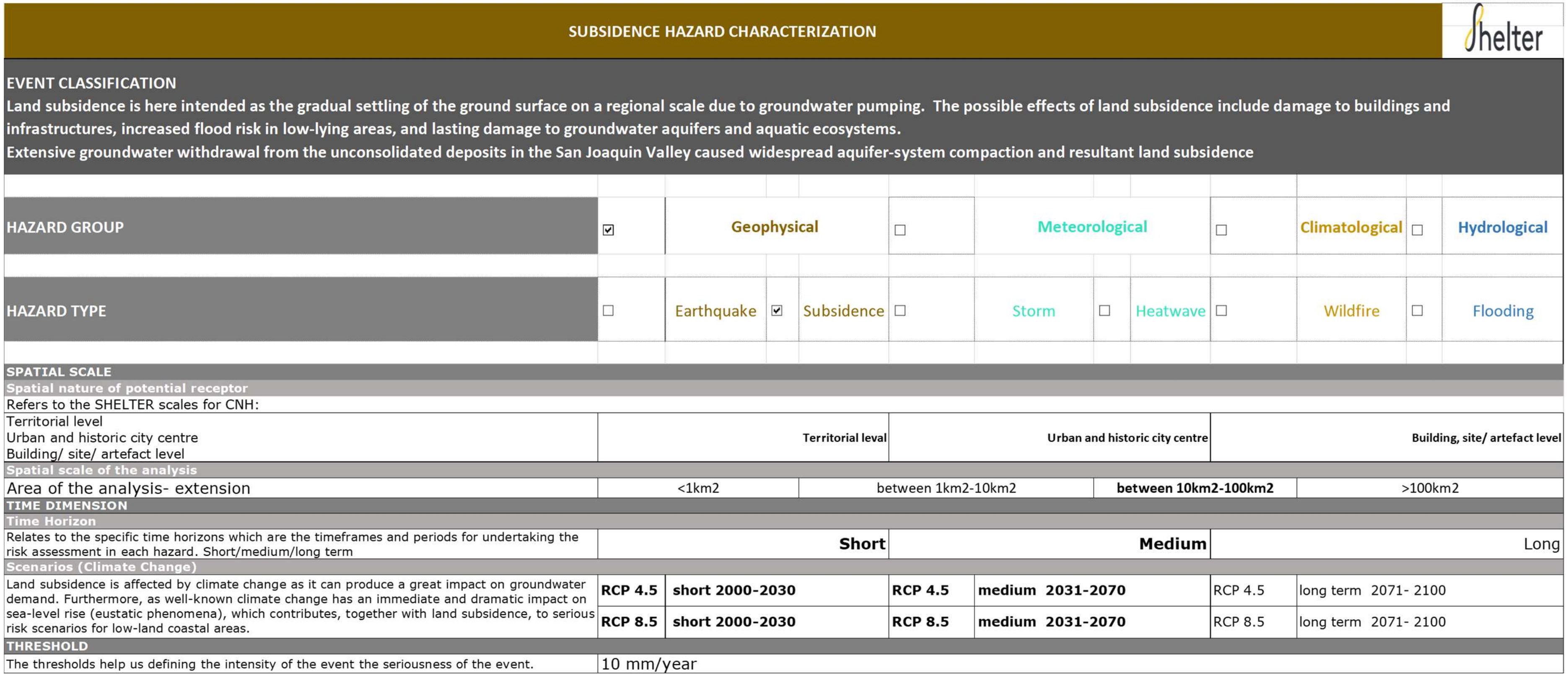
The thresholds help us defining the intensity of the event the seriousness of the event.	PGA = 0.5g (peak ground acceleration) related to an Extreme event classified by the Modified Mercalli scale

PARAMETERS	
Magnitud and Intensity	
Main variables	Spectra Peak Ground Acceleration PGA recorded during the seismic event (cm/s2) Maximum Amplitude of the ground motion recorded by seismograph (mm) Distance from epicenter (km) Time interval beetween the arrival of the Pressure wave and Surface wave. (s) Spectra Peak Ground Velocity PGV (cm/s) Spectra Peak Ground Displacement PGD (cm) Seismic energy (Mton) Number of primary events per year (n/year) 
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	Epicenter
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	Depth (km)
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	T=10,50,475,1000 (ex. V=50 years, Pv=63%, T=475 years)
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	Presence of a fault system and/or volcanic activity Soil type
Physical dimension	
Urban morphology	
Key characteristics /determinants related the hazard	Urban density level and distance between buildings and territorial development
Geomorphology	
Key characteristics /determinants related the hazard	Topographic coefficient
Asset/artefact	
Key characteristics /determinants related the hazard	Construction and structural characteristics and seismic safety level.
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	Building maintenence and rehabilitation. Improvment of seismic resistance.
Urban planning	
Planning conditions at urban level	Infrastructure health check and maintenance. Assigned gathering spot and strategic buildings (ex. Hospotal, parking, gym,
	instruments for Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional level	Istitutional coordination based on shared guide line about prevention and emergency.
Social dimension	
Particularly related to social behaviour that act as a driver to influence the hazard i.e. particularly relevant for Wild Fires	Awareness of the seismic hazard
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	National Policy related to the quality of built heritage. Reserch project about new seismic technologies
Other potential drivers	

7.2. Subsidence

Land subsidence is here intended as the gradual settling of the ground surface on a regional scale. This potentially destructive hazard can be caused by a wide range of natural or anthropogenic causes and mainly results from solid or fluid mobilization underground. Subsidence due to groundwater depletion is a slow and gradual process that develops on large time scales (months to years), producing progressive loss of land elevation (centimetres to decimetres per year) typically over very large areas (tens to thousands of square kilometres), with various effects on urban and agricultural areas ([8] Gerardo Herrera-García et al.,2020)[83]



SUBSIDENCE HAZARD CHARACTERIZATION						
EVENT CLASSIFICATION **Land subsidence is here intended as the gradual settling of the ground surface on a regional scale due to groundwater pumping. The possible effects of land subsidence include damage to buildings and infrastructures, increased flood risk in low-lying areas, and lasting damage to groundwater aquifers and aquatic ecosystems.** **Extensive groundwater withdrawal from the unconsolidated deposits in the San Joaquin Valley caused widespread aquifer-system compaction and resultant land subsidence**						
HAZARD GROUP	☑ **Geophysical**		☐ **Meteorological**		☐ **Climatological**	☐ **Hydrological**
HAZARD TYPE	☐ Earthquake	☑ Subsidence	☐ Storm	☐ Heatwave	☐ Wildfire	☐ Flooding
SPATIAL SCALE						
Spatial nature of potential receptor						
Refers to the SHELTER scales for CNH:						
Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**		**Urban and historic city centre**		**Building, site/ artefact level**	
Spatial scale of the analysis						
Area of the analysis- extension	<1km2	between 1km2-10km2	**between 10km2-100km2**	>100km2		
TIME DIMENSION						
Time Horizon						
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short**		**Medium**		Long	
Scenarios (Climate Change)						
Land subsidence is affected by climate change as it can produce a great impact on groundwater demand. Furthermore, as well-known climate change has an immediate and dramatic impact on sea-level rise (eustatic phenomena), which contributes, together with land subsidence, to serious risk scenarios for low-land coastal areas.	**RCP 4.5**	**short 2000-2030**	**RCP 4.5**	**medium 2031-2070**	RCP 4.5	long term 2071- 2100
	RCP 8.5	**short 2000-2030**	**RCP 8.5**	**medium 2031-2070**	RCP 8.5	long term 2071- 2100
THRESHOLD						
The thresholds help us defining the intensity of the event the seriousness of the event.	10 mm/year					

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[83] *Science*(2020).DOI: 10.1126/science.abb8549

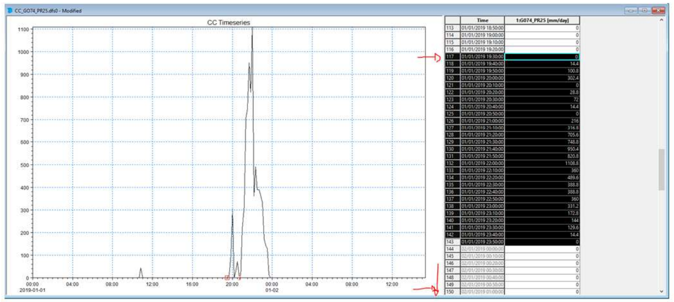
PARAMETERS	
Magnitud and Intensity	
Main variables	Subsidence rate: trend of settlements with time [mm/year] Maps of isolines of total settlement and isokinetics (with annual subsidence rate) Deflection ratio (relative differential settlement) [mm]: Ratio of the differential settlement between two points in the area and the relative distance It can be deduced from field maps at the previous point and depends on the type of structure or infrastructure involved at the ground surface Piezometric drawdown trend Thickness of soil layer and soil compressibility
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	Subsiding area (hectares)
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	
Physical dimension	
Urban morphology	
Key characteristics /determinants related the hazard	Over-exploitation of groundwater resources for industial water supply, but also for domestic use in rapidly expanding urba
Geomorphology	
Key characteristics /determinants related the hazard	Groundwater areas, water courses
Asset/artefact	
Key characteristics /determinants related the hazard	
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	Subsidence involves many policy fields, complex technical aspects and governance embedment. Because of its complex, cross-sectoral nature, it is often not fully recognised, expecially by institutions and authorities. Thus, there is a need for an integrated approach in order to manage subsidence and to develop appropriate strategies and measures effective in the short and in the long-term. As an example, land subsidence has to be taken into account in regulations for groundwater extraction, but also integrated into long-term flood management and mitigation stategies.
Urban planning	
Planning conditions at urban level	Development of an integrated urban water (resources) management strategy
Spatial planning	
Planning conditions at regional level	Water policies and plans
Social dimension	
Particularly related to social behaviour that act as a driver to influence the hazard i.e. particularly relevant for Wild Fires	
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	
Other potential drivers	

7.3. Flooding (pluvial)

Pluvial flooding relates to a flood event due to surface water runoff. The flow of water that occurs when excess stormwater.

PLUVIAL FLOODING HAZARD CHARACTERIZATION												
EVENT CLASSIFICATION **Flood event due to surface water runoff (m3/s). The flow of water that occurs when excess stormwater.**												
HAZARD GROUP	☐	**Geophysical**			☐	**Meteorological**			☐	**Climatological**	☑	**Hydrological**
HAZARD TYPE	☐	Earthquake	☐	Subsidence	☐	Storm	☐	Heatwave	☐	Wildfire	☑	Flooding
SPATIAL SCALE												
Spatial nature of potential receptor												
Refers to the SHELTER scales for CNH: Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**				**Urban and historic city centre**				**Building, site/ artefact level**			
Spatial scale of the analysis												
Area of the analysis- extension	**<1km2**		**between 1km2-10km2** the analysis should be done by catchment (for which spatial scale can vary, it can be focused in sub-catchments				between 10km2-100km2		>100km2			
TIME DIMENSION												
Time Horizon												
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short** For surface flood the most interesting time scale is sub-daily, focusing on short but intense precipitations (2-4 hours duration) which causes problems in drainage systems				**Medium**				Long			
Scenarios (Climate Change)												
Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5**	**short 2000-2030**			**RCP 4.5**	**medium 2031-2070**			RCP 4.5	long term 2071- 2100		
	RCP 8.5	**short 2000-2030**			**RCP 8.5**	**medium 2031-2070**			RCP 8.5	long term 2071- 2100		
THRESHOLD												
The thresholds help us defining the intensity of the event the seriousness of the event.	Flood Peak height (m) Time to Flood Peak (hours) The threshold is more interesting for the vulnerability analysis (for example, some researches highlighted taht a flood water depth above 0.5 meters causes traffic disrupsions). In this case, more than thresholds I would use hazard indicators that hepls describing the hazards: like maximum water depth, water velocity or time to peak in a certain return period. We always refers to acertain return period because we analyse the effect of a rain event which has a return period. In flood hazard analysis in urban areas, the most inetersting return period is 25 years, for which the sewedge system are hypotetically designed, the 1o and 50 retuns periods are also interesting and they gives an idea of the range.											

PARAMETERS	
Magnitud and Intensity	
Main variables	Daily maximum precipitation corresponding to the return period T Subdaily distribution of a type of rain (hourly, 10 minutes), instead of having a number, it is more useful if we have a distribution of the precipitation Hourly maximum precipitation for a return period T Surface runoff in relation to precipitation quantity (mm/%) Flood depth (m) This is the result of applying a precipitation event with a certain retun period and therefor the floof water level also is for a certain return period. The same occurs for water velocity for example Water velocity (in the flooded area) (m/s) Torrentiality index (factor). Hourly precipitation intensity and corrected daily mean. Its value is determined in function of the geographical area. Combination of flood depth and velocity = flood hazard (= d*(v+0.5) +DF) Hyetograph, distribution of the rainfall intensity over time, corresponding to the return period T and a duration of the event (e.g. less than 8 hours for pluvial flood) 
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	Flooded area m2
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	Return period T5, T10, T25, T50
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

	Time	1:G074_PR25 [mm/day]
113	01/01/2019 18:50:00	0
114	01/01/2019 19:00:00	0
115	01/01/2019 19:10:00	0
116	01/01/2019 19:20:00	0
117	01/01/2019 19:30:00	0
118	01/01/2019 19:40:00	14.4
119	01/01/2019 19:50:00	100.8
120	01/01/2019 20:00:00	302.4
121	01/01/2019 20:10:00	0
122	01/01/2019 20:20:00	28.8
123	01/01/2019 20:30:00	72
124	01/01/2019 20:40:00	14.4
125	01/01/2019 20:50:00	0
126	01/01/2019 21:00:00	216
127	01/01/2019 21:10:00	316.8
128	01/01/2019 21:20:00	705.6
129	01/01/2019 21:30:00	748.8
130	01/01/2019 21:40:00	950.4
131	01/01/2019 21:50:00	820.8
132	01/01/2019 22:00:00	1108.8
133	01/01/2019 22:10:00	360
134	01/01/2019 22:20:00	489.6
135	01/01/2019 22:30:00	388.8
136	01/01/2019 22:40:00	388.8
137	01/01/2019 22:50:00	360
138	01/01/2019 23:00:00	331.2
139	01/01/2019 23:10:00	172.8
140	01/01/2019 23:20:00	144
141	01/01/2019 23:30:00	129.6
142	01/01/2019 23:40:00	14.4
143	01/01/2019 23:50:00	0
144	02/01/2019 00:00:00	0
145	02/01/2019 00:10:00	0
146	02/01/2019 00:20:00	0
147	02/01/2019 00:30:00	0
148	02/01/2019 00:40:00	0
149	02/01/2019 00:50:00	0
150	02/01/2019 01:00:00	0

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	Contaminated soils afected by flooding- dispersion of pollutants
Physical dimension	
Urban morphology	
Key characteristics /determinants related the hazard	Channelled and underground water networks sewedge system are crucial in this hazard but also the urban configuration, the streets and buildings affect the water flows that why for example buildings need to be considered when modeling the hazard. The green areas are also important due to their capacity to infiltrate water
Geomorphology	
Key characteristics /determinants related the hazard	micro-basins configurations Terrain Digital Mode (MDT)- slope %
Asset/artefact	
Key characteristics /determinants related the hazard	Local traditional architecture, materials sensitive to patogens
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	Capacity of waste water threatment plants The big municipalities manages the sewedge system opening and closing some gates. This can increase the pluvial flood problem. Unitary or separate networks plays an important role but in most cities the reality is that even they have in some places separative network, at the end this is connected again to the unitary bnetwrok in some point...
Urban planning	
Planning conditions at urban level	Drainage system/ sewage networks Instruments for Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional level	Drainage system/ sewage networks
Social dimension	
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	Mobility patterns
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	
Other potential drivers	

7.4. Flooding (fluvial)

A river flood occurs when a river overspills its banks; that is, when its flow can no longer be contained within its channel.

FLUVIAL FLOODING HAZARD CHARACTERIZATION												
EVENT CLASSIFICATION A river flood occurs when a river overspills its banks; that is, when its flow can no longer be contained within its channel.												
HAZARD GROUP	☐	Geophysical			☐	Meteorological			☐	Climatological	☑	Hydrological
HAZARD TYPE	☐	Earthquake	☐	Subsidence	☐	Storm	☐	Heatwave	☐	Wildfire	☑	Flooding
SPATIAL SCALE												
Spatial nature of potential receptor												
Refers to the SHELTER scales for CNH:												
Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**				**Urban and historic city centre**				**Building, site/ artefact level**			
Spatial scale of the analysis												
Area of the analysis- extension	<1km2			**between 1km2-10km2** River basin km2			between 10km2-100km2			>100km2		
TIME DIMENSION												
Time Horizon												
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short**				**Medium** For fluvial flood the most interesting time scale is daily, focusing on continuous 2-3 days of precipitations which causes problems in the watershed (after a saturation of the soils come)				Long			
Scenarios (Climate Change)												
Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5**	**short 2000-2030**			**RCP 4.5**	**medium 2031-2070**			RCP 4.5	long term 2071- 2100		
	RCP 8.5	**short 2000-2030**			**RCP 8.5**	**medium 2031-2070**			RCP 8.5	long term 2071- 2100		
THRESHOLD												
The thresholds help us defining the intensity of the event the seriousness of the event.	Flood peak flow rate (m3/s) Maximum annual river flow corresponding to the return period T at the drainage point of the basin Flood peak height (m) Flood peak volume (m3) Time to flood peak (i.e., lag time hours) Flood excess volume (m3), i.e., volume of hydrograph above bank-full discharge											

PARAMETERS	
Magnitud and Intensity	
Main variables	Daily maximum precipitation (mm) corresponding to the return period T Hyetograph, distribution of the rainfall intensity over time, corresponding to the return period T and a duration of the event (e.g. less than 3 days for fluvial flood) IDF (intensity duration frequency) curves Total sediment transport (m3)
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: lati	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	Flood area (m2/km2) corresponding to the return period T
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	Return period T5, T10, T50, T100, T200, T500
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that m	Contaminated soils afected by flooding- dispersion of pollutants
Physical dimension	
Urban morphology	
Key characteristics /determinan	Channelled and underground water networks
Geomorphology	
Key characteristics /determinan	Having a good bathymetry is crucial for modelling river floods and it is very difficult to have good information on that if there is no field work
Asset/artefact	
Key characteristics /determinan	Local traditional architecture, materials sensitive to patogens
Planning dimension	
Sector planning	
Sector policies : water, energy,	Agro-forestry policies Maintenance of rivers/riverbeds Land use at the upper part of the watershed affects most the fluvial flood water dam management also plays an important role in fluvial floods
Urban planning	
Planning conditions at urban level	In addition to the channels, any infrastructure built close to the river affects in the flood hazard, beacuse they reduce the space to the river Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional l	River basin management
Social dimension	
Social behaviour	
Mankind drivers for natural haza	Ilegal agricultural practices, ilegal dumps,
Socio-economic dimension	
Socio economic development, l	
Other potential drivers	

7.5. Wildfires

Wildfires hazard should be understood as the interaction among changing weather and climate, vegetation condition and composition, and human factors. Weather and climate define the composition and structure of vegetation fuels which may help to predict the potential spread and intensity of fires once are ignited.

WILD FIRES HAZARD CHARACTERIZATION												
EVENT CLASSIFICATION **Wildfires hazard should be understood as interaction among changing weather and climate, vegetation condition and composition, and human factors.** **Weather and climate define the composition and structure of vegetation fuels which may help to predict the potential spread and intensity of fires once are ingited.** **most of forest fires in EU are intentional or unintentional human driven.**												
HAZARD GROUP	☐	**Geophysical**			☑	**Meteorological**			☑	**Climatological**	☐	**Hydrological**
HAZARD TYPE	☐	Earthquake	☐	Subsidence	☐	Storm	☐	Heatwave	☑	Wildfire	☐	Flooding
SPATIAL SCALE												
Spatial nature of potential receptor												
Refers to the SHELTER scales for CNH:												
Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**				**Urban and historic city centre**				**Building, site/ artefact level**			
Spatial scale of the analysis												
Area of the analysis- extension	**<1km2**			between 1km2-10km2			between 10km2-100km2			>100km2		
TIME DIMENSION												
Time Horizon												
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short**				**Medium**				Long			
Scenarios (Climate Change)												
Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5**	**short 2000-2030**			**RCP 4.5**	**medium 2031-2070**			RCP 4.5	long term 2071- 2100		
	RCP 8.5	**short 2000-2030**			**RCP 8.5**	**medium 2031-2070**			RCP 8.5	long term 2071- 2100		
THRESHOLD												
The thresholds help us defining the intensity of the event the seriousness of the event.	Fire weather index											

PARAMETERS	
Magnitud and Intensity	
Main variables	TX Mean of daily maximum air temperature TX [ºC] TXx, Monthly maximum value of daily maximum temperature [ºC] Montly minimum value of daily minimum precipitation (mm) Relative humidity (%) Wind (direction) Wind speed (m/s) Vegetation moisture Soil Moisture Composition and structure of vegetation fuels Land surface temperature (LST) Hillshade Elevation Slope
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	to be completed
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	to be completed
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	Degradation of ecosystems services and the local vegetation Accumulation of dead woody debris on the ground Land use distribution patterns
Physical dimension	
Connectivity	
Key characteristics /determinants related the hazard	Ecosystems services and habitats connectivity (structural/functional)
Geomorphology	
Key characteristics /determinants related the hazard	Orientation and natural/seminatural firebreaks
Asset/artefact	
Key characteristics /determinants related the hazard	Local traditional architecture and materials
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	Agro-forestry Management plans Water management plans Biodiversity conservation plans Local /regional forest fires prevention plans
Urban planning	
Planning conditions at urban level	Human activities in the urban rural interface
	Instruments for Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional level	Agro-forestry model
Social dimension	
Particularly related to social behaviour that act as a driver to influence the hazard i.e. particularly relevant for Wild Fires	Demographic patterns Depopulation/ shrinking areas Emergency/evacuation plans
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	Agro-forestry practices Human activities drying of fine fuel (litter, needles, mosses, twigs)
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	
Other potential drivers	

7.6. Heat waves

The World Health Organization WHO/Europe Euro HEAT project[84] defines a heatwave (HW) as a period in which the maximum and minimum apparent temperatures are over the ninetieth percentile of the monthly distribution for at least two days. The impact of long heatwaves (more than four days) was 1.5–5 times that of short ones (WHO, 2020). Although there is no standard definition of the heat wave, it can be referred as a period of consecutive days of abnormal high temperature. The WMO guidance on heat-health warning 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 ([12] Oak, 1982)[85]. Therefore, the main indicators to characterize HW are temperature and relative humidity (RH); with levels of RH defining if it is a dry heat wave or a humid heat wave. When assessing heat waves in urbanized contexts we must also pay attention to the Urban Heat Island (UHI) effect. UHI it is becoming a very important element and criteria in planning decisions particularly in the face of a climate change and global warming context where urban planning could and must play a key role in designing healthy, comfortable, inclusive and well-adapted public spaces. UHI it is becoming a very important element and criteria in planning decisions particularly in the face of a climate change and global warming context where urban planning could and must play a key role in designing healthy, comfortable, inclusive and well-adapted public spaces. The most common variables used when assessing the HW are the air temperature and surface temperature. Air temperature is measured by two horizontal dimensions of temperature distribution, at 2 meters above surface known as **thermal map**, and when the air temperature is combined with wind intensity and direction it is known as a **climate map**.

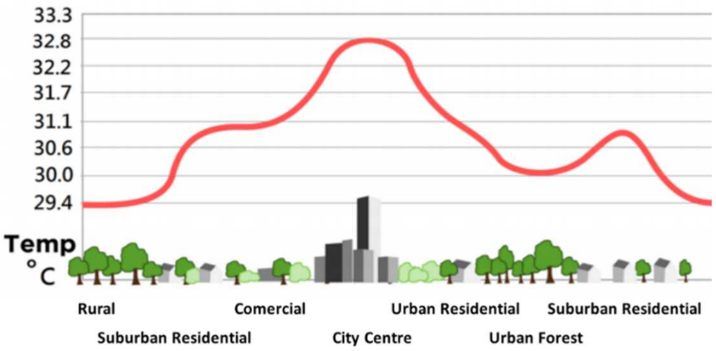


Figure 13 Graph demonstrating UHI- linking temperatures with theoretical urban morphology and land uses classification.

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[84] https://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/archive/the-euroheat-project

[85] Oke, T.R., 1982. The energetic basis of the urban heat island. Q. J. R. Meteorol. Soc. 108, 1–24.Oke, Tim R., 2006. Towards better scientific communication in urban climate. Theoret. Appl. Climatol. https://doi.org/10.1007/s00704-005-0153-0 . issn: 14344483. Openshaw, Stan, 1983. The modifiable areal unit problem. In: CATMOG - Concepts and Techniques in Modern Geography. vol. 38. pp. 41. http://www.getcited. org/pub/102412488 .

HEAT WAVES HAZARD CHARACTERIZATION

EVENT CLASSIFICATION

A heatwave is a period of consecutive days with hot temperatures where both length and peak temperature are important. It could be expressed for example by the number of combined tropical nights (>20°C) & hot days (>35°C) per annum

HAZARD GROUP	☐	**Geophysical**	☑	**Meteorological**	☐	**Climatological**	☐	**Hydrological**

HAZARD TYPE	☐	Earthquake	☐	Subsidence	☐	Storm	☑	Heatwave	☐	Wildfire	☐	Flooding

SPATIAL SCALE					
Spatial nature of potential receptor					
Refers to the SHELTER scales for CNH: Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**		**Urban and historic city centre**		**Building, site/ artefact level**
Spatial scale of the analysis					
Area of the analysis- extension	**<1km2**	between 1km2-10km2		between 10km2-100km2	>100km2
TIME DIMENSION					
Time Horizon					
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short**		**Medium**		Long
Scenarios (Climate Change)					
Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5** **short 2000-2030**		**RCP 4.5** **medium 2031-2070**		RCP 4.5 long term 2071- 2100
	RCP 8.5 **short 2000-2030**		**RCP 8.5** **medium 2031-2070**		RCP 8.5 long term 2071- 2100
THRESHOLD					
The thresholds help us defining the intensity of the event the seriousness of the event.	Heatwave number (HWN) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN. The number of individual heatwaves that occur each summer (Nov–Mar in southern hemisphere and May–Sep in northern hemisphere). A heatwave is defined as 3 or more days where either the EHF is positive, TX > 90th percentile of TX or where TN < 90th percentile of TN, where percentiles are calculated from base period specified by user. Heatwave frequency (HWF) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN Heatwave amplitude (HWA) as defined by either the Excess Heat Factor (EHF), 90th percentile of TX or the 90th percentile of TN Perkins, S.E. & Alexander, L.V. 2013. On the Measurement of heatwaves, J. Climate, 26, 4500–17. doi: 10.1175/JCLI-D-12-00383.1				

PARAMETERS	
Magnitud and Intensity	
Main variables	Mean Temperature [ºC] TX Mean of daily maximum air temperature TX [ºC] TXx, Monthly maximum value of daily maximum temperature [ºC] TN Mean of daily minimum air temperature [ºC] TNn, Monthly minimum value of daily minimum temperature [ºC] Mean Relative Humidity [%] Apparent temperature [ºC] Daily RH shocks (RHn-RHn+1)>25% [%] Daily sun hours [nº of hours] Wind spead (km/h) Humidity cicles nRH>75% [%] Radiation levels Wind (direction) Thermal shock (Tmax-Tmin) [ºC]
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	to be completed
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	heat wave/year
Duration	Heat wave duration Index HWDI
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	Stratospheric ozone (O3) levels Street noise [dB] Air quality (i.e. PM5 PM10)
Physical dimension	
Urban morphology	
Key characteristics /determinants related the hazard	Widht of the streets and building height, street canyons, % of soil sealed
Geomorphology	
Key characteristics /determinants related the hazard	not apply
Asset/artefact	
Key characteristics /determinants related the hazard	Local traditional architecture, materials sensitive to patogens
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	Energy efficiency policies
Urban planning	
Planning conditions at urban level	Climate change policies, energy efficiency and urban regeneration, mobility strategies for car traffic reduction, green infrastructure
	Instruments for Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional level	Green infrastructure
Social dimension	
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	Use of air conditioners Road traffic, car dependency Use of public spaces- open air public live
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	
Other potential drivers	

7.7. Storms

A terrestrial storm is an extreme weather condition, a violent disturbance of the atmosphere with strong winds measuring 10 or higher on the Beaufort scale, meaning a wind speed of 24.5 m/s, which is 89 km/h or 55 mph or more.

STORM HAZARD CHARACTERIZATION												
EVENT CLASSIFICATION **A terrestrial storm is an extreme weather condition, a violent disturbance of the atmosphere with strong winds measuring 10 or higher on the Beaufort scale, meaning a wind speed of 24.5 m/s, which is 89 km/h or 55 mph or more.**												
HAZARD GROUP	☐	**Geophysical**			☑	**Meteorological**			☐	**Climatological**	☐	**Hydrological**
HAZARD TYPE	☐	Earthquake	☐	Subsidence	☑	Storm	☐	Heatwave	☐	Wildfire	☐	Flooding
SPATIAL SCALE												
Spatial nature of potential receptor												
Refers to the SHELTER scales for CNH: Territorial level Urban and historic city centre Building/ site/ artefact level	**Territorial leval**				**Urban and historic city centre**				**Building, site/ artefact level**			
Spatial scale of the analysis												
Area of the analysis- extension	<1km2			between 1km2-10km2			between 10km2-100km2			**>100km2**		
TIME DIMENSION												
Time Horizon												
Relates to the specific time horizons which are the timeframes and periods for undertaking the risk assessment in each hazard. Short/medium/long term	**Short**				**Medium**				Long			
Scenarios (Climate Change)												
Climate change may have an affect the intensity, duration and frequency of an event	**RCP 4.5**	**short 2000-2030**			**RCP 4.5**	**medium 2031-2070**			RCP 4.5	long term 2071- 2100		
	RCP 8.5	**short 2000-2030**			**RCP 8.5**	**medium 2031-2070**			RCP 8.5	long term 2071- 2100		
THRESHOLD												
The thresholds help us defining the intensity of the event the seriousness of the event.	Winds are called strong gale when the speed is higher than 75 km/h or 9 Beaufort. Wind speeds higher than 117 km/h are defined as hurricane. If the wind only reaches gale force for a short time (for a few seconds), it is called a storm gust. Mostly a storm is also associated with heavy rainfall, therefore the term is often used colloquially as a synonym for a heavy shower or thunderstorm. Nevertheless, both are only accompanying symptoms or special cases of a storm. A differentiation according to the season is also sometimes used, one speaks then for example of a winter storm.											

PARAMETERS	
Magnitud and Intensity	
Main variables	Minimum and maximum wind speed Precipitation rate (if any) Precipitation type Temperature Wind chill, freeze Heat, evaporation rate
Location and Spatial Dispersion	
Location (Coordinates)	
Coordinate of the locations: latitude, longitude	to be completed
Spatial dispersion (Extent)	
Total area (km2, hectares, other units) affected by the extreme event during the period of occurrence from Start Date to End Date.	Direction of movement, Spatial dispersion (Extent)
Frequency	
How often an event is repeated. It is expressed by the inter-event interval times	Development stage, mature stage, dissipation stage
Duration	Time above or bellow a certain threshold.
Starting date	DD-MM-YYYY
Ending date	DD-MM-YYYY

DRIVERS	
Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change: socio economic development, land use and demography patterns, social behaviour. Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning	
Environmental dimension	
Environmental conditions that may influence the intensity and frequency of the hazard	Temperature differences Athmosperic humidity Barometric pressure
Physical dimension	
Urban morphology	
Key characteristics /determinants related the hazard	Street canyons, coastal areas
Geomorphology	
Key characteristics /determinants related the hazard	Biogeography/biospheric
Asset/artefact	
Key characteristics /determinants related the hazard	Sensible materials i.e. stained glass windows
Planning dimension	
Sector planning	
Sector policies : water, energy, agroforestry, health, river basin planning, etc	not apply
Urban planning	
Planning conditions at urban level	Instruments for Disaster Risk Reduction- early warning systems-
Spatial planning	
Planning conditions at regional level	not apply
Social dimension	
Social behaviour	
Mankind drivers for natural hazards. E.g wildfire ignition.	Social live- public spaces
Socio-economic dimension	
Socio economic development, land use distribution, mobility patterns and demography patterns	Economic crisis preparedness strategic infrastructure resilience
Other potential drivers	

8. Impact chains: direct and in-direct impacts of natural hazards on CNH

A number of principles where applied when building the impact chains for natural hazards on CNH in SHELTER project as described below:

Spatial scale matters. The spatial scale at which a hazard or event is perceived has a profound effect on the receptors that could be potentially harmed. In SHELTER CNH are classified in three macro categories: CNH at Territorial scale, Urban & city historic centre scale, and building and site/artefact scale. This is utterly relevant when characterizing the potential exposed receptors.

CNH uses and functions matter. The services and functions determine the selection of parameters and indicators to characterize exposure and vulnerability. The CNH uses and functions could include residential, equipment, educational, tourism, public use of space, provision of ecosystem services, etc.

CNH intrinsic value matters. Intrinsic and unique value of the CNH should be incorporated within the overall framework for risk assessment as part of the vulnerability component of risk.

Extreme events matter. But also matter the progressive changes of climate variables in a climate change context, creating frequent and recurrent events that could cause a constant and continuous damage on CNH. The IPCC particularly highlights the importance of extreme events related to climate change:

> *" A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events."* ([9] IPCC 2012: 5)

In SHELTER project, natural hazard characterization must necessarily contemplate both, the progressive changes of natural processes and climate variables as well as extreme events when addressing the evaluation of the risks faced by the CNH.

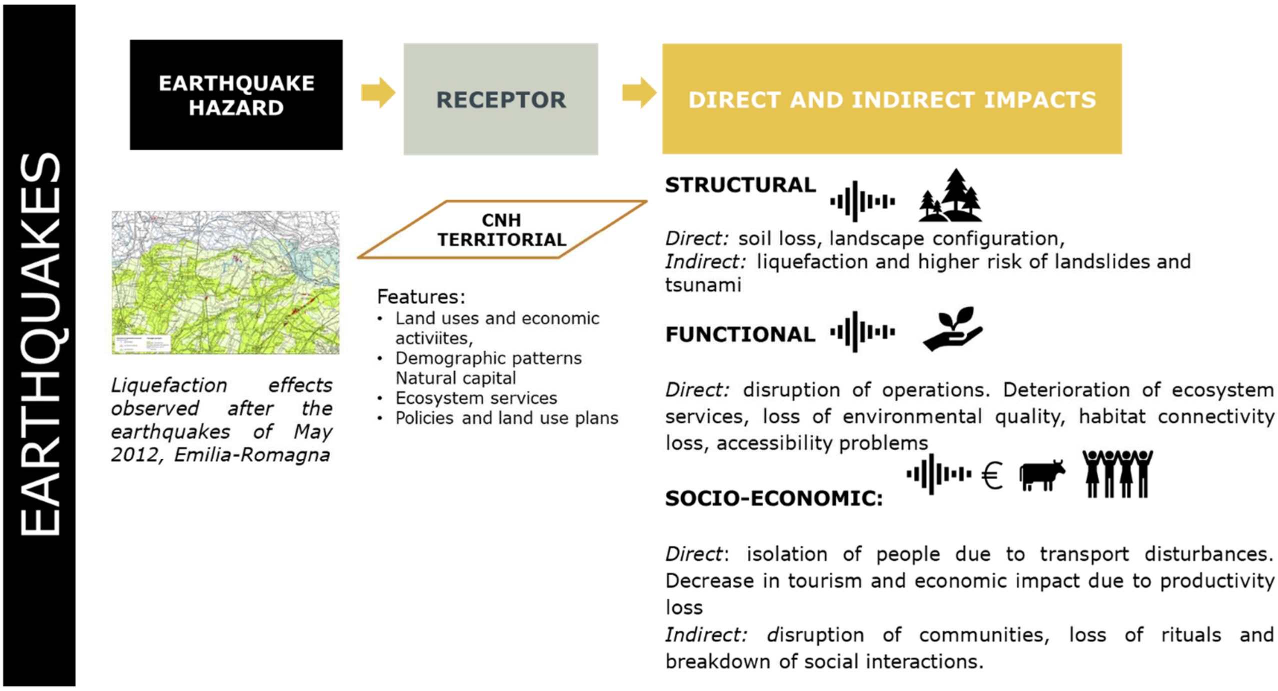
Different types of vulnerabilities and potential impacts should be addressed:

- **Structural** which refers to the potential affection to the static properties as well as the peculiar characteristics of a CNH (e.g. volume, style, decoration, interior and exterior architecture, territorial, etc)
- **Functional** which refers to the potential disruptions on the functions and operation of use of the CNH (e.g. museum, education, residential, ecological corridor, etc)
- **Social and economic** which refers to the potential impacts on socioeconomic activities (e.g. productivity, tourism, human comfort, etc).

These terms as already argued in the methodology section, must still be agreed in the context of the overall risk assessment in SHELTER project T2.5

8.1. Earthquakes

Following the approach for building impact chains in SHELTER structured in three level of CNH and for the three types of vulnerabilities to be potentially assessed in the risks assessment, three impact chains have been elaborated for Earthquakes, that are shown in **Figure 14**, **Figure 15** and **Figure 16**, below.



EARTHQUAKES

EARTHQUAKE HAZARD → **RECEPTOR** → **DIRECT AND INDIRECT IMPACTS**

Liquefaction effects observed after the earthquakes of May 2012, Emilia-Romagna

CNH TERRITORIAL

Features:
- Land uses and economic activiites,
- Demographic patterns
  Natural capital
- Ecosystem services
- Policies and land use plans

STRUCTURAL

Direct: soil loss, landscape configuration,
Indirect: liquefaction and higher risk of landslides and tsunami

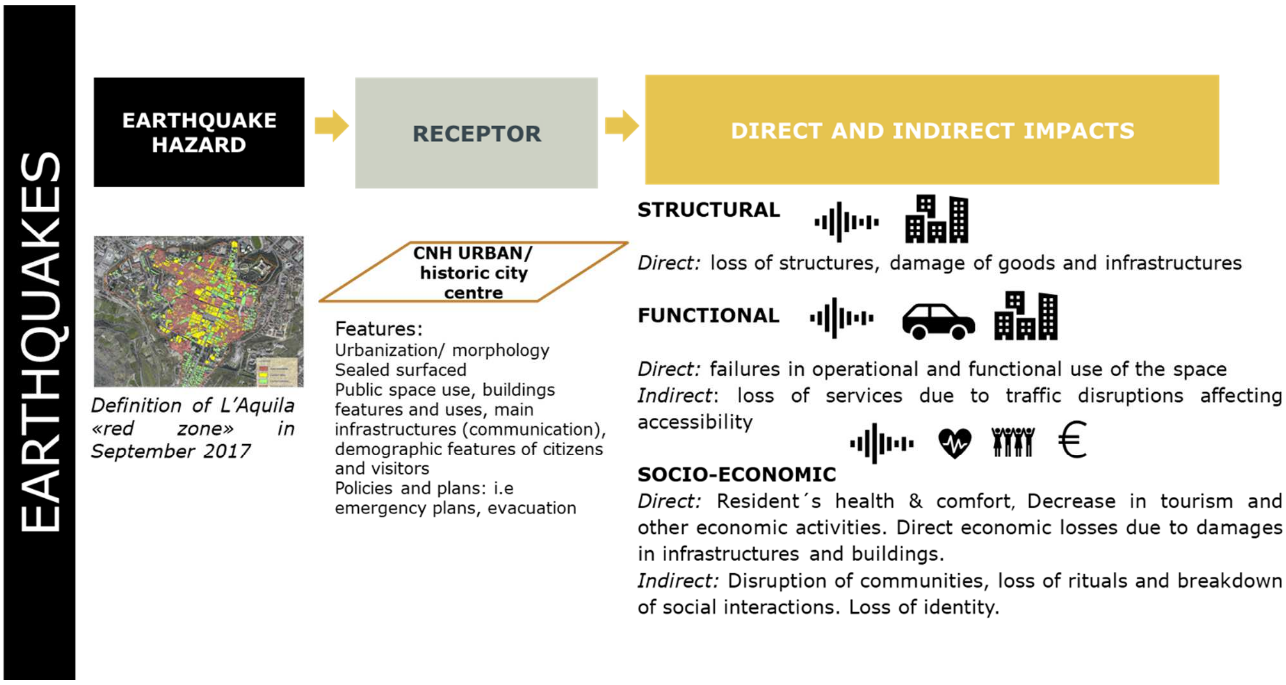
FUNCTIONAL

Direct: disruption of operations. Deterioration of ecosystem services, loss of environmental quality, habitat connectivity loss, accessibility problems

SOCIO-ECONOMIC: €

Direct: isolation of people due to transport disturbances. Decrease in tourism and economic impact due to productivity loss
*Indirect: d*isruption of communities, loss of rituals and breakdown of social interactions.

Figure 14 Earthquake on CNH at territorial level.



EARTHQUAKES

EARTHQUAKE HAZARD → **RECEPTOR** → **DIRECT AND INDIRECT IMPACTS**

Definition of L'Aquila «red zone» in September 2017

CNH URBAN/ historic city centre

Features:
Urbanization/ morphology
Sealed surfaced
Public space use, buildings features and uses, main infrastructures (communication), demographic features of citizens and visitors
Policies and plans: i.e emergency plans, evacuation

STRUCTURAL

Direct: loss of structures, damage of goods and infrastructures

FUNCTIONAL

Direct: failures in operational and functional use of the space
Indirect: loss of services due to traffic disruptions affecting accessibility

SOCIO-ECONOMIC €

Direct: Resident´s health & comfort, Decrease in tourism and other economic activities. Direct economic losses due to damages in infrastructures and buildings.
Indirect: Disruption of communities, loss of rituals and breakdown of social interactions. Loss of identity.

Figure 15 Earthquake on CNH urban and historic city centres

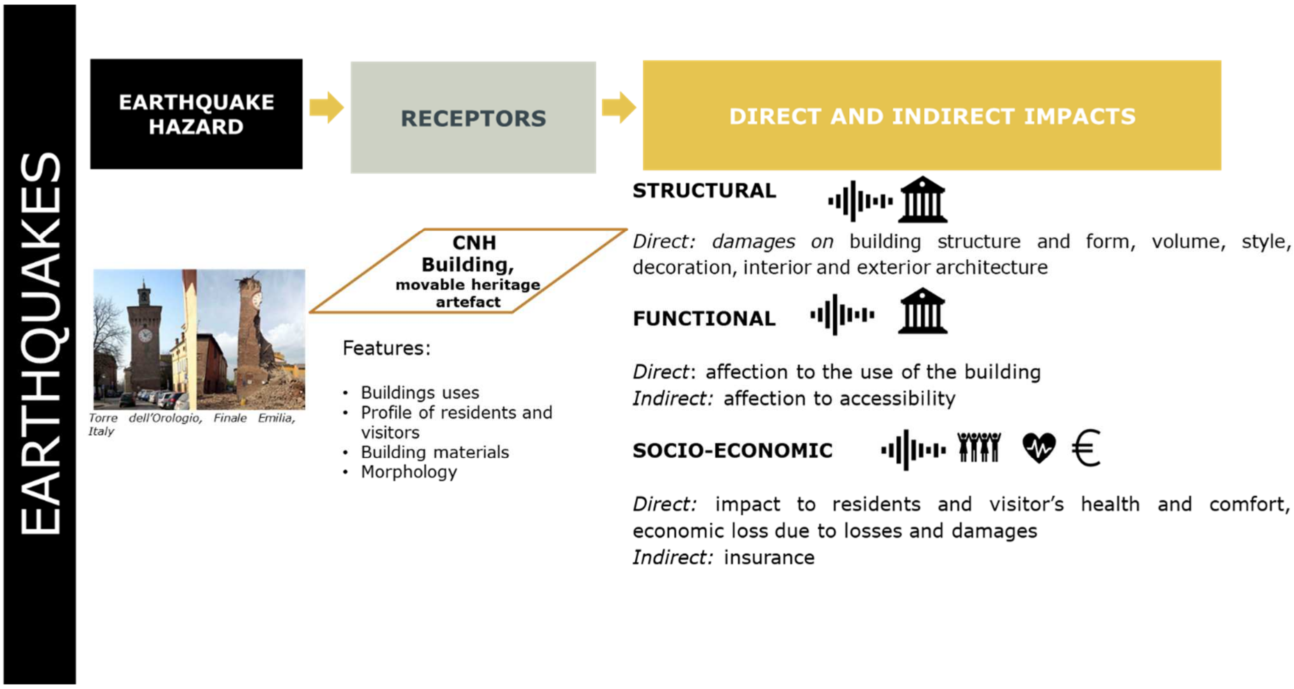

EARTHQUAKES
EARTHQUAKE HAZARD
RECEPTORS
DIRECT AND INDIRECT IMPACTS
Torre dell'Orologio, Finale Emilia, Italy
CNH Building, movable heritage artefact
Features:
• Buildings uses
• Profile of residents and visitors
• Building materials
• Morphology
STRUCTURAL
Direct: damages on building structure and form, volume, style, decoration, interior and exterior architecture
FUNCTIONAL
Direct: affection to the use of the building
Indirect: affection to accessibility
SOCIO-ECONOMIC
Direct: impact to residents and visitor's health and comfort, economic loss due to losses and damages
Indirect: insurance

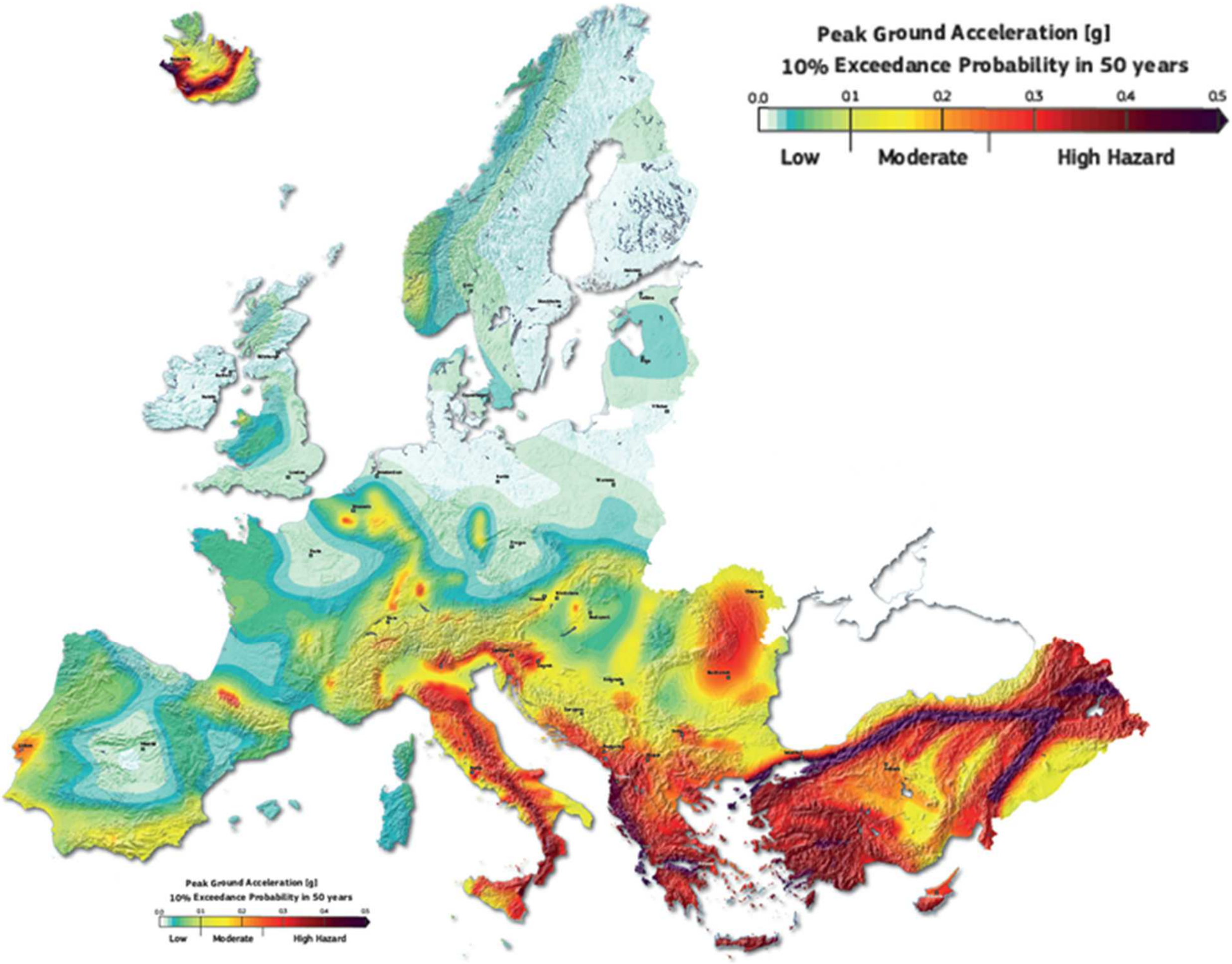
Figure 16 Earthquake on CNH Building level, mobile heritage and artefact

Common minimum information

The seismic risk is the combination of the seismic hazard (related to the site), of the vulnerability (i.e. characteristic of each building) and of the exposure (i.e. activities carried out inside a building).

The seismic hazard of a territory is represented by the frequency and strength of earthquakes that affect it (seismicity). The seismic hazard is the probability that an earthquake exceeding a threshold of intensity, magnitude or peak ground acceleration (PGA) of our interest occurs in a given area and in a certain time interval.

The study of the seismic hazard for territorial and regional analysis defines the map zoning (basic hazard for seismic classification) or the microzoning (local hazard). Microzoning foresees the seismic hazard assessment through the identification of areas on a municipal scale where the seismic event may be magnified; it also provides useful guidance for urban planning.

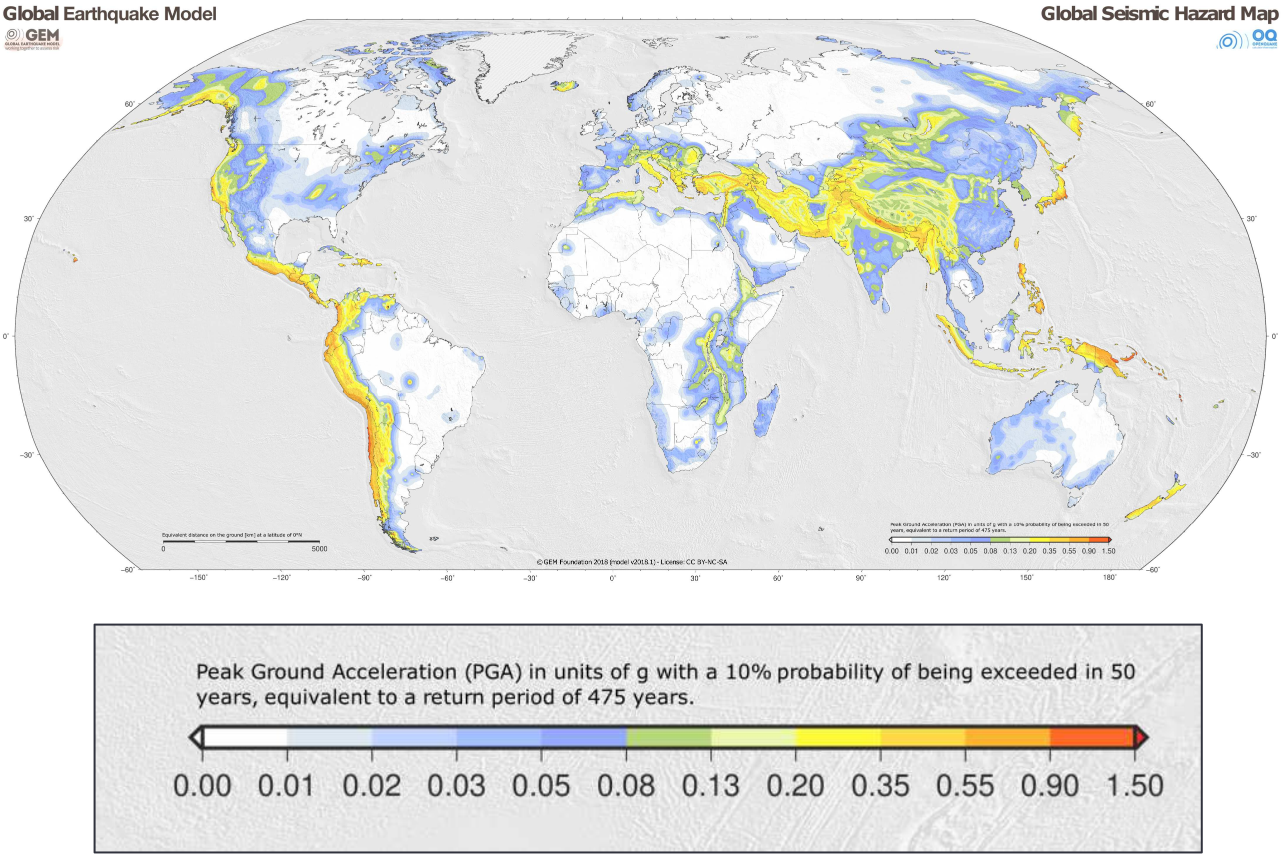

Peak Ground Acceleration [g]
10% Exceedance Probability in 50 years
0.0
0.1
0.2
0.3
0.4
0.5
Low
Moderate
High Hazard

Map 2 Seismic Hazard Harmonization in Europe www.share-eu.org

Seismic hazard maps provide information about the geographic distribution of the Peak Ground Acceleration (PGA) with a 10% probability of being exceeded in 50 years, computed for reference rock conditions (shear wave velocity, V, of 760-800 m/s).

Hazard map input characterisation:

- Probability 10%
- Period of reference 50 years
- Return period 475 years


Global Earthquake Model
GEM
Global Seismic Hazard Map
OQ
60°
30°
0°
−30°
−60°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
180°
Equivalent distance on the ground [km] at a latitude of 0°N
0
5000
© GEM Foundation 2018 (model v2018.1) - License: CC BY-NC-SA
Peak Ground Acceleration (PGA) in units of g with a 10% probability of being exceeded in 50 years, equivalent to a return period of 475 years.
0.00
0.01
0.02
0.03
0.05
0.08
0.13
0.20
0.35
0.55
0.90
1.50

Map 3 The Global Earthquake Model (GEM) Global Seismic Hazard[86]

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[86] Map (version 2018.1) https://www.globalquakemodel.org/ *Eurocode 8: Values of probability of exceedance and equivalent return period must be defined based on National building codes referring to European codes and National annex.

8.2. Subsidence

Figure 17 below shows the conceptual map that explains the causes of subsidence in the context of climate change, the socio-economic development and the impact and expected consequences.

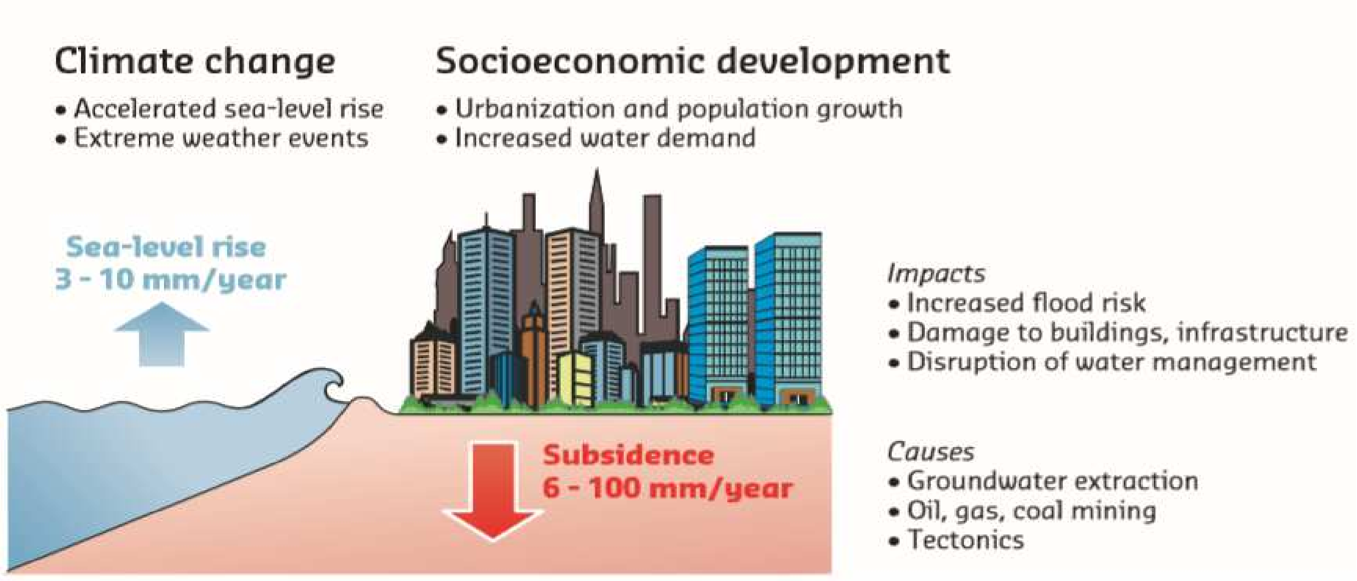
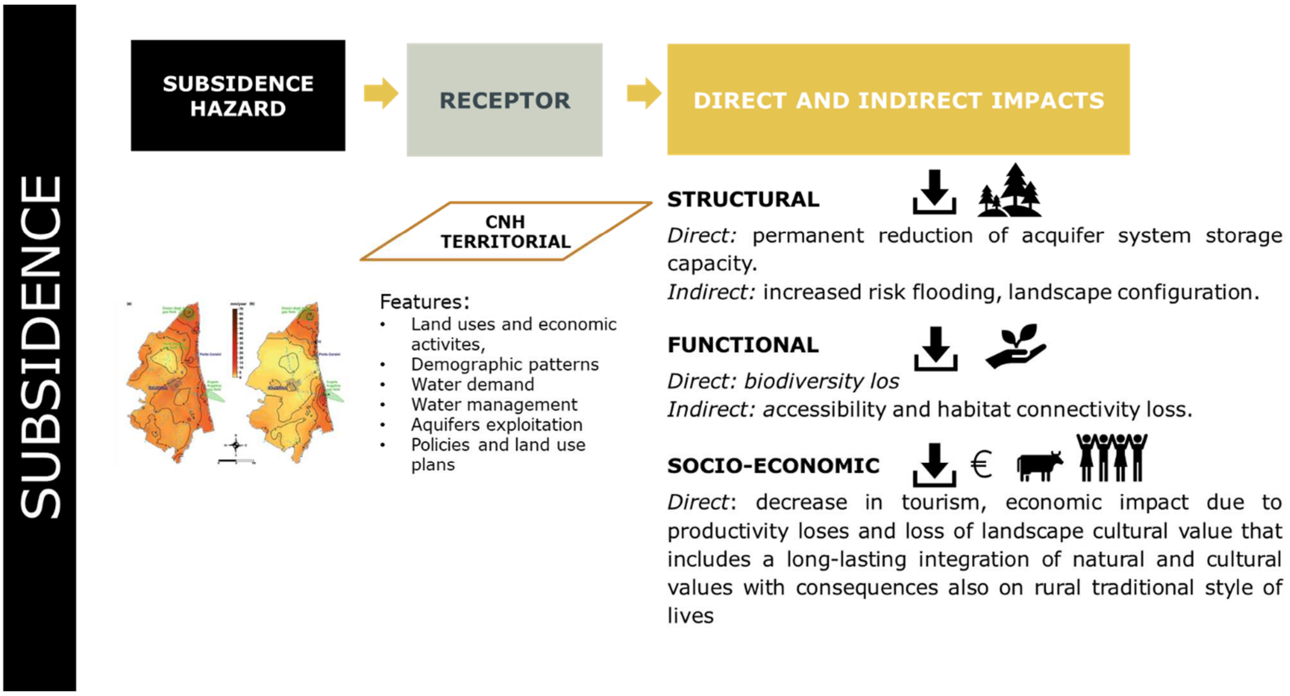

Climate change
• Accelerated sea-level rise
• Extreme weather events
Socioeconomic development
• Urbanization and population growth
• Increased water demand
Sea-level rise
3 - 10 mm/year
Impacts
• Increased flood risk
• Damage to buildings, infrastructure
• Disruption of water management
Subsidence
6 - 100 mm/year
Causes
• Groundwater extraction
• Oil, gas, coal mining
• Tectonics

Figure 17 Concept map of causes of subsidence and related impacts

Following the approach for building impact chains in SHELTER structured in three level of CNH and for the three types of vulnerabilities to be assessed in the risks assessment, impact chains have been elaborated for Subsidence that are shown in **Figure 18**, **Figure 19** and **Figure 20**, below.


SUBSIDENCE
SUBSIDENCE HAZARD
RECEPTOR
DIRECT AND INDIRECT IMPACTS
CNH TERRITORIAL
STRUCTURAL
FUNCTIONAL
SOCIO-ECONOMIC
€

Features:
- Land uses and economic activites,
- Demographic patterns
- Water demand
- Water management
- Aquifers exploitation
- Policies and land use plans

STRUCTURAL

Direct: permanent reduction of acquifer system storage capacity.
Indirect: increased risk flooding, landscape configuration.

FUNCTIONAL

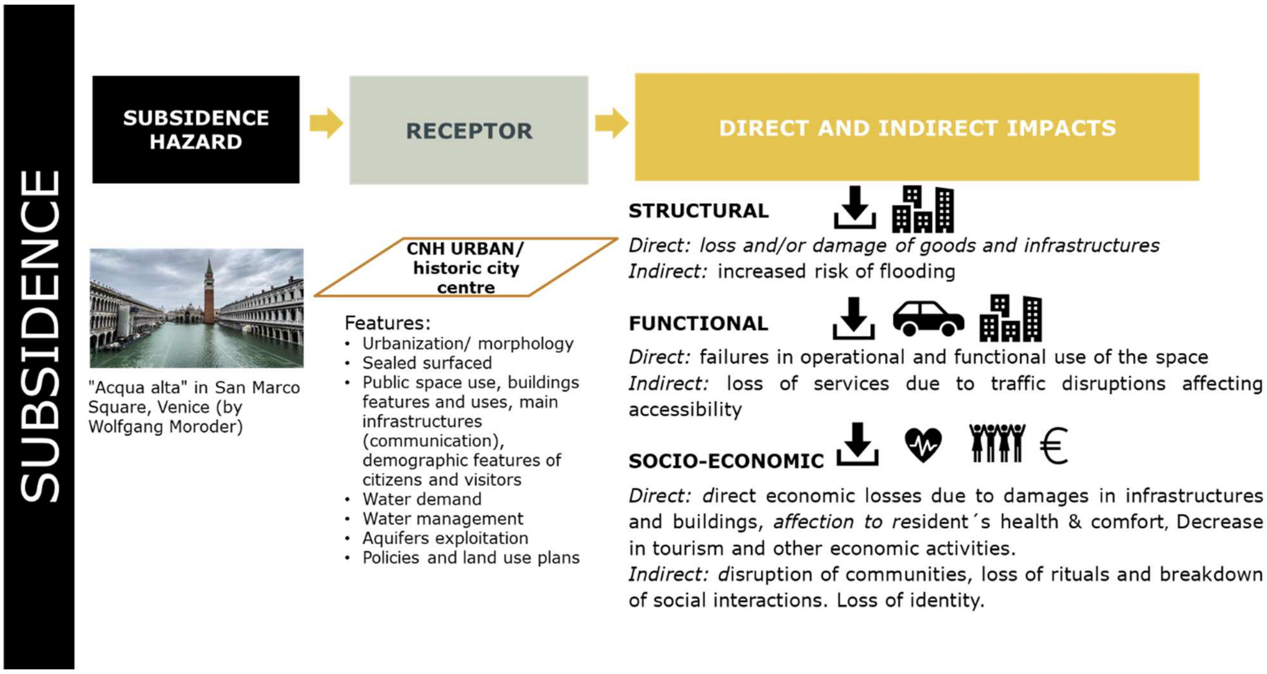
Direct: biodiversity los
Indirect: accessibility and habitat connectivity loss.

SOCIO-ECONOMIC

Direct: decrease in tourism, economic impact due to productivity loses and loss of landscape cultural value that includes a long-lasting integration of natural and cultural values with consequences also on rural traditional style of lives

Figure 18 Subsidence on CNH at territorial level

Subsidence provokes relevant loss in rural territories with consequences on rural productions. It also provokes a cultural loss in term of landscape as a cultural value that includes a long-lasting integration of natural and cultural values with consequences also on rural traditional style of lives.


SUBSIDENCE
SUBSIDENCE HAZARD
RECEPTOR
DIRECT AND INDIRECT IMPACTS
CNH URBAN/ historic city centre

"Acqua alta" in San Marco Square, Venice (by Wolfgang Moroder)

Features:
- Urbanization/ morphology
- Sealed surfaced
- Public space use, buildings features and uses, main infrastructures (communication), demographic features of citizens and visitors
- Water demand
- Water management
- Aquifers exploitation
- Policies and land use plans

STRUCTURAL

Direct: loss and/or damage of goods and infrastructures
Indirect: increased risk of flooding

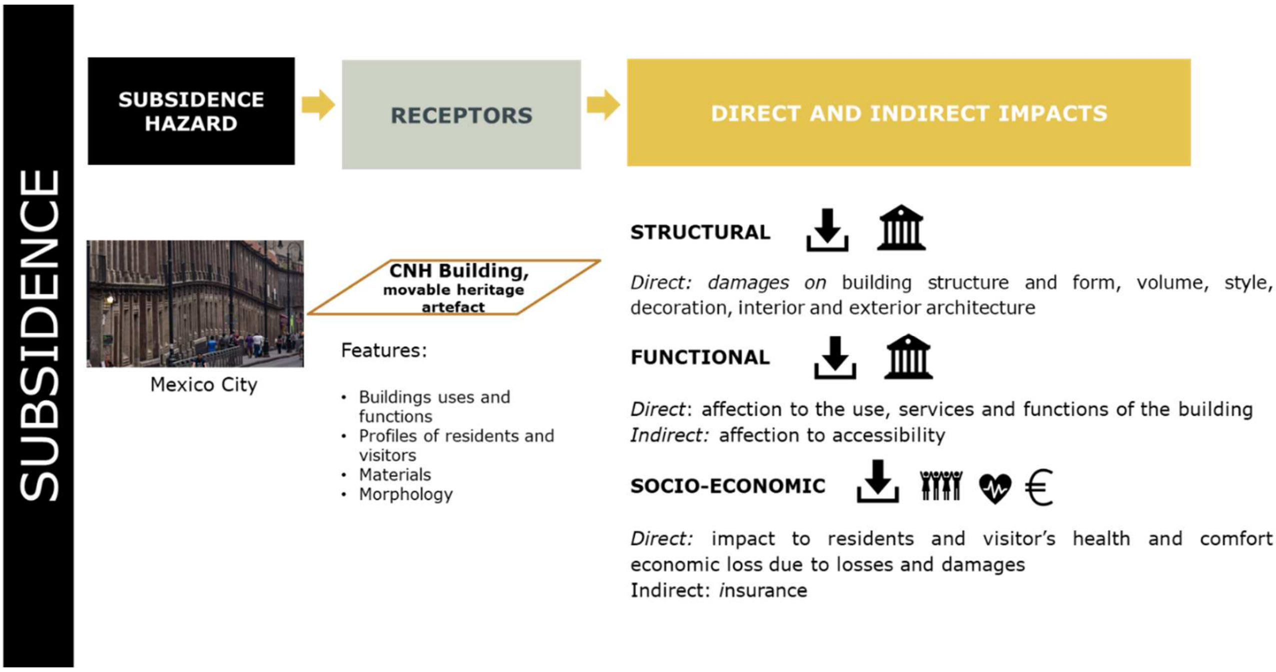
FUNCTIONAL

Direct: failures in operational and functional use of the space
Indirect: loss of services due to traffic disruptions affecting accessibility

SOCIO-ECONOMIC

*Direct: d*irect economic losses due to damages in infrastructures and buildings, *affection to r*esident´s health & comfort, Decrease in tourism and other economic activities.
*Indirect: d*isruption of communities, loss of rituals and breakdown of social interactions. Loss of identity.

Figure 19 Subsidence on CNH urban level and historic city centres


SUBSIDENCE
SUBSIDENCE HAZARD
RECEPTORS
DIRECT AND INDIRECT IMPACTS
CNH Building, movable heritage artefact

Mexico City

Features:
- Buildings uses and functions
- Profiles of residents and visitors
- Materials
- Morphology

STRUCTURAL

Direct: damages on building structure and form, volume, style, decoration, interior and exterior architecture

FUNCTIONAL

Direct: affection to the use, services and functions of the building
Indirect: affection to accessibility

SOCIO-ECONOMIC

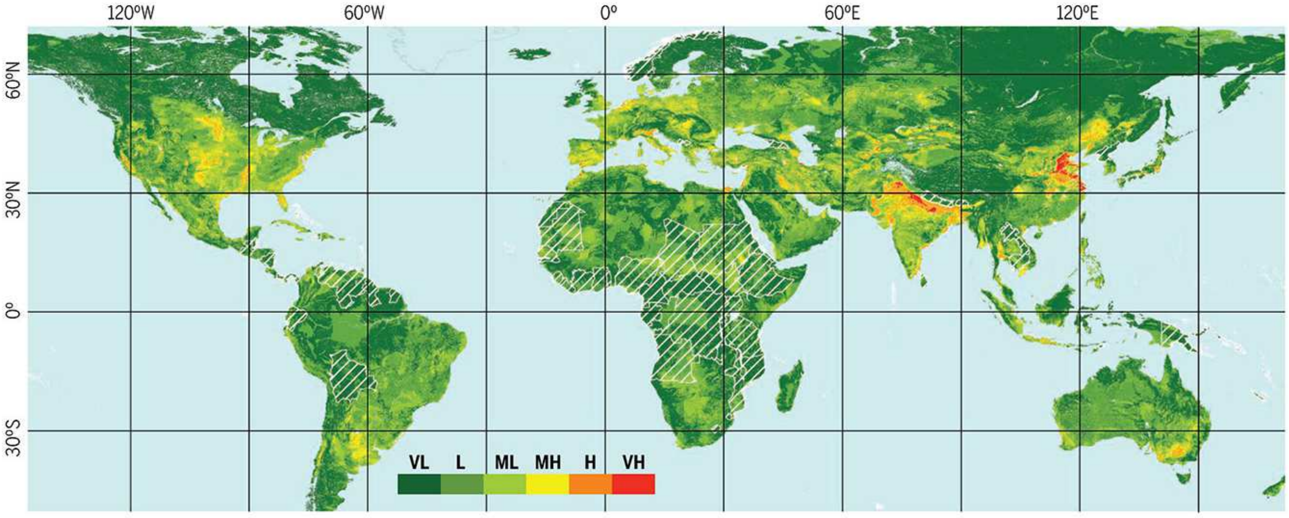
Direct: impact to residents and visitor's health and comfort economic loss due to losses and damages
Indirect: *i*nsurance

Figure 20 Subsidence on CNH at building level, mobile heritage and artefact

Common minimum information

The analysis of subsidence hazard should be based on *subsidence magnitude and rate*, but this data is unknown at global scale. [8] Gerardo Herrera-García et al. (2020)[87] suggest predicting a proxy of subsidence hazard, by combining *subsidence susceptibility* with the *probability of groundwater depletion*. The result of the analysis is shown in the maps, as prediction in 2040. This analysis, provided in, permits identification of exposed areas where the probability of land subsidence occurrence is high. Even though these results do not necessarily translate to direct impacts or damages, they are useful for identifying potential subsidence areas where further local-scale analysis is necessary.

Seven of the first ten ranked countries have the greatest subsidence impact, accounting for the greatest amount of reported damages (Netherlands, China, USA, Japan, Indonesia, México and Italy)



Map 4 Potential global subsidence (2040) The colour scale indicates the probability intervals classified from very low (VL) to very high (VH), for every 30-arcsec resolution pixel (1 km by 1 km at the Equator).[88]

Figure 21 shows the different types of subsidence maps.

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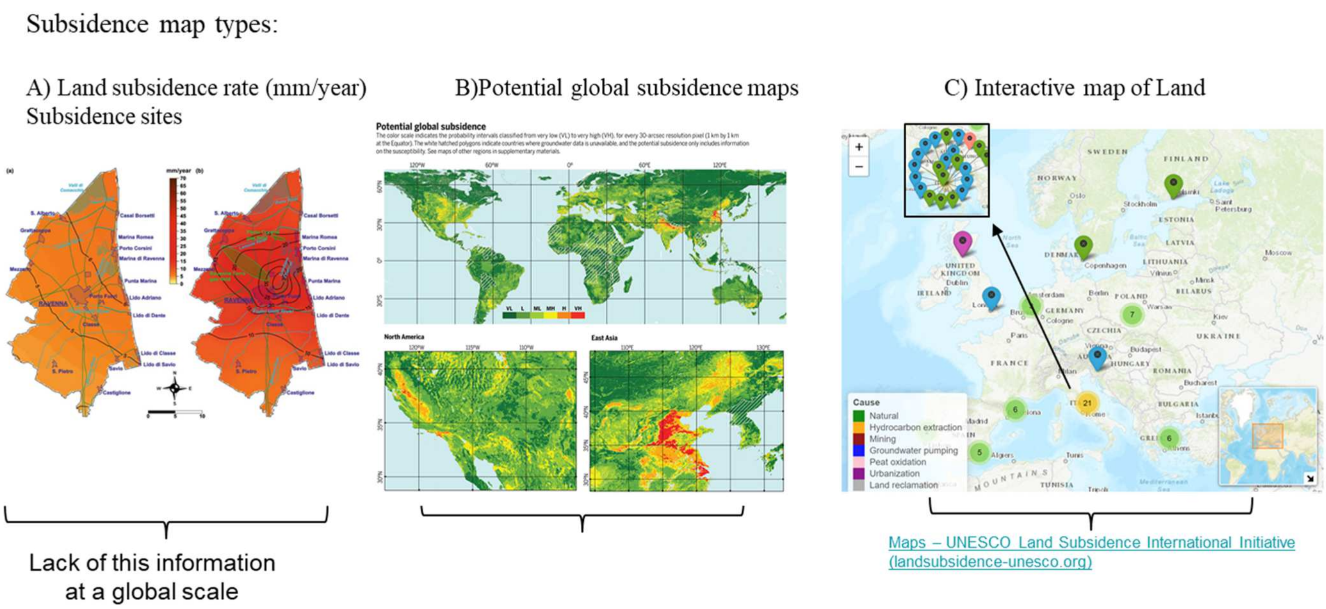
[87] Gerardo Herrera-García et al. Mapping the global threat of land subsidence *Science*(2020).[DOI: 10.1126/science.abb8549](https://doi.org/10.1126/science.abb8549)

[88] The white hatched polygons indicate countries where groundwater data is unavailable, and the potential subsidence only includes information on the susceptibility. Gerardo Herrera-García et al. Mapping the global threat of land subsidence, Science (2020). DOI: 10.1126/science.abb8549


Subsidence map types:

A) Land subsidence rate (mm/year) Subsidence sites

B)Potential global subsidence maps

C) Interactive map of Land

Lack of this information at a global scale

Maps – UNESCO Land Subsidence International Initiative (landsubsidence-unesco.org)

Figure 21 Subsidence Maps Types. [89]

The potential global subsidence maps offer information to 2040. Combine subsidence susceptibility and the probability of groundwater depletion, predicting a proxy of subsidence hazard, which permits identification of exposed areas where the probability of land subsidence occurrence is high or very high.

The main variables favouring land subsidence in the global model are:

- environmental settings= Statistical analyses of lithology, land-surface slope, land cover, and Koppen-Geiger climate classes are used to predict global subsidence susceptibility
- anthropogenic factors: leading to groundwater depletion = urban and irrigated areas suffering water stress and where groundwater demand is high (probability of groundwater depletion)

Map 5 Show an example of the potential global subsidence map with a zoom into North America and East Asia.

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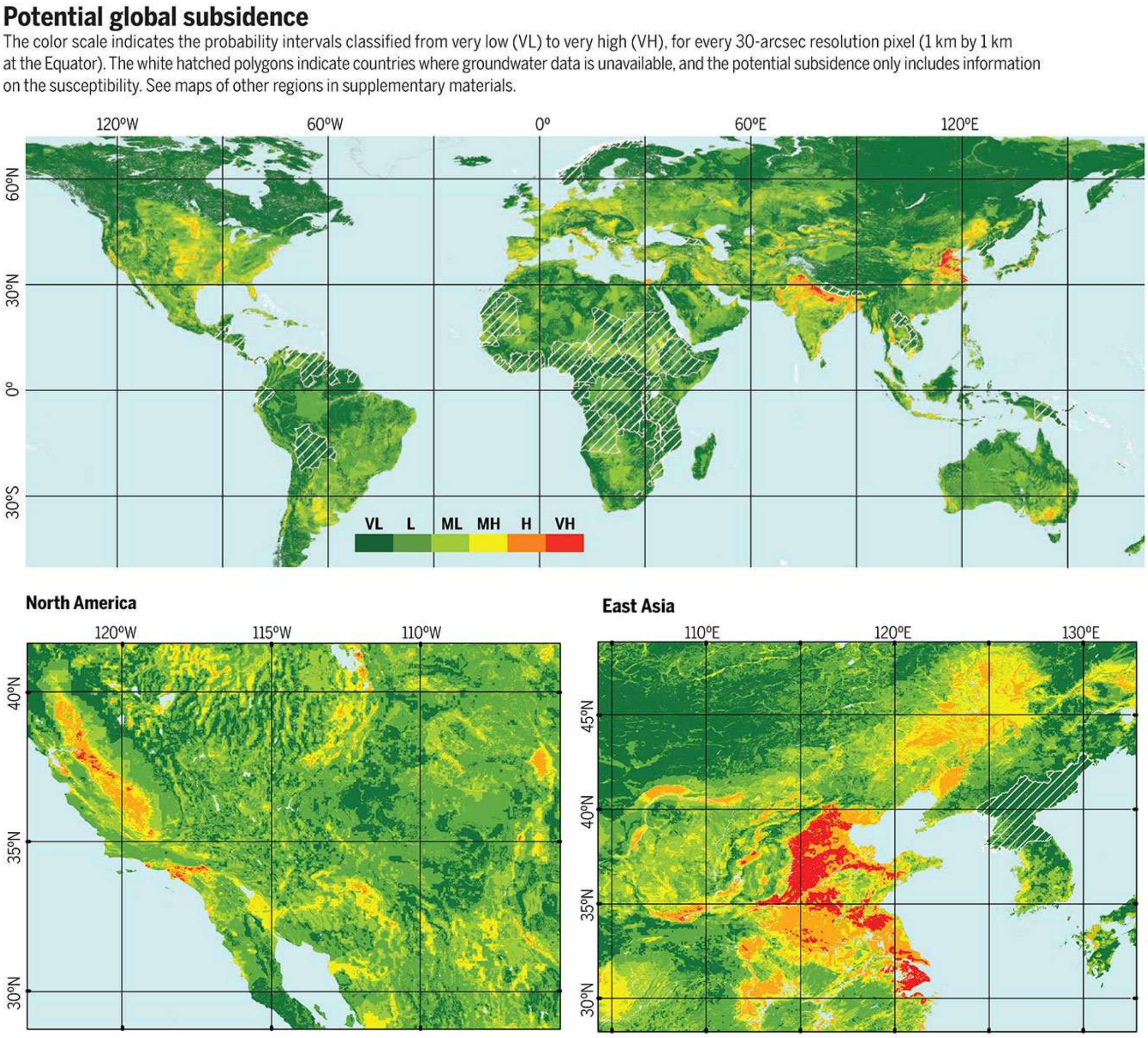
[89] These maps have been published in Science on January 4, 2021:G. Herrera-Garcia, P. Ezquerro, R. Tomas, M. Bejar-Pizarro, J. Lopez-Vinielles, M. Rossi, R. M. Mateos, D. Carreon-Freyre, J. Lambert, P. Teatini, E. Cabral-Cano, G. Erkens, D. Galloway, W.-C. Hung, N. Kakar, M. Sneed, L. Tosi, H. Wand and S. Ye, Mapping the global threat of land subsidence, Science, 371 (6524), 34-36, doi:10.1126/science.abb8549, 2021 .


Potential global subsidence
The color scale indicates the probability intervals classified from very low (VL) to very high (VH), for every 30-arcsec resolution pixel (1 km by 1 km at the Equator). The white hatched polygons indicate countries where groundwater data is unavailable, and the potential subsidence only includes information on the susceptibility. See maps of other regions in supplementary materials.
120°W
60°W
0°
60°E
120°E
60°N
30°N
0°
30°S
VL
L
ML
MH
H
VH
North America
120°W
115°W
110°W
40°N
35°N
30°N
East Asia
110°E
120°E
130°E
45°N
40°N
35°N
30°N

Map 5 Potential global subsidence maps

8.3. Flooding (pluvial)

The **Figure 22** below shows a generic impact chain for the pluvial flood hazard on CNH, based on literature review and inspired by impact chains developed in the context the FPVII project RAMSES.

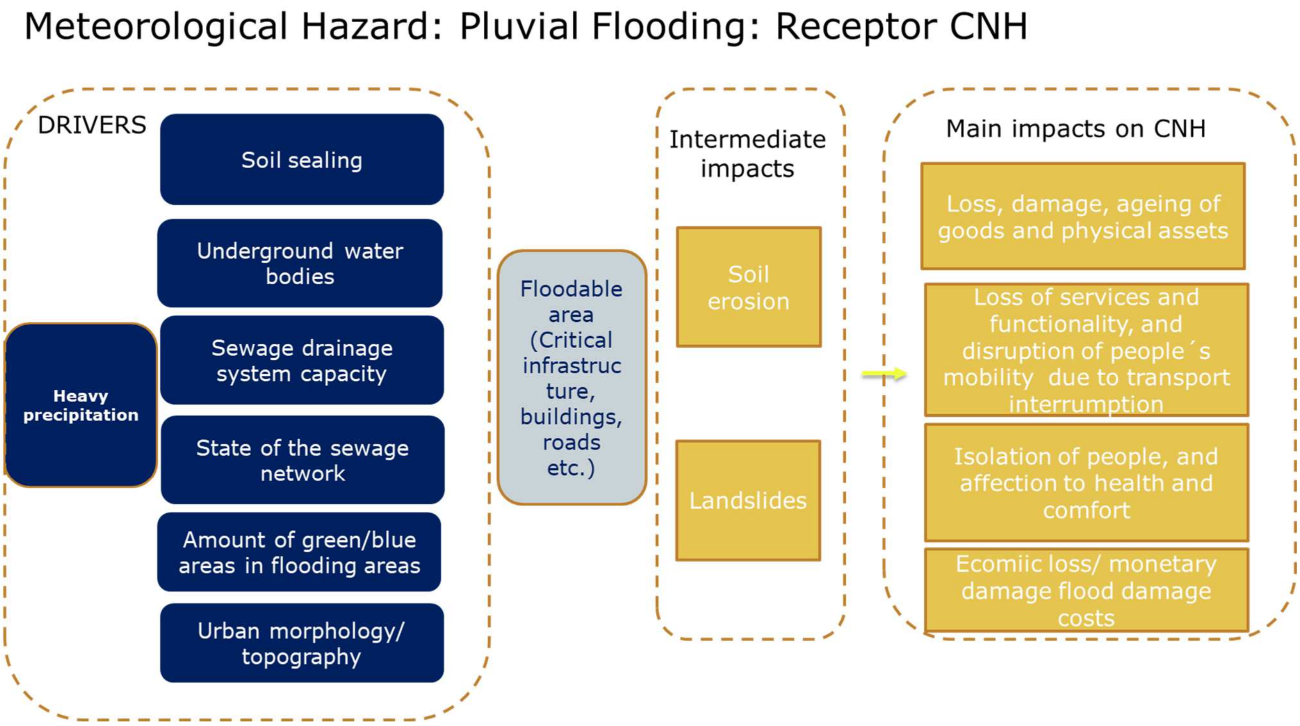
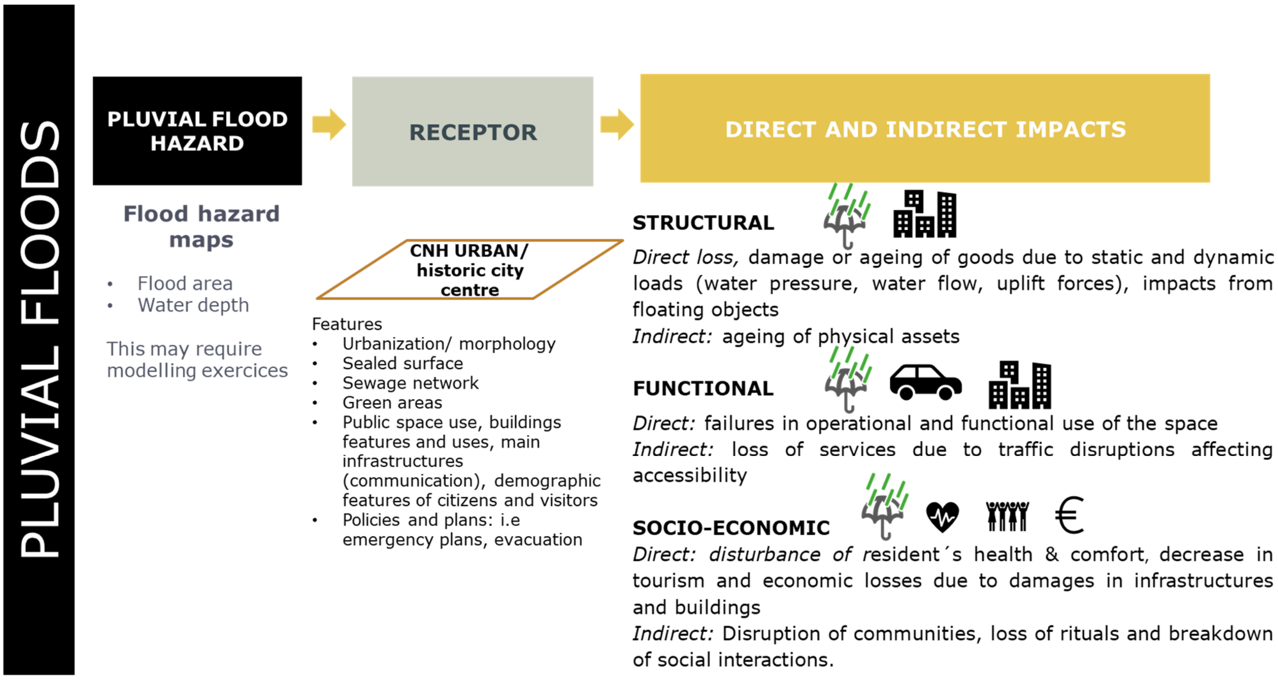

Meteorological Hazard: Pluvial Flooding: Receptor CNH
DRIVERS
Soil sealing
Underground water bodies
Sewage drainage system capacity
State of the sewage network
Amount of green/blue areas in flooding areas
Urban morphology/ topography
Heavy precipitation
Floodable area (Critical infrastructure, buildings, roads etc.)
Intermediate impacts
Soil erosion
Landslides
Main impacts on CNH
Loss, damage, ageing of goods and physical assets
Loss of services and functionality, and disruption of people´s mobility due to transport interruption
Isolation of people, and affection to health and comfort
Ecomiic loss/ monetary damage flood damage costs

Figure 22 Impact chain for meteorological hazard related to pluvial flooding on CNH.

Following the approach for building impact chains in SHELTER project and for the three types of vulnerabilities to be assessed in the risk assessment, two impact chains have elaborated related to CNH at the urban level and historic city level (**Figure 23**) and the site level (**Figure 24**) that are shown below.

For the territorial level, an impact chain for pluvial flooding may not be meaningful.



PLUVIAL FLOODS

PLUVIAL FLOOD HAZARD

Flood hazard maps

- Flood area
- Water depth

This may require modelling exercices

RECEPTOR

CNH URBAN/ historic city centre

Features
- Urbanization/ morphology
- Sealed surface
- Sewage network
- Green areas
- Public space use, buildings features and uses, main infrastructures (communication), demographic features of citizens and visitors
- Policies and plans: i.e emergency plans, evacuation

DIRECT AND INDIRECT IMPACTS

STRUCTURAL

Direct loss, damage or ageing of goods due to static and dynamic loads (water pressure, water flow, uplift forces), impacts from floating objects
Indirect: ageing of physical assets

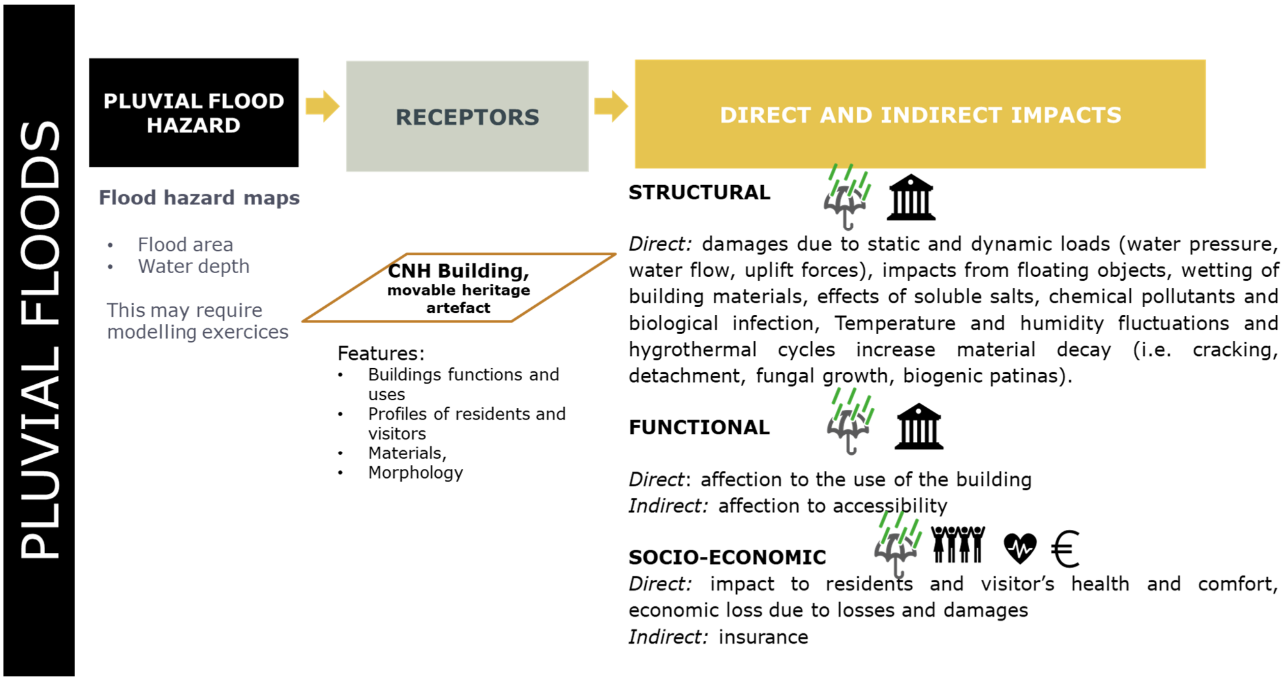
FUNCTIONAL

Direct: failures in operational and functional use of the space
Indirect: loss of services due to traffic disruptions affecting accessibility

SOCIO-ECONOMIC

Direct: disturbance of resident´s health & comfort, decrease in tourism and economic losses due to damages in infrastructures and buildings
Indirect: Disruption of communities, loss of rituals and breakdown of social interactions.

Figure 23 Pluvial flooding on CNH at urban level and historic city centre



PLUVIAL FLOODS

PLUVIAL FLOOD HAZARD

Flood hazard maps

- Flood area
- Water depth

This may require modelling exercices

RECEPTORS

CNH Building, movable heritage artefact

Features:
- Buildings functions and uses
- Profiles of residents and visitors
- Materials,
- Morphology

DIRECT AND INDIRECT IMPACTS

STRUCTURAL

Direct: damages due to static and dynamic loads (water pressure, water flow, uplift forces), impacts from floating objects, wetting of building materials, effects of soluble salts, chemical pollutants and biological infection, Temperature and humidity fluctuations and hygrothermal cycles increase material decay (i.e. cracking, detachment, fungal growth, biogenic patinas).

FUNCTIONAL

Direct: affection to the use of the building
Indirect: affection to accessibility

SOCIO-ECONOMIC

Direct: impact to residents and visitor's health and comfort, economic loss due to losses and damages
Indirect: insurance

Figure 24 Pluvial flooding on CNH at building, mobile heritage and artefact level

8.4. Flooding (fluvial)

The **Figure 25** below shows a generic impact chain for the fluvial flood hazard on CNH based on literature review and inspired by impact chains developed in the context the FPVII project RAMSES.

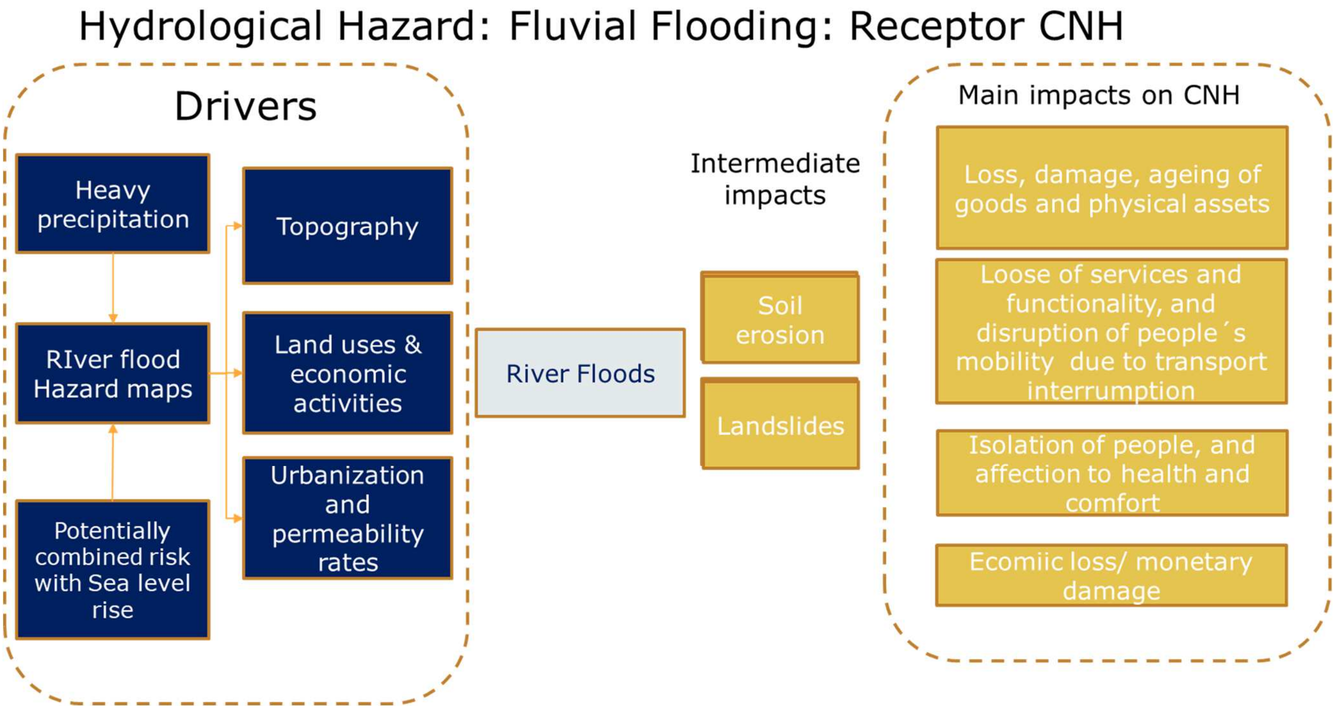
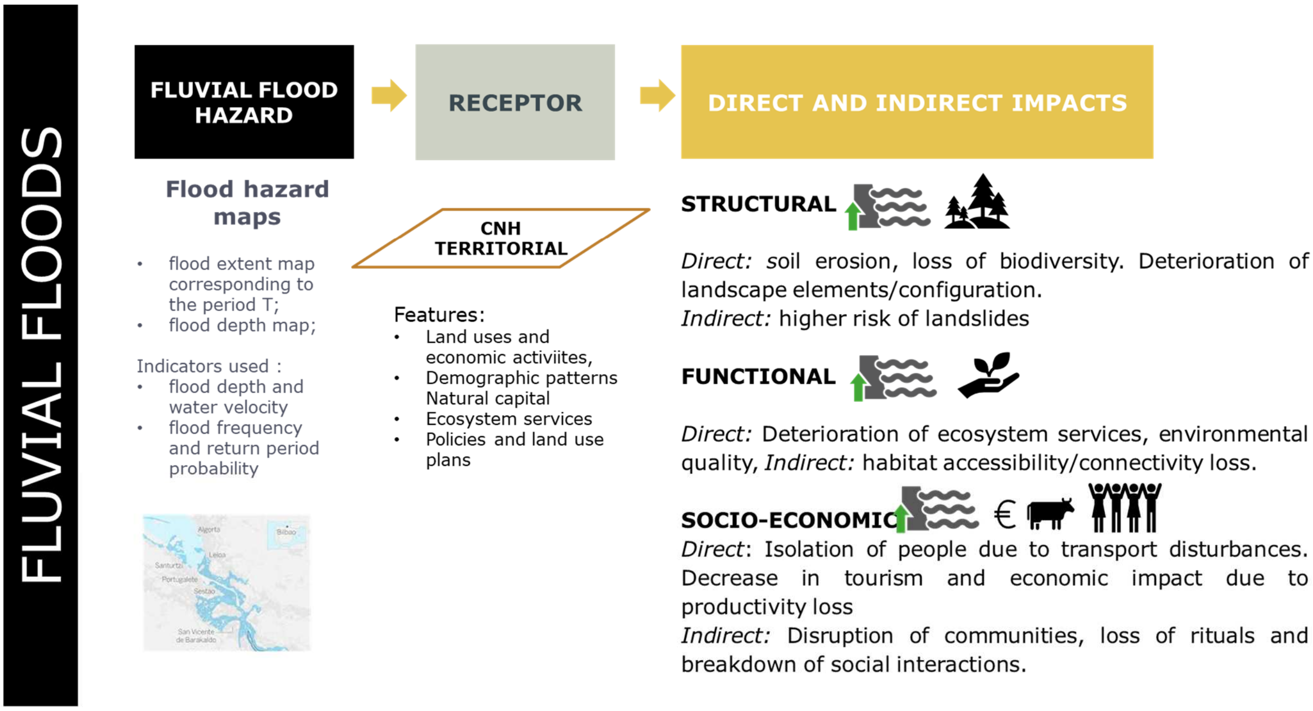

Hydrological Hazard: Fluvial Flooding: Receptor CNH
Drivers
Heavy precipitation
RIver flood Hazard maps
Potentially combined risk with Sea level rise
Topography
Land uses & economic activities
Urbanization and permeability rates
River Floods
Intermediate impacts
Soil erosion
Landslides
Main impacts on CNH
Loss, damage, ageing of goods and physical assets
Loose of services and functionality, and disruption of people´s mobility due to transport interrumption
Isolation of people, and affection to health and comfort
Ecomiic loss/ monetary damage

Figure 25 Impact chain for hydrological hazard related to fluvial flooding on Natural and Cultural Heritage

Following the approach for building impact chains in SHELTER structured in three level of CNH and for the three types of vulnerabilities to be assessed in the risks assessment, three impact chains have elaborated for fluvial floods that are shown in **Figure 26**, **Figure 27**and **Figure 28**, below.



FLUVIAL FLOODS

FLUVIAL FLOOD HAZARD → **RECEPTOR** → **DIRECT AND INDIRECT IMPACTS**

Flood hazard maps

- flood extent map corresponding to the period T;
- flood depth map;

Indicators used :
- flood depth and water velocity
- flood frequency and return period probability

CNH TERRITORIAL

Features:
- Land uses and economic activiites,
- Demographic patterns Natural capital
- Ecosystem services
- Policies and land use plans

STRUCTURAL

Direct: soil erosion, loss of biodiversity. Deterioration of landscape elements/configuration.
Indirect: higher risk of landslides

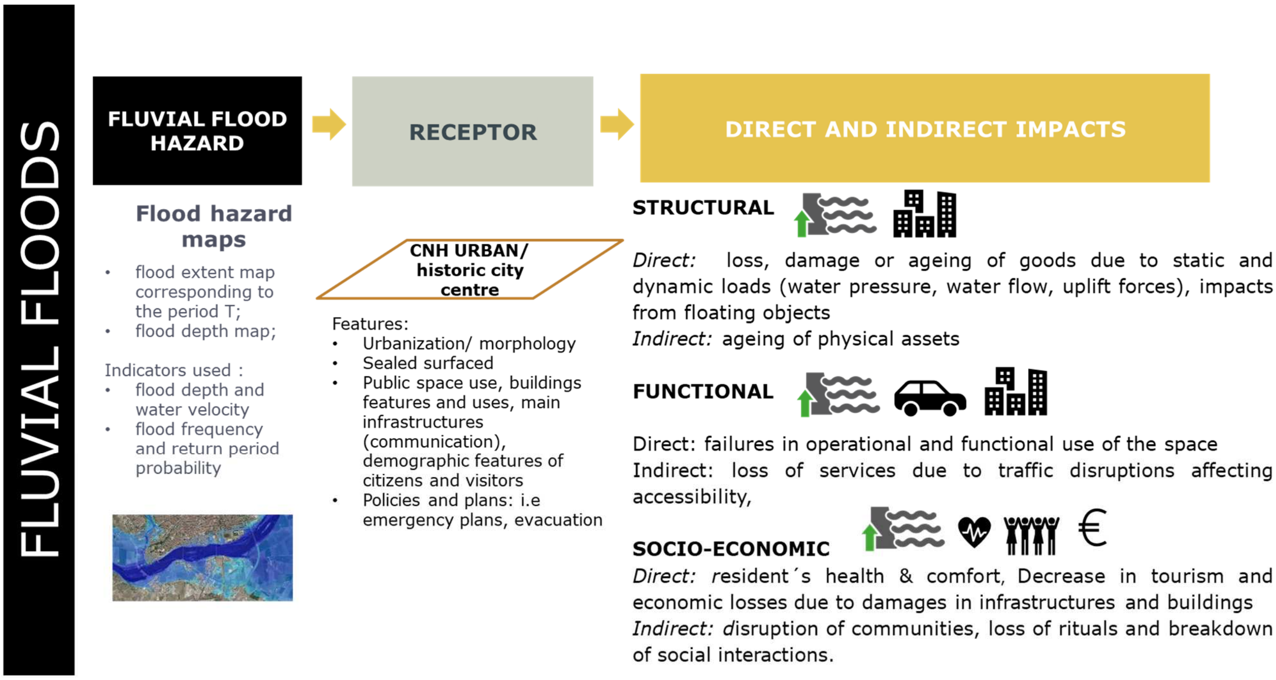
FUNCTIONAL

Direct: Deterioration of ecosystem services, environmental quality, *Indirect:* habitat accessibility/connectivity loss.

SOCIO-ECONOMIC €

Direct: Isolation of people due to transport disturbances. Decrease in tourism and economic impact due to productivity loss
Indirect: Disruption of communities, loss of rituals and breakdown of social interactions.

Figure 26 Fluvial flood on CNH at territorial level.



FLUVIAL FLOODS

FLUVIAL FLOOD HAZARD → **RECEPTOR** → **DIRECT AND INDIRECT IMPACTS**

Flood hazard maps

- flood extent map corresponding to the period T;
- flood depth map;

Indicators used :
- flood depth and water velocity
- flood frequency and return period probability

CNH URBAN/ historic city centre

Features:
- Urbanization/ morphology
- Sealed surfaced
- Public space use, buildings features and uses, main infrastructures (communication), demographic features of citizens and visitors
- Policies and plans: i.e emergency plans, evacuation

STRUCTURAL

Direct: loss, damage or ageing of goods due to static and dynamic loads (water pressure, water flow, uplift forces), impacts from floating objects
Indirect: ageing of physical assets

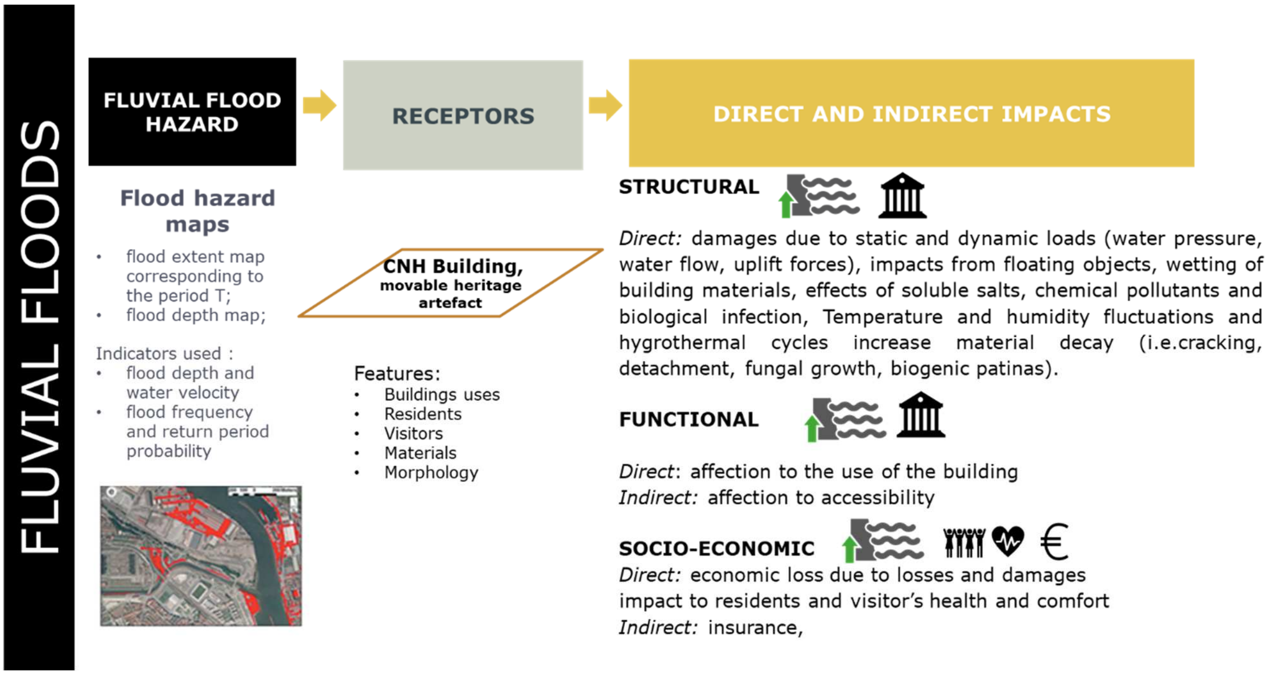
FUNCTIONAL

Direct: failures in operational and functional use of the space
Indirect: loss of services due to traffic disruptions affecting accessibility,

SOCIO-ECONOMIC €

Direct: resident´s health & comfort, Decrease in tourism and economic losses due to damages in infrastructures and buildings
Indirect: disruption of communities, loss of rituals and breakdown of social interactions.

Figure 27 Fluvial flood on CNH Urban and historic city centres



- flood extent map corresponding to the period T;
- flood depth map;

Indicators used :

- flood depth and water velocity
- flood frequency and return period probability

Features:

- Buildings uses
- Residents
- Visitors
- Materials
- Morphology

Direct: damages due to static and dynamic loads (water pressure, water flow, uplift forces), impacts from floating objects, wetting of building materials, effects of soluble salts, chemical pollutants and biological infection, Temperature and humidity fluctuations and hygrothermal cycles increase material decay (i.e.cracking, detachment, fungal growth, biogenic patinas).

Direct: affection to the use of the building
Indirect: affection to accessibility

Direct: economic loss due to losses and damages impact to residents and visitor's health and comfort
Indirect: insurance,

Figure 28 Fluvial flood on CNH Building scale, mobile heritage and artefact

Common minimum information

Flood mapping is a crucial element of flood risk management. Directive 2007/60/EC on the assessment and management of flood risks, required Member States to prepare two types of maps by 2013 (art 6):

- **Flood hazard maps**, showing the extent and expected water depths/levels of an area flooded in three scenarios, a low probability scenario or extreme events, in a medium probability scenario (at least with a return period of 100 years) and if appropriate a high probability scenario.
- **Flood risk maps**, shall also be prepared for the areas flooded under these scenarios showing potential population, economic activities and the environment at potential risk from flooding, and other information that Member States may find useful to include, for instance other sources of pollution.

Flood hazard maps and flood risk maps are described in Figure 29.

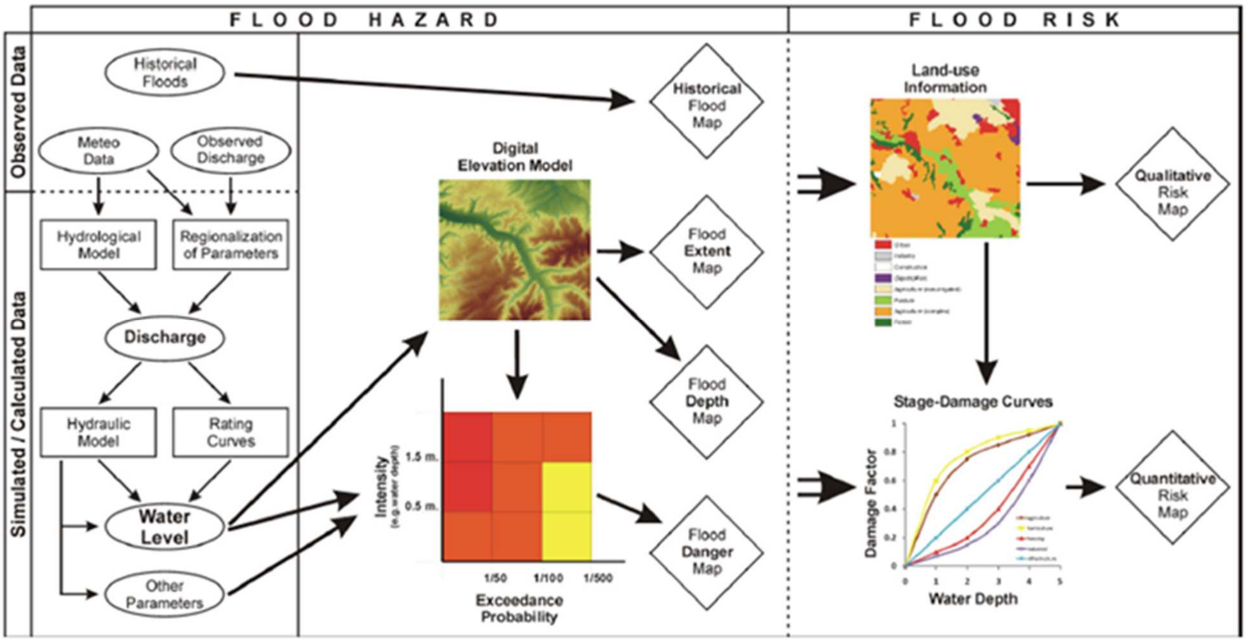

FLOOD HAZARD
FLOOD RISK
Observed Data
Simulated / Calculated Data
Historical Floods
Meteo Data
Observed Discharge
Hydrological Model
Regionalization of Parameters
Discharge
Hydraulic Model
Rating Curves
Water Level
Other Parameters
Digital Elevation Model
Intensity (e.g. water depth)
1.5 m.
0.5 m.
1/50
1/100
1/500
Exceedance Probability
Historical Flood Map
Flood Extent Map
Flood Depth Map
Flood Danger Map
Land-use Information
Qualitative Risk Map
Stage-Damage Curves
Damage Factor
Water Depth
Quantitative Risk Map

Figure 29 Flood maps in Europe–methods, availability and use [2] De Moel et al 2009 DOI: 10.5194/nhess-9-289-2009

The most interesting and meaningful maps for hazard characterization in SHELTER project are flood area and water depth maps. In **Figure 30** are those B and C respectively underlined by the red rectangle.

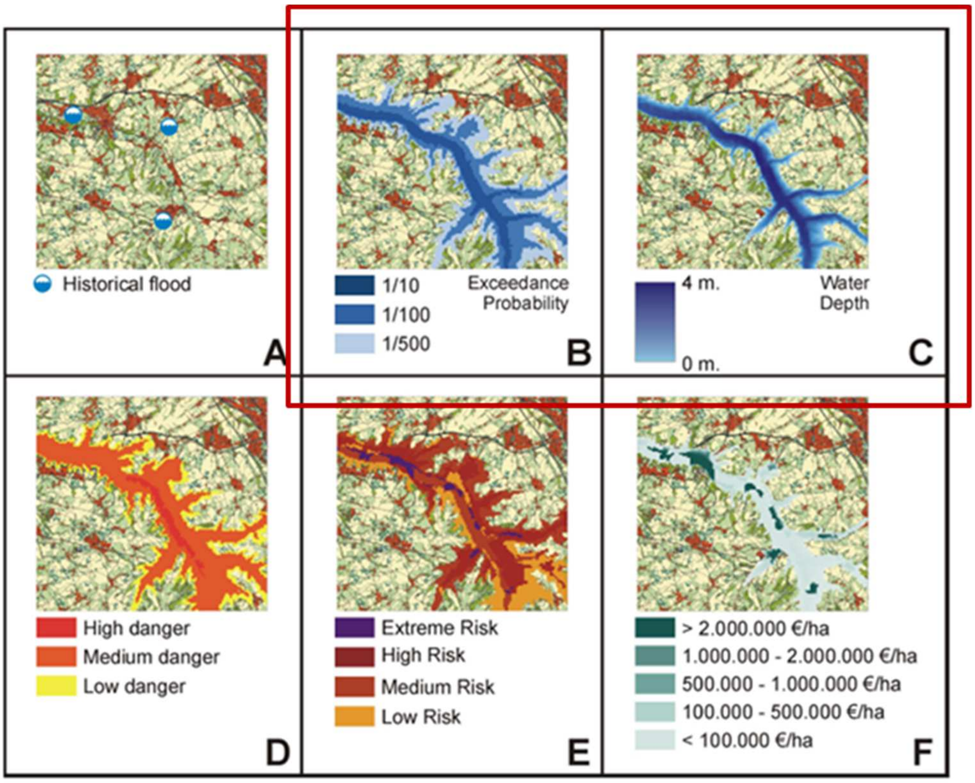

Historical flood
A
1/10
1/100
1/500
Exceedance Probability
B
4 m.
0 m.
Water Depth
C
High danger
Medium danger
Low danger
D
Extreme Risk
High Risk
Medium Risk
Low Risk
E
> 2.000.000 €/ha
1.000.000 - 2.000.000 €/ha
500.000 - 1.000.000 €/ha
100.000 - 500.000 €/ha
< 100.000 €/ha
F

Figure 30 Flood maps in Europe–methods, availability and use [2] De Moel et al 2009 DOI: 10.5194/nhess-9-289-2009

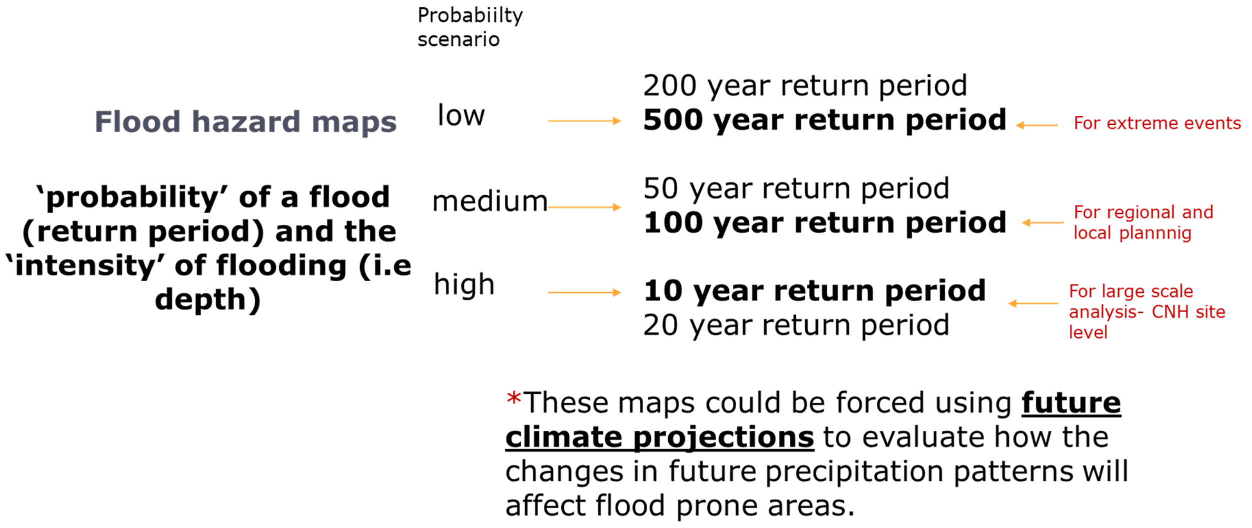

Probabiilty scenario
Flood hazard maps
'probability' of a flood (return period) and the 'intensity' of flooding (i.e depth)
low
medium
high
200 year return period
500 year return period
For extreme events
50 year return period
100 year return period
For regional and local plannnig
10 year return period
20 year return period
For large scale analysis- CNH site level
*These maps could be forced using future climate projections to evaluate how the changes in future precipitation patterns will affect flood prone areas.

Figure 31 Flood hazard maps and relevant probability scenarios to be used for CNH in SHELTER project. Own elaboration 2021.

Figure 31 describe the different probability scenarios to be used in flood hazard maps expressed in return periods. For assessing extreme events a low probability scenario of 500-year return period may be appropriate. For informing decision making for spatial planning and urban planning a probability of at least 100-year return period must be used. For large scale analysis a high probability scenario should be used of <20-year return period.

8.5. Wildfires

The **Figure 32** below shows a conceptual model of wildfire origin and expected consequences.

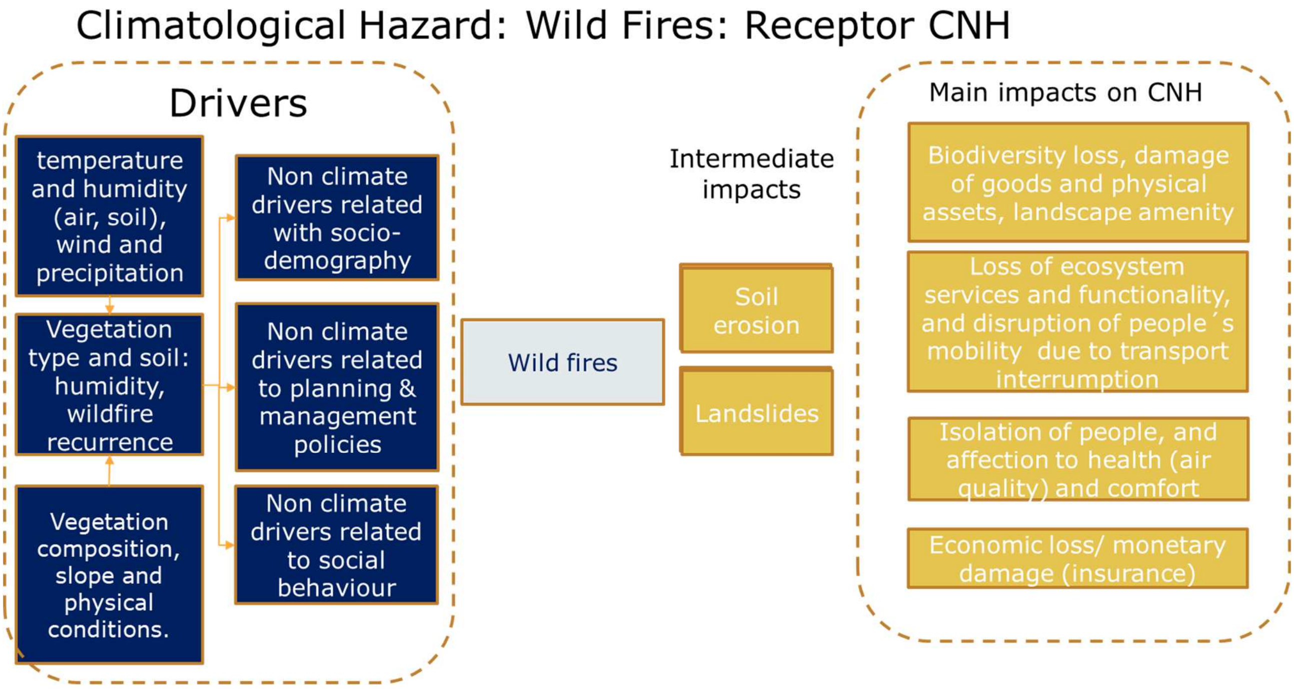
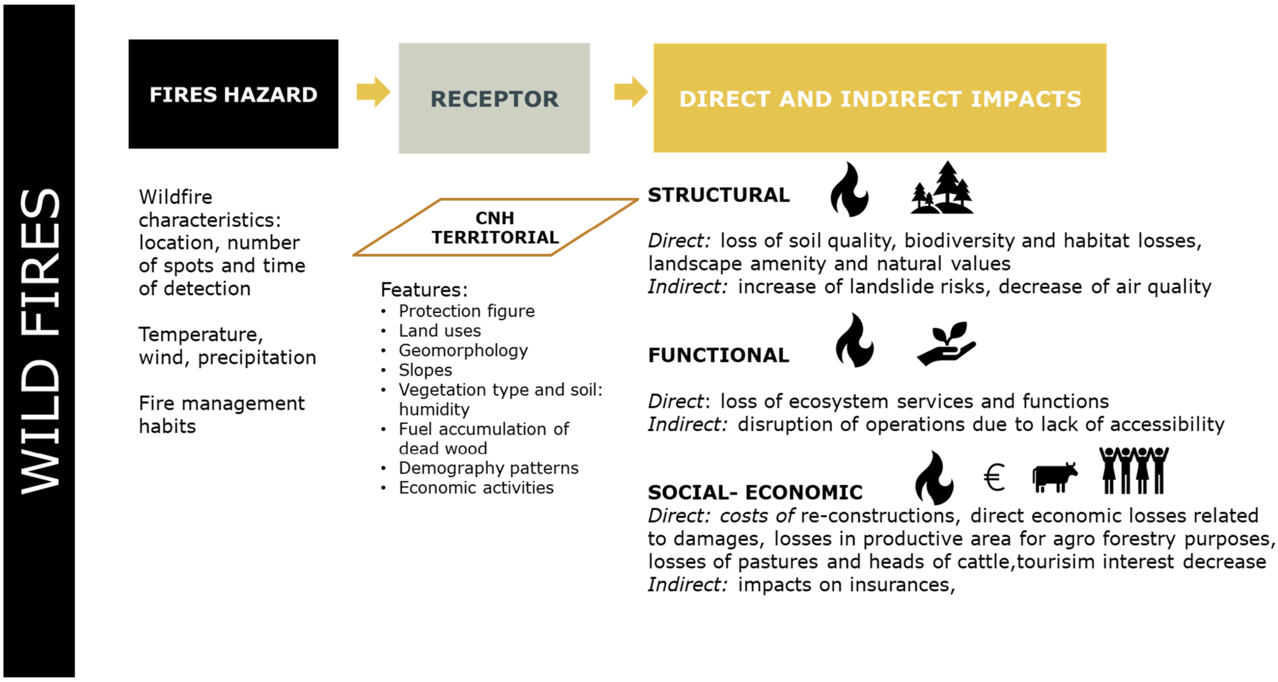

Climatological Hazard: Wild Fires: Receptor CNH
Drivers
temperature and humidity (air, soil), wind and precipitation
Vegetation type and soil: humidity, wildfire recurrence
Vegetation composition, slope and physical conditions.
Non climate drivers related with socio-demography
Non climate drivers related to planning & management policies
Non climate drivers related to social behaviour
Wild fires
Intermediate impacts
Soil erosion
Landslides
Main impacts on CNH
Biodiversity loss, damage of goods and physical assets, landscape amenity
Loss of ecosystem services and functionality, and disruption of people´s mobility due to transport interruption
Isolation of people, and affection to health (air quality) and comfort
Economic loss/ monetary damage (insurance)

Figure 32 Concept model for wildfires characterization and expected impacts

Following the approach for building impact chains in SHELTER structured in three level of CNH and for the three types of vulnerabilities to be assessed in the risk assessment, three impact chains have elaborated that are shown in **Figure 33**, **Figure 34** and **Figure 35**, below.



Wildfire characteristics: location, number of spots and time of detection

Temperature, wind, precipitation

Fire management habits

Features:
- Protection figure
- Land uses
- Geomorphology
- Slopes
- Vegetation type and soil: humidity
- Fuel accumulation of dead wood
- Demography patterns
- Economic activities

STRUCTURAL

Direct: loss of soil quality, biodiversity and habitat losses, landscape amenity and natural values
Indirect: increase of landslide risks, decrease of air quality

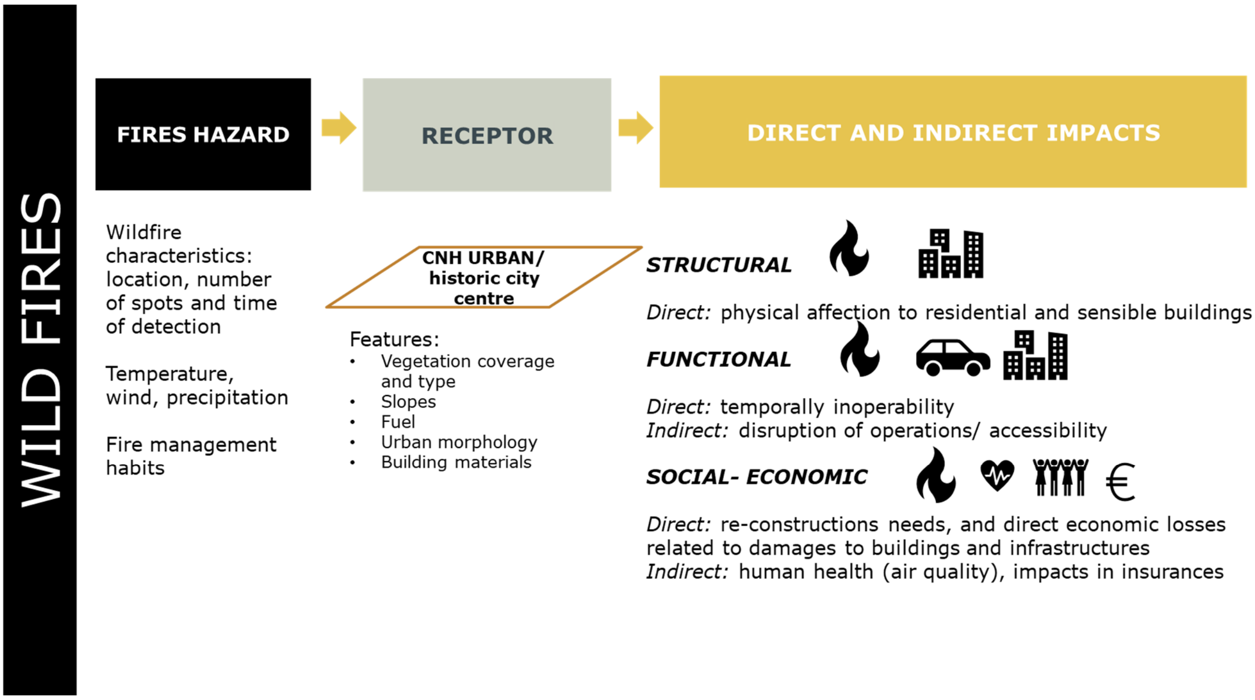
FUNCTIONAL

Direct: loss of ecosystem services and functions
Indirect: disruption of operations due to lack of accessibility

SOCIAL- ECONOMIC €

Direct: costs of re-constructions, direct economic losses related to damages, losses in productive area for agro forestry purposes, losses of pastures and heads of cattle,tourisim interest decrease
Indirect: impacts on insurances,

Figure 33 Wildfires on NH and CNH at territorial level



Wildfire characteristics: location, number of spots and time of detection

Temperature, wind, precipitation

Fire management habits

Features:
- Vegetation coverage and type
- Slopes
- Fuel
- Urban morphology
- Building materials

STRUCTURAL

Direct: physical affection to residential and sensible buildings

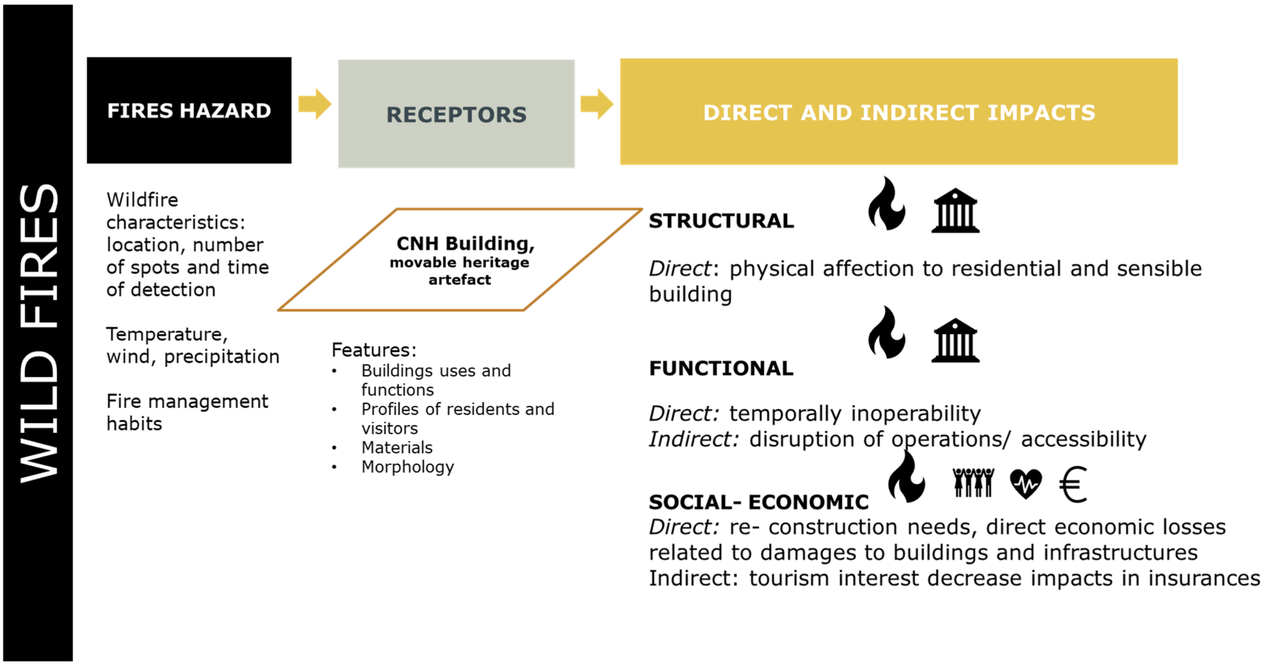
FUNCTIONAL

Direct: temporally inoperability
Indirect: disruption of operations/ accessibility

SOCIAL- ECONOMIC €

Direct: re-constructions needs, and direct economic losses related to damages to buildings and infrastructures
Indirect: human health (air quality), impacts in insurances

Figure 34 Wildfires on CNH at urban level and historic city centres



WILD FIRES

FIRES HAZARD

Wildfire characteristics: location, number of spots and time of detection

Temperature, wind, precipitation

Fire management habits

RECEPTORS

CNH Building, movable heritage artefact

Features:
- Buildings uses and functions
- Profiles of residents and visitors
- Materials
- Morphology

DIRECT AND INDIRECT IMPACTS

STRUCTURAL

Direct: physical affection to residential and sensible building

FUNCTIONAL

Direct: temporally inoperability
Indirect: disruption of operations/ accessibility

SOCIAL- ECONOMIC
Direct: re- construction needs, direct economic losses related to damages to buildings and infrastructures
Indirect: tourism interest decrease impacts in insurances

Figure 35 Wildfire on CNH at building level, mobile heritage and artefact

Common minimum information

The European Forest Fire Information System (EFFIS) offers an online fire danger forecast. Figure 36 shows a screen shot of the online information offered by EFFIS.

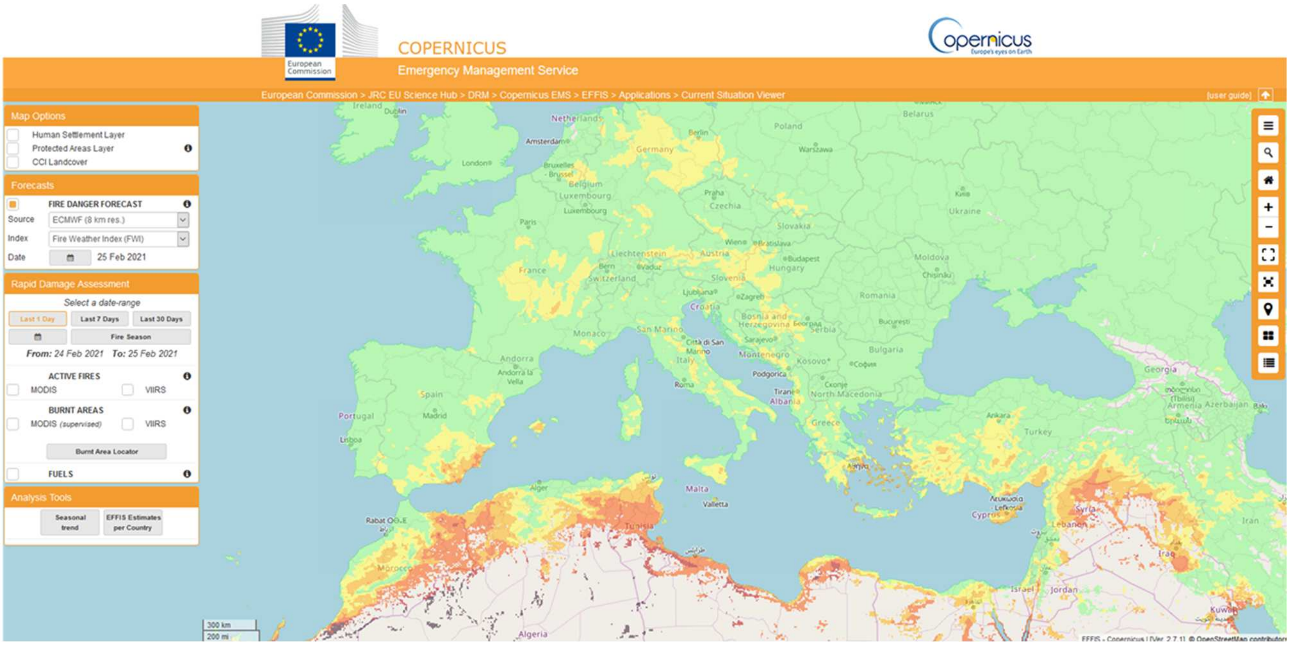

European Commission
COPERNICUS
Emergency Management Service
Copernicus Europe's eyes on Earth
European Commission > JRC EU Science Hub > DRM > Copernicus EMS > EFFIS > Applications > Current Situation Viewer
[user guide]
Map Options
Human Settlement Layer
Protected Areas Layer
CCI Landcover
Forecasts
FIRE DANGER FORECAST
Source ECMWF (8 km res.)
Index Fire Weather Index (FWI)
Date 25 Feb 2021
Rapid Damage Assessment
Select a date-range
Last 1 Day
Last 7 Days
Last 30 Days
Fire Season
From: 24 Feb 2021 To: 25 Feb 2021
ACTIVE FIRES
MODIS
VIIRS
BURNT AREAS
MODIS (supervised)
VIIRS
Burnt Area Locator
FUELS
Analysis Tools
Seasonal trend
EFFIS Estimates per Country
300 km
200 mi

Figure 36 Screenshot of Fire Danger Forecast online map (access 25/02/21)

The **Table 6** below shows the variables offered by Copernicus with European coverage that could be used for the characterization of wild fire as well as their spatial resolution.

These variables do have a maximum resolution of 250m. More detailed information might be needed when assessing risks on CNH in small areas and urban contexts.

Theme	Variable	Spatial Resolution	
		Coarse >=1km	Medium 250m-500m
Vegetation	Fraction of photosynthetically active radiation absorbed by the vegetation	Archive only; Near-Real Time (NRT) to be resampled from 300m	In production
	Fraction of green vegetation cover	Archive only; NRT to be resampled from 300m	In production
	Leaf Area index	Archive only; NRT to be resampled from 300m	In production
	Normalized Difference Vegetation Index	Archive only; NRT to be resampled from 300m	In production
	Vegetation Condition Index	Archive only	
	Vegetation Productivity Index	Archive only	
	Dry Matter Productivity	Archive only; NRT to be resampled from 300m	In production
	Burnt Area	Archive only; NRT to be resampled from 300m	In production
	Soil Water Index	In production	
	Surface Soil Moisture	In production	
Energy	Land Surface Temperature	In production	
	Top Of Canopy Reflectance	In production	
	Surface Albedo	Archive only	
Water	Water Bodies	Archive only	In production
	Lake Surface Water Temperature	In production	
	Lake Water Quality	In production	In production
Cryosphere	Lake Ice Extent		In production
	Snow Cover Extent	In production	In production
	Snow Water Equivalent	In production	

Table 6 Overview of variables used for wildfire characterization as well as the spatial resolution provided by Copernicus[90].

---

[90] https://land.copernicus.eu/global/products/

8.6. Heat waves

Figure 37 below shows a generic impact chain related to heat stress developed in the context the FPVII project RAMSES, used as inspiration for developing the impact chain for heat waves in SHELTER project.

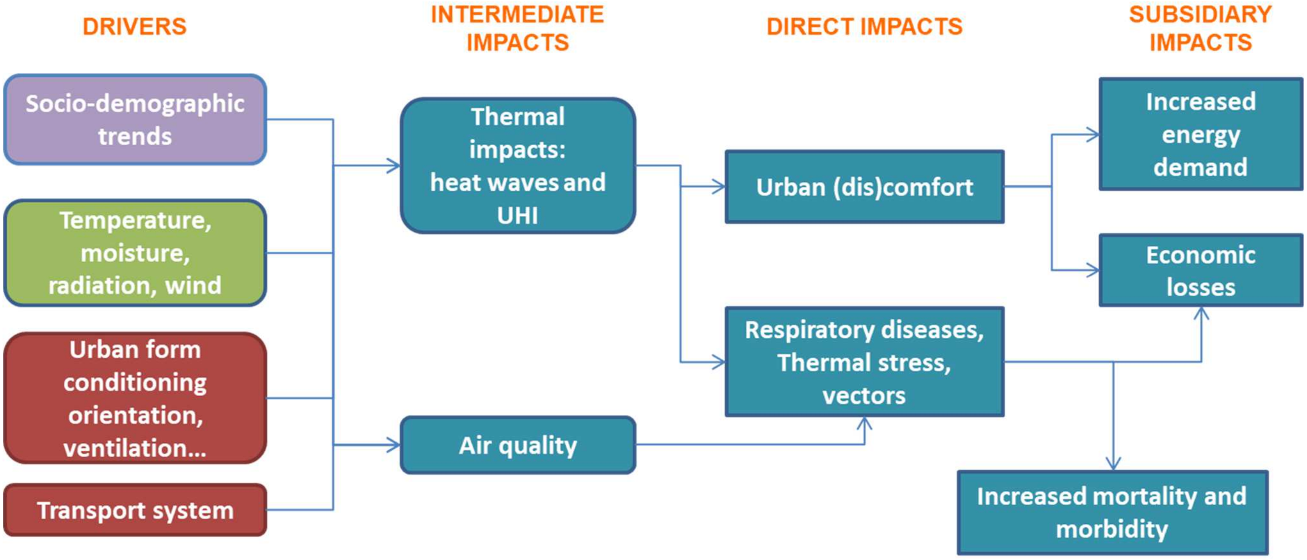

DRIVERS
INTERMEDIATE IMPACTS
DIRECT IMPACTS
SUBSIDIARY IMPACTS
Socio-demographic trends
Temperature, moisture, radiation, wind
Urban form conditioning orientation, ventilation...
Transport system
Thermal impacts: heat waves and UHI
Air quality
Urban (dis)comfort
Respiratory diseases, Thermal stress, vectors
Increased energy demand
Economic losses
Increased mortality and morbidity

Figure 37 Figure Heat Stress Impact Chain. From drivers to impacts. Source: FPVII Project: RAMSES Reconciling Adaptation, Mitigation and Sustainable Development for Cities", FP7. 2012-2017

Following the approach for building impact chains in SHELTER structured in three level of CNH and for the three types of vulnerabilities to be assessed in the risk assessment, three impact chains have elaborated for heat waves that are shown **Figure 38**, **Figure 39**and **Figure 40** below.

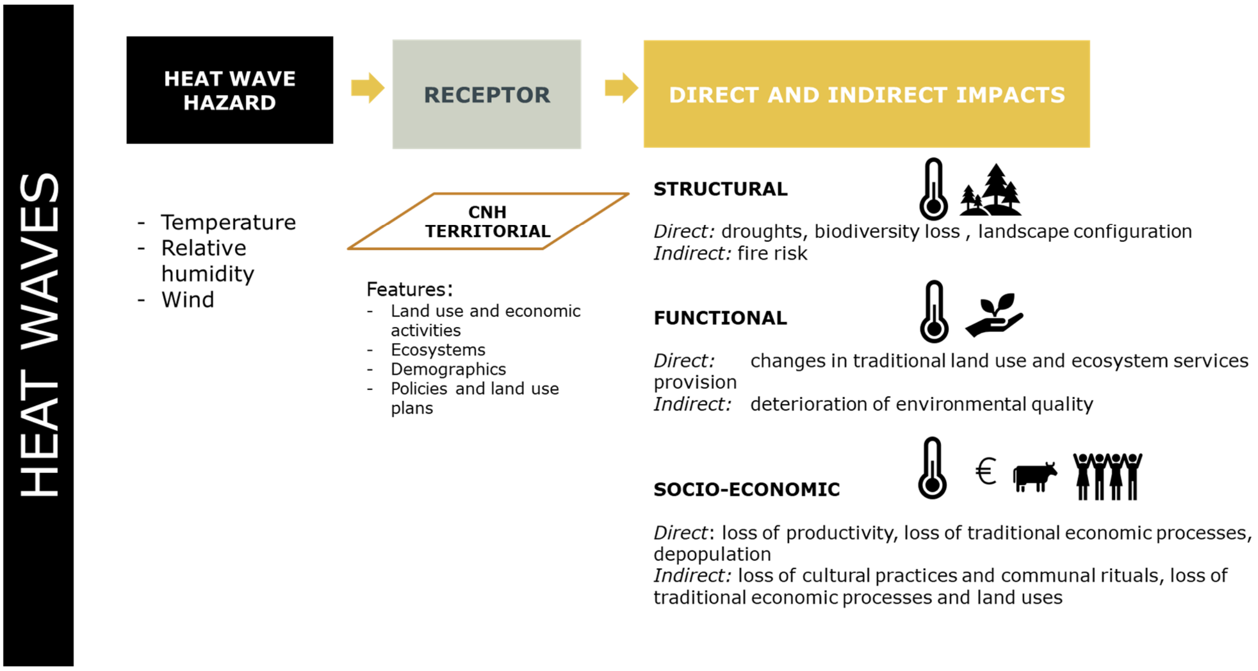

HEAT WAVES
HEAT WAVE HAZARD
RECEPTOR
DIRECT AND INDIRECT IMPACTS
- Temperature
- Relative humidity
- Wind
CNH TERRITORIAL
Features:
- Land use and economic activities
- Ecosystems
- Demographics
- Policies and land use plans
STRUCTURAL
Direct: droughts, biodiversity loss , landscape configuration
Indirect: fire risk
FUNCTIONAL
Direct: changes in traditional land use and ecosystem services provision
Indirect: deterioration of environmental quality
SOCIO-ECONOMIC
€
Direct: loss of productivity, loss of traditional economic processes, depopulation
Indirect: loss of cultural practices and communal rituals, loss of traditional economic processes and land uses

Figure 38 Heat wave on CNH at territorial level

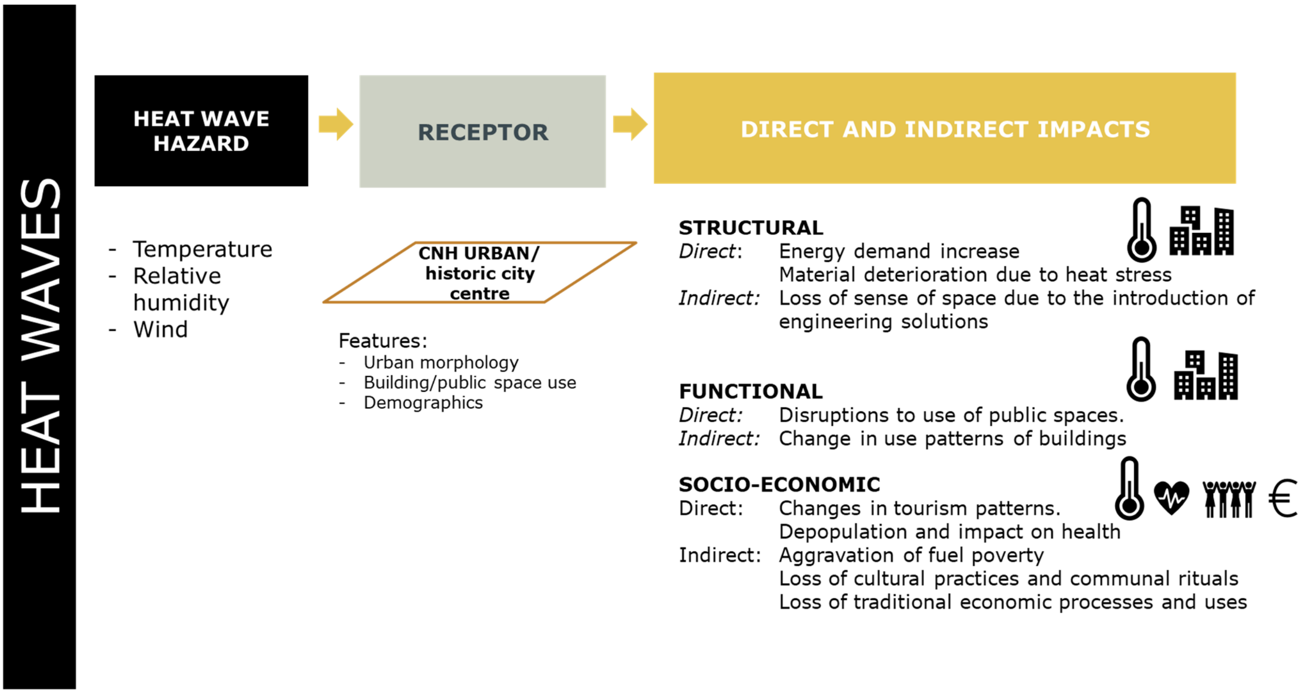
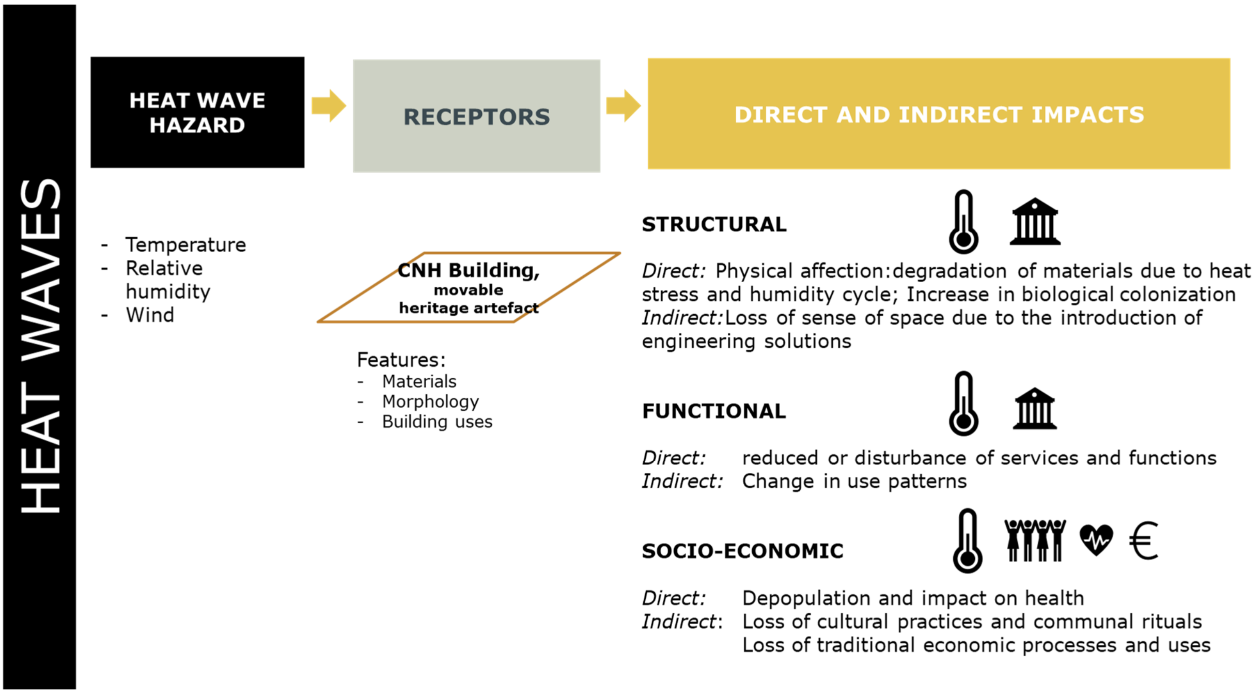

HEAT WAVES
HEAT WAVE HAZARD
RECEPTOR
DIRECT AND INDIRECT IMPACTS
- Temperature
- Relative humidity
- Wind
CNH URBAN/ historic city centre
Features:
- Urban morphology
- Building/public space use
- Demographics
STRUCTURAL
Direct: Energy demand increase
Material deterioration due to heat stress
Indirect: Loss of sense of space due to the introduction of engineering solutions
FUNCTIONAL
Direct: Disruptions to use of public spaces.
Indirect: Change in use patterns of buildings
SOCIO-ECONOMIC
Direct: Changes in tourism patterns.
Depopulation and impact on health
Indirect: Aggravation of fuel poverty
Loss of cultural practices and communal rituals
Loss of traditional economic processes and uses
€

Figure 39 Heat wave on CNH at urban scale and historic city centre


HEAT WAVES
HEAT WAVE HAZARD
RECEPTORS
DIRECT AND INDIRECT IMPACTS
- Temperature
- Relative humidity
- Wind
CNH Building, movable heritage artefact
Features:
- Materials
- Morphology
- Building uses
STRUCTURAL
FUNCTIONAL
SOCIO-ECONOMIC

Direct: Physical affection:degradation of materials due to heat stress and humidity cycle; Increase in biological colonization
Indirect: Loss of sense of space due to the introduction of engineering solutions

Direct: reduced or disturbance of services and functions
Indirect: Change in use patterns

Direct: Depopulation and impact on health
Indirect: Loss of cultural practices and communal rituals
Loss of traditional economic processes and uses

Figure 40 Heat wave on CNH at building level, mobile hertage and artefact level.

Common minimum information

Copernicus does offer the common minimum information to be used for heat wave characterization.

One of the most useful and meaningful information for the assessment of heat waves is the Land surface temperature maps**.** Using data from 3 geostationary satellite missions Copernicus Global Land component of the Land Service (CGLS)[91] provides global estimates of Land Surface Temperature, updated hourly. By comparing temperatures with the 2010-2018 reference period, CGLS can visualise anomalies in daily figures.

Figure 41 shows a land surface temperature map provided by Copernicus sentinel.

---

[91] https://land.copernicus.eu/global/products/lst

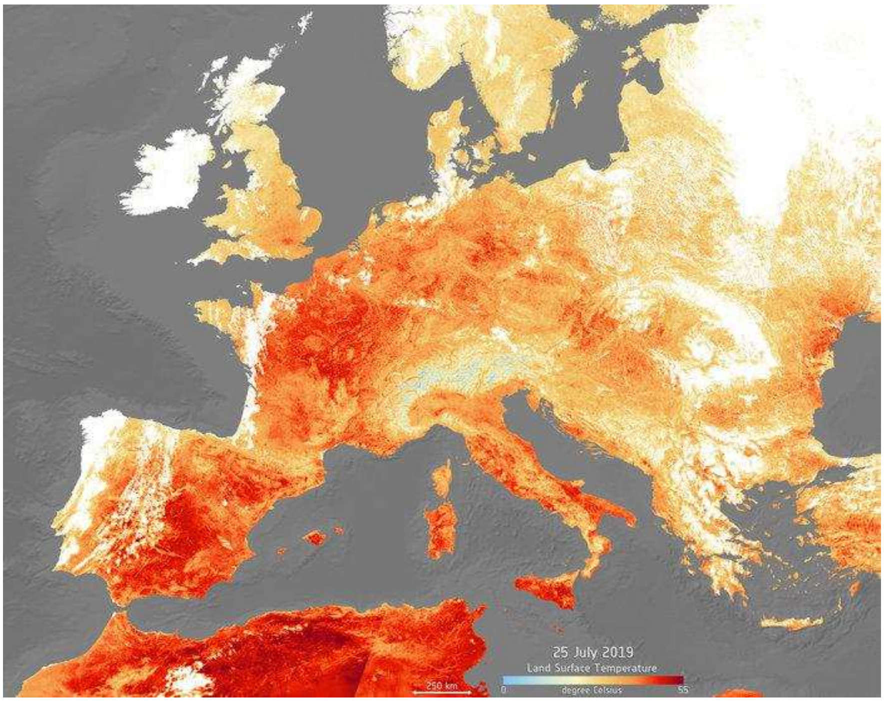


Figure 41 Land surface temperature map. Copernicus sentinel.

Copernicus does also provide data on Air Temperature which is a very relevant variable for heat wave characterization.[92]

The Heat and Cold Wave Index (HCWI) that is implemented in the Copernicus European Drought Observatory (EDO) (see Figure 42) is used to detect and monitor periods of extreme-temperature anomalies (i.e. heat and cold waves) that can have strong impacts on human activities and health. The HCWI indicator is computed for each location (grid-cell), using the methodology developed by Lavaysse et al. (2018), based on the persistence for at least three consecutive days of events with both daily minimum and maximum temperatures (Tmin and Tmax) above the 90th percentile daily threshold (for heat waves) orbelow the 10th percentile daily threshold (for cold waves). For each location, the daily thresholdvaluesfor Tmin and Tmaxare derived froma 30-year climatological baseline period (1981-2010), using the JRC's MARS AGRI4CAST database of daily meteorological observations.

---

[92] https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-urban-climate-cities?tab=overview

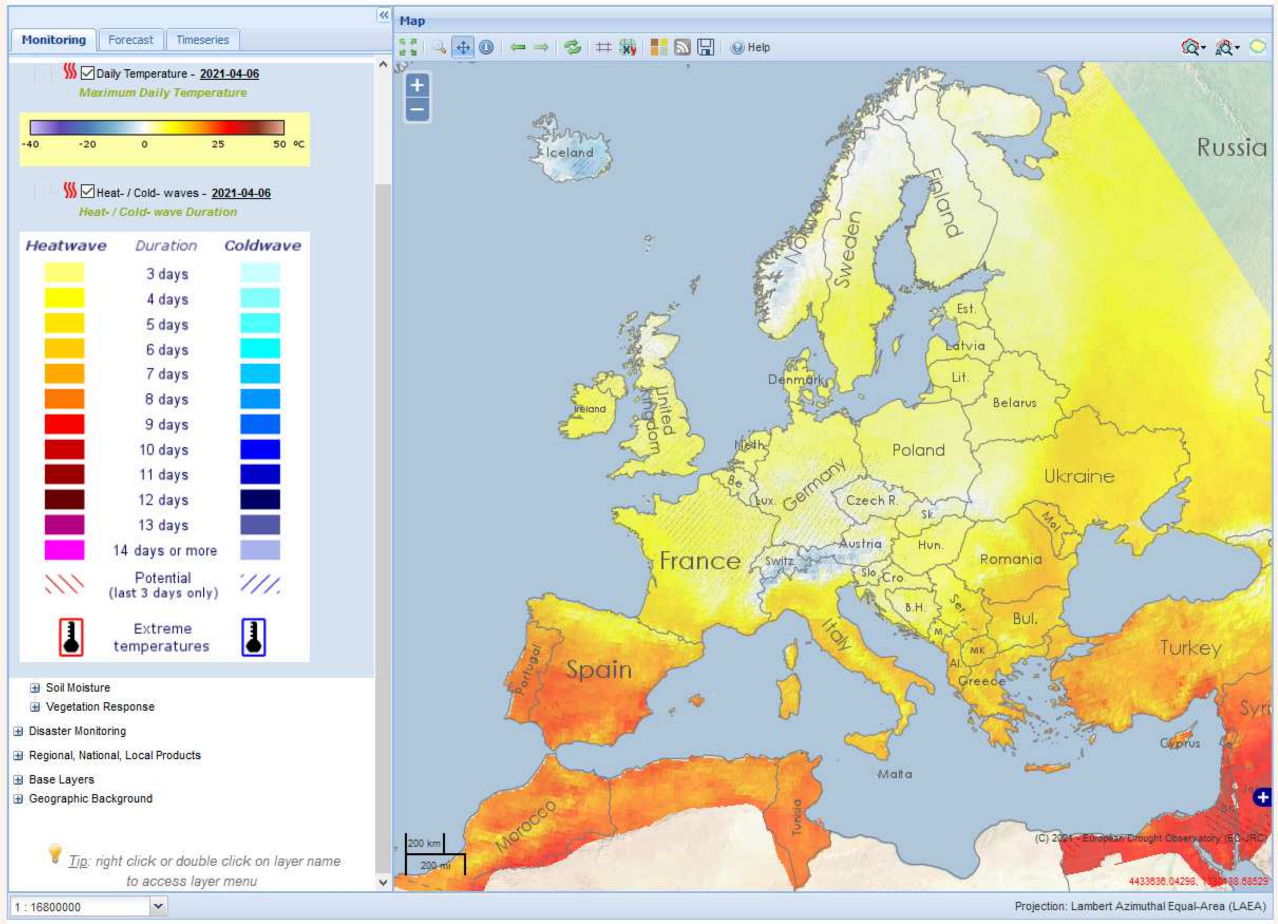

Monitoring
Forecast
Timeseries
☑ Daily Temperature - 2021-04-06
Maximum Daily Temperature
-40
-20
0
25
50 ºC
☑ Heat- / Cold- waves - 2021-04-06
Heat- / Cold- wave Duration
Heatwave
Duration
Coldwave
3 days
4 days
5 days
6 days
7 days
8 days
9 days
10 days
11 days
12 days
13 days
14 days or more
Potential (last 3 days only)
Extreme temperatures
Soil Moisture
Vegetation Response
Disaster Monitoring
Regional, National, Local Products
Base Layers
Geographic Background
Tip: right click or double click on layer name to access layer menu
1 : 16800000
Map
Help
Iceland
Russia
Finland
Norway
Sweden
Est.
Latvia
Lit.
Belarus
Denmark
Ireland
United Kingdom
Neth.
Poland
Ukraine
Be.
Lux.
Germany
Czech R.
Sk.
Mol.
France
Switz.
Austria
Hun.
Romania
Slo.
Cro.
B.H.
Ser.
Bul.
Italy
M.
MK
Al.
Greece
Turkey
Spain
Portugal
Syri
Cyprus
Malta
Tunisia
Morocco
200 km
200 mi
(C) 2021 - European Drought Observatory (EDO-JRC)
Projection: Lambert Azimuthal Equal-Area (LAEA)

Figure 42 Copernicus European Drought Observatory (EDO)[93]

Climate Adapt platform by the EEA does have an online interactive visor for accessing data for heat stress in Europe (see Figure 43).

---

[93] https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1111

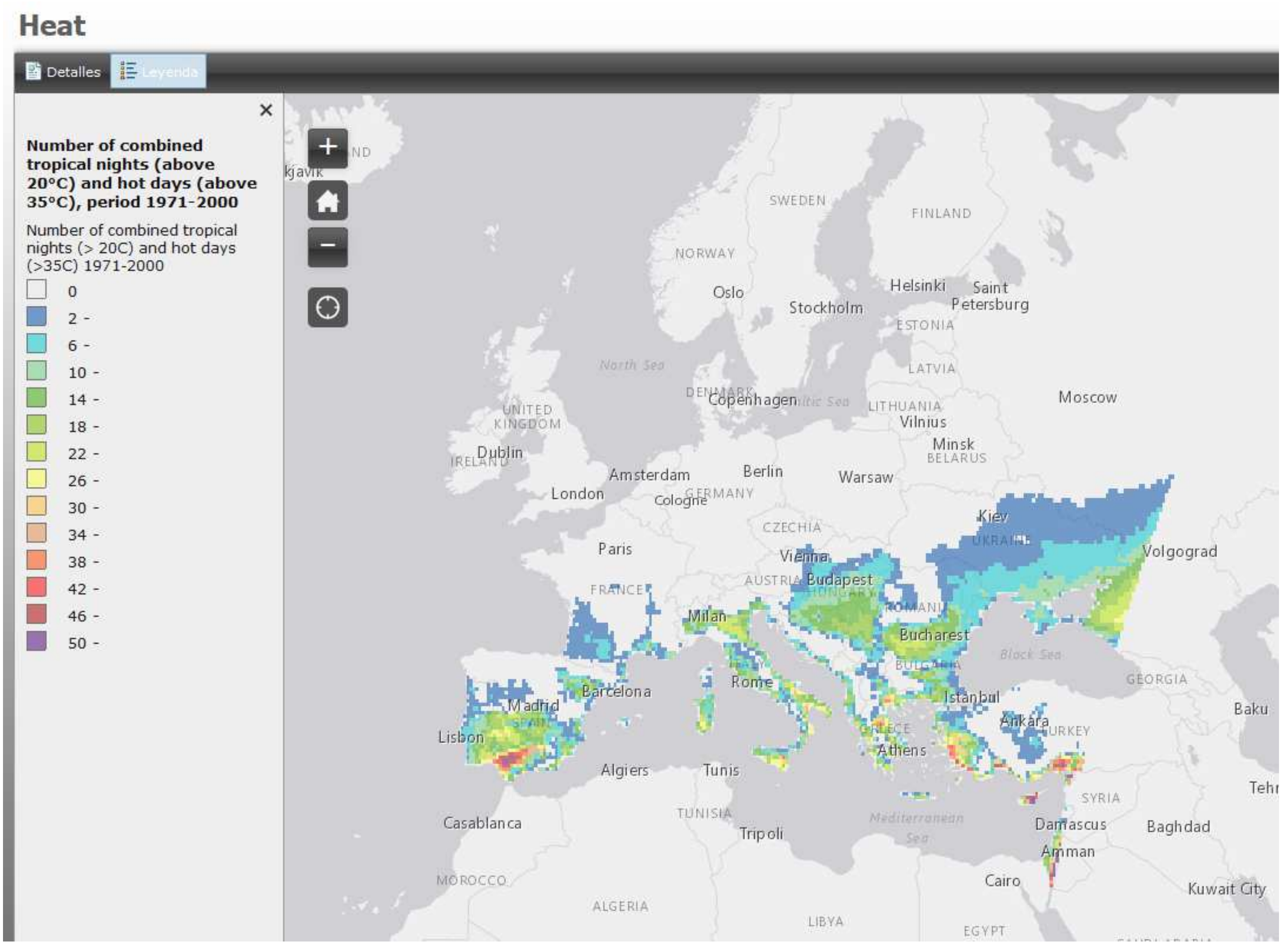

Heat
Detalles
Leyenda
Number of combined tropical nights (above 20°C) and hot days (above 35°C), period 1971-2000
Number of combined tropical nights (> 20C) and hot days (>35C) 1971-2000
0
2 -
6 -
10 -
14 -
18 -
22 -
26 -
30 -
34 -
38 -
42 -
46 -
50 -
SWEDEN
FINLAND
NORWAY
Oslo
Stockholm
Helsinki
Saint Petersburg
ESTONIA
LATVIA
North Sea
DENMARK
Copenhagen
LITHUANIA
Vilnius
Moscow
UNITED KINGDOM
Dublin
IRELAND
Minsk
BELARUS
Amsterdam
Berlin
Warsaw
London
Cologne
GERMANY
Kiev
UKRAINE
CZECHIA
Paris
Vienna
Volgograd
AUSTRIA
Budapest
HUNGARY
FRANCE
ROMANIA
Milan
Bucharest
Black Sea
BULGARIA
GEORGIA
Rome
Barcelona
Istanbul
Baku
Madrid
SPAIN
Ankara
TURKEY
Lisbon
GREECE
Athens
Algiers
Tunis
Tehr
SYRIA
TUNISIA
Mediterranean Sea
Casablanca
Tripoli
Damascus
Baghdad
Amman
Cairo
Kuwait City
MOROCCO
ALGERIA
LIBYA
EGYPT

Figure 43 Climate **ADAPT data** for heat stress in Europe (2019)[94]

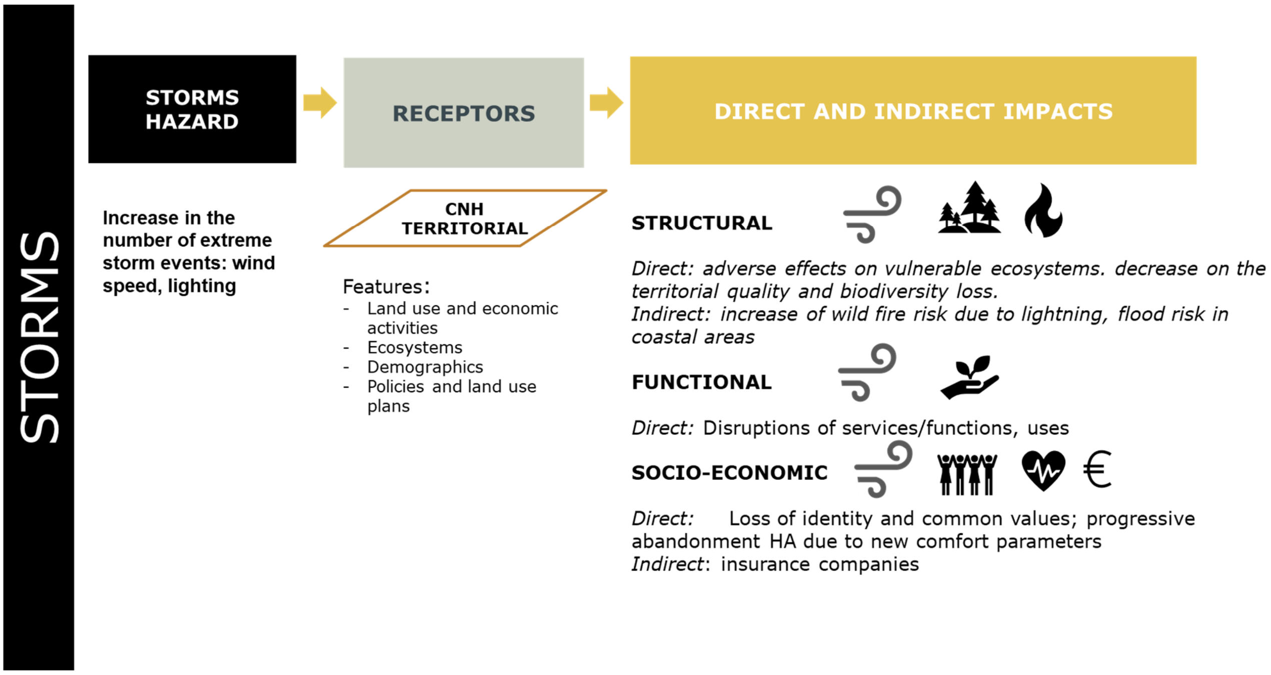
---

[94] https://maps.eea.europa.eu/EEABasicviewer/v4/?appid=e6f0c5adad4d445684c48312dbce2331&webmap=7c91ec6aa2c2445a9a1684f54391f6a3&embed=false

8.7. Storms

A terrestrial storm is an extreme weather condition, a violent disturbance of the atmosphere with strong winds measuring 10 or higher on the Beaufort scale[95], meaning a wind speed of 24.5 m/s, which is 89 km/h or 55 mph or more.

Following the approach for building impact chains in SHELTER project structured in three level of CNH and for the three types of vulnerabilities to be assessed in the risk assessment, three impact chains have elaborated for storms that are shown in Figure 44, Figure 45 and Figure 46 below.



Increase in the number of extreme storm events: wind speed, lighting

Features:
- Land use and economic activities
- Ecosystems
- Demographics
- Policies and land use plans

Direct: adverse effects on vulnerable ecosystems. decrease on the territorial quality and biodiversity loss.
Indirect: increase of wild fire risk due to lightning, flood risk in coastal areas

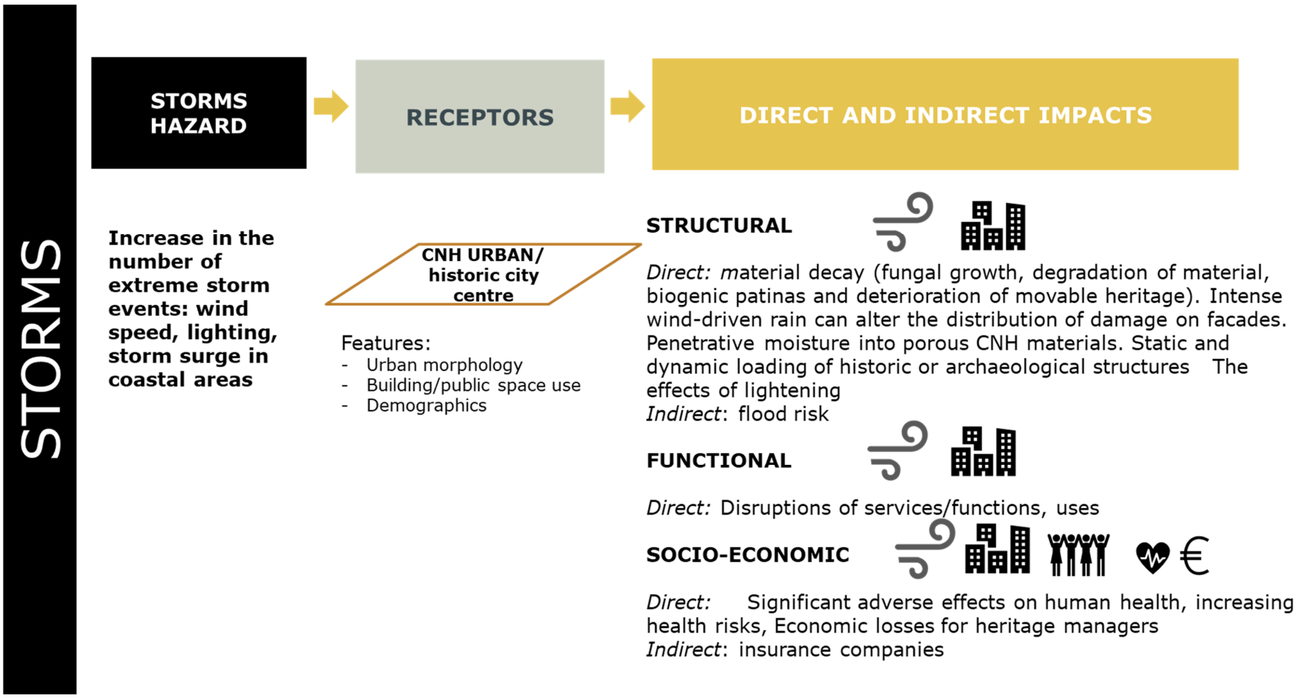
Direct: Disruptions of services/functions, uses

Direct: Loss of identity and common values; progressive abandonment HA due to new comfort parameters
Indirect: insurance companies

Figure 44 Storms on CNH at territorial level

---

[95] https://www.rmets.org/resource/beaufort-scale



STORMS

STORMS HAZARD → **RECEPTORS** → **DIRECT AND INDIRECT IMPACTS**

Increase in the number of extreme storm events: wind speed, lighting, storm surge in coastal areas

CNH URBAN/ historic city centre

Features:
- Urban morphology
- Building/public space use
- Demographics

STRUCTURAL

Direct: material decay (fungal growth, degradation of material, biogenic patinas and deterioration of movable heritage). Intense wind-driven rain can alter the distribution of damage on facades. Penetrative moisture into porous CNH materials. Static and dynamic loading of historic or archaeological structures The effects of lightening
Indirect: flood risk

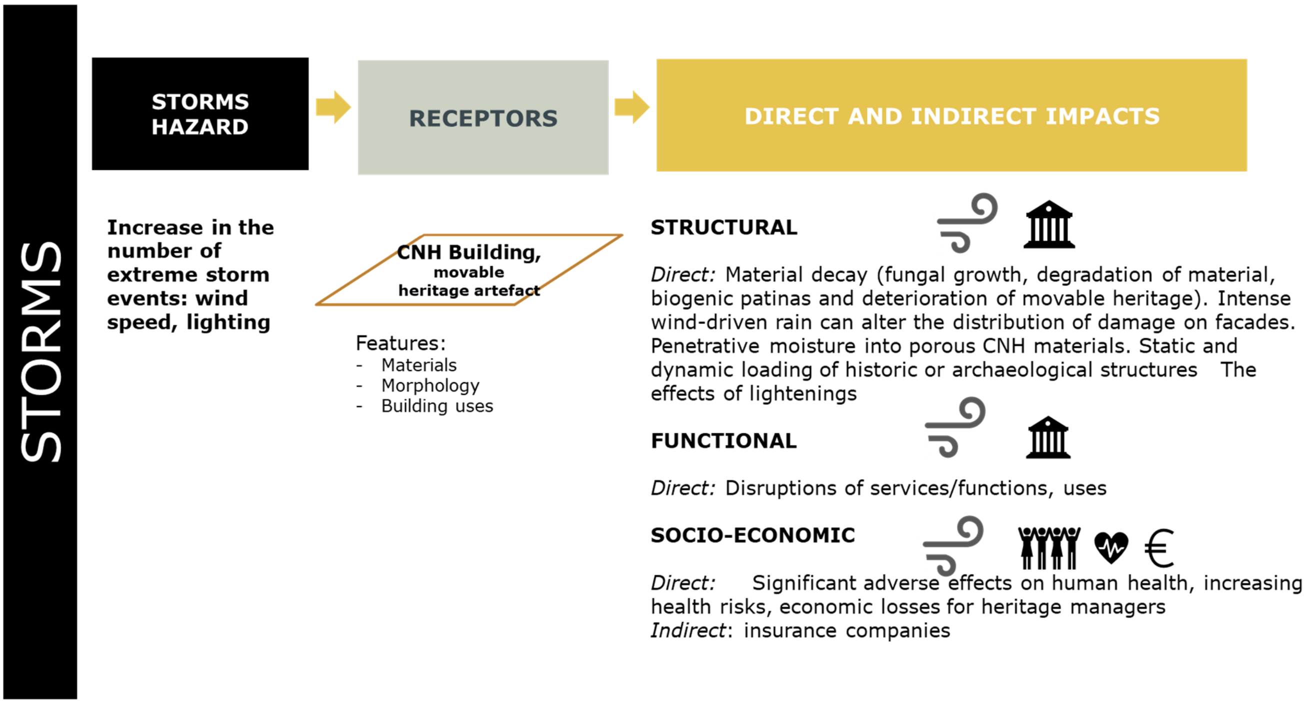
FUNCTIONAL

Direct: Disruptions of services/functions, uses

SOCIO-ECONOMIC €

Direct: Significant adverse effects on human health, increasing health risks, Economic losses for heritage managers
Indirect: insurance companies

Figure 45 Storms on CNH at urban and historic city centre scale



STORMS

STORMS HAZARD → **RECEPTORS** → **DIRECT AND INDIRECT IMPACTS**

Increase in the number of extreme storm events: wind speed, lighting

CNH Building, movable heritage artefact

Features:
- Materials
- Morphology
- Building uses

STRUCTURAL

Direct: Material decay (fungal growth, degradation of material, biogenic patinas and deterioration of movable heritage). Intense wind-driven rain can alter the distribution of damage on facades. Penetrative moisture into porous CNH materials. Static and dynamic loading of historic or archaeological structures The effects of lightenings

FUNCTIONAL

Direct: Disruptions of services/functions, uses

SOCIO-ECONOMIC €

Direct: Significant adverse effects on human health, increasing health risks, economic losses for heritage managers
Indirect: insurance companies

Figure 46 Storms on CNH at building, artefact and site level

Appendix 2 includes a detailed impact chain on storms.

Common minimum information

The EEA provides information on windstorms data. The EEA provides information on changes in extreme wind speed (98th percentile of daily maximum wind speed) based on Global Climate Models (GCM)r and Regional Climate Models (RCM) ensemble ([3] Donat et al. , 2011). It has a resolution of 25 x 25 km for the period up to 2100 for most Europe. The data is accessible on official request to https://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment

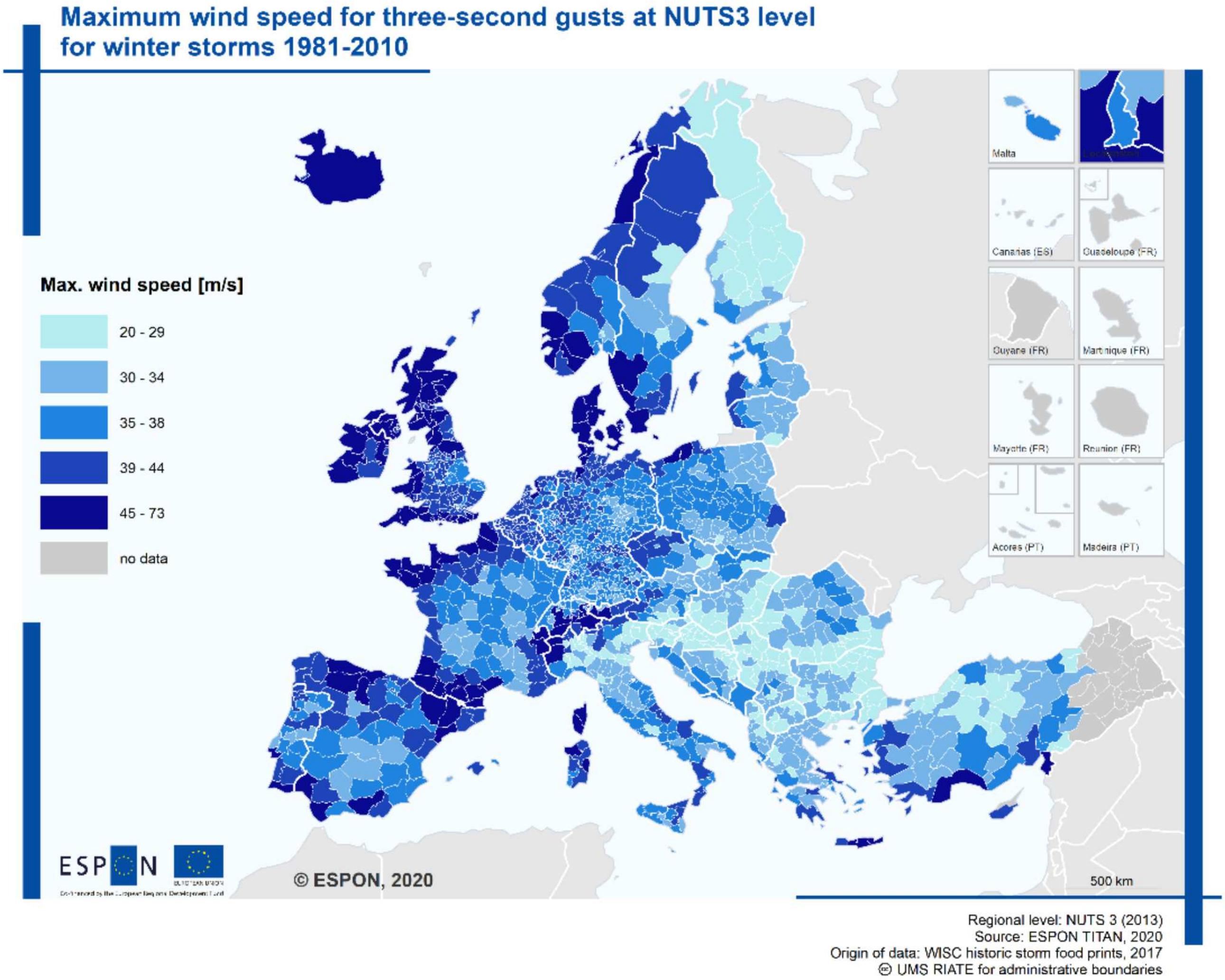
The ESPON TITAN project used the data provided by the WISC Project[96] to map the maximum 3-second gust speeds over a 72-hour period for significant winter storms between 1940 and 2014. This indicator has a resolution of 4 x 4 km, for the period 1950-2016. Includes most Europe but does not include oversea areas, Acores, Madeira, Canarias. The data is available on request at https://wisc.climate.copernicus.eu/wisc/#/help/products#footprint_download.

According to Map 6 areas most affected by windstorms are coastal regions of the North Sea and exposed coastal areas of the Baltic Sea. Further affected are some specific coastal areas of the Mediterranean region by local windstorm patterns, as well the mountain regions of the Pyrenees and the Alps. The storm hazard map shows maximum 3-second gust speeds (m/s) over a 72-hour period for winter storms in the years 1981-2010 at NUTS3.

As a general observation, this implies that particularly coastal areas must take this hazard into account in planning systems, along with rising sea levels caused by climate change even more so. A combined river and storm surge analysis for coastal areas could provide additional insight.

---

[96] https://wisc.climate.copernicus.eu/wisc/#/


Maximum wind speed for three-second gusts at NUTS3 level
for winter storms 1981-2010
Max. wind speed [m/s]
20 - 29
30 - 34
35 - 38
39 - 44
45 - 73
no data
Malta
Canarias (ES)
Guadeloupe (FR)
Guyane (FR)
Martinique (FR)
Mayotte (FR)
Reunion (FR)
Acores (PT)
Madeira (PT)
ESPON
© ESPON, 2020
500 km
Regional level: NUTS 3 (2013)
Source: ESPON TITAN, 2020
Origin of data: WISC historic storm food prints, 2017
© UMS RIATE for administrative boundaries

Map 6 Storm hazard map (maximum wind speed for three-second gust at Nomenclature of Territorial Units for Statistics (NUTS)3, 1981-2010) ESPON TITAN. Origin of data C3S Operational Windstorm Service.[97]

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[97] https://wisc.climate.copernicus.eu/wisc/#/

9. Overarching themes in SHELTER project

9.1. Climate change scenarios, projections and time horizons considered in SHELTER project

In SHELTER project, all hazards considered, but earthquakes, are climate-related physical events. Therefore, developing an understanding of current and potential future hazards in a climate change context is an important element of adapting and building resilience for CNH.

Several themes are central to understanding how risks associated with progressive changes and extreme weather due to climate change arise. Multiple interacting socio-economic and biophysical drivers of change impact on and shape territories, particularly cities, and will continue to do so. Climate change is one such driver. Related hazards and longer-term shifts in the climate including floods, droughts and heat waves generate physical (e.g. damage to infrastructure) and socio-economic (e.g. loss of business revenue) impacts. Although extreme events are of particular concern due to the magnitude of impacts, they can generate ([9] IPCC, 2012), incremental changes to the climate or a sequence of less severe events can nevertheless pose major challenges territories. The importance of extreme events is addressed in Section 8 of the present deliverable report.

9.1.1. What are climate scenarios?

The assessment of future hazard frequency and intensity/severity can be informed by the consideration of climate change scenarios, such as those prepared by the IPCC.

Climate change scenarios highlight that different climate futures (and therefore hazard patterns and intensities) are possible depending on factors including greenhouse gas emissions.

A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change ([11] IPCC,2014).

Projections on the future frequency and intensity of weather and climate hazards depend on the greenhouse gas emissions scenario selected. However, because it is not possible to determine emissions trajectories, it is also not clear as to the precise nature of future weather and climate hazards.

Different climate models produce different climate variable and hazard projections, even when using the same underlying emissions scenario.

- In some cases, due to factors including uncertainty in climate projections and a lack of spatially refined climate model outputs, it may not be possible to give a clear and unambiguous picture of future climate hazards for a particular area and territory.

– Detailed analysis of hazard could allow a better informed, and science-based decisions regarding the definition of adaptation measures and resilience strategies and actions. However, some responses can be also developed to reduce exposure and vulnerability to hazards, by applying assumptions based on qualitative approaches, local knowledge, expert knowledge relying on data available.

9.1.2. What are the RCPs?

RCP stands for Representative Concentration Pathway. To understand how the climate may change in future, it is needed to predict how humanity will behave. For example, will we continue to burn fossil fuels at an ever-increasing rate, or will we shift towards renewable energy.

The RCPs try to capture these future trends. They make predictions of how concentrations of greenhouse gases in the atmosphere will change in future because of human activities.

RCPs were used in the Fifth Assessment Report of the IPCC in 2014 as a basis for the report’s findings.

Previous IPCC assessment reports used a set of scenarios known as SRES (Special Report on Emissions Scenarios), which start with socioeconomic circumstances from which emissions trajectories and climate impacts are projected. In contrast, RCPs fix the emissions trajectory and resultant radiative forcing rather than the socioeconomic circumstances.

The four RCPs range from very high (RCP8.5) through to very low (RCP2.6) future concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0 and 8.5) refer to the concentrations in 2100. See **Figure 48**

2 °C increase in temperature is recognised as the threshold at which climate change becomes dangerous.

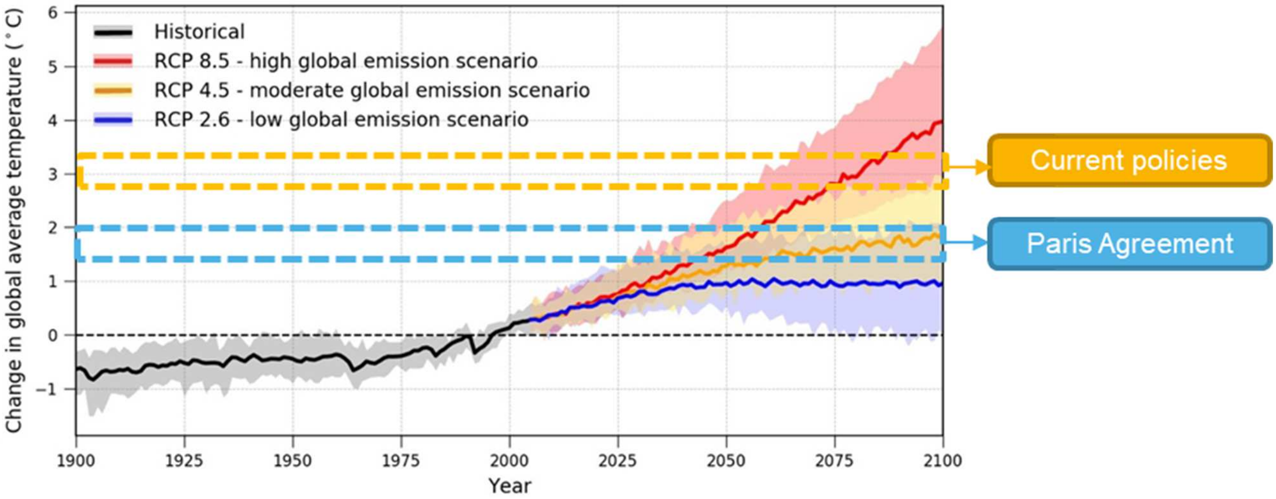
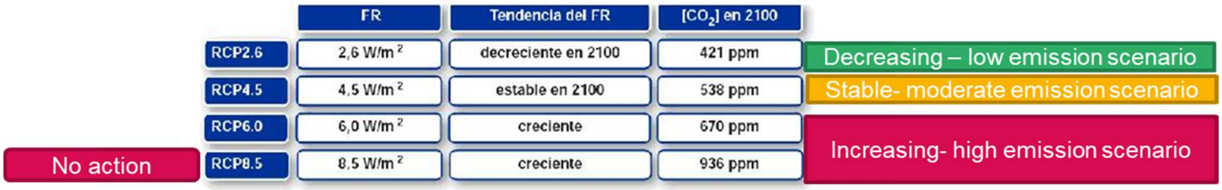


Figure 47 Change in global average temperature from 1900 to 2100 considering historical data evolution and the RCPs 2.6, 4.5 and 8.5.



		FR	Tendencia del FR	$[CO_2]$ en 2100	
	RCP2.6	2,6 W/m ^{2}	decreciente en 2100	421 ppm	Decreasing – low emission scenario
	RCP4.5	4,5 W/m ^{2}	estable en 2100	538 ppm	Stable- moderate emission scenario
	RCP6.0	6,0 W/m ^{2}	creciente	670 ppm	Increasing- high emission scenario
No action	RCP8.5	8,5 W/m ^{2}	creciente	936 ppm	

Figure 48 RCPs according to AR5 of the IPCC

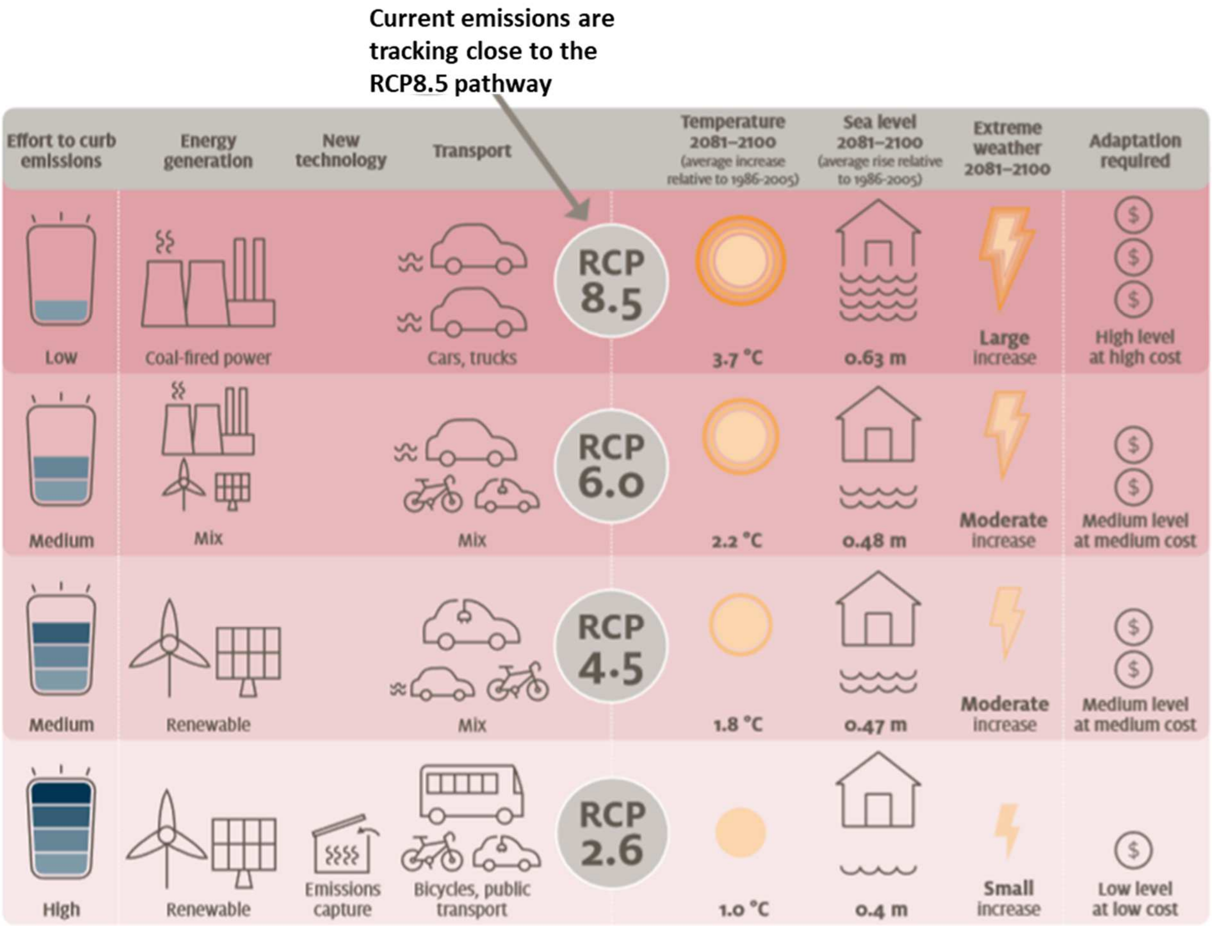

Current emissions are tracking close to the RCP8.5 pathway
Effort to curb emissions
Energy generation
New technology
Transport
Temperature 2081–2100 (average increase relative to 1986-2005)
Sea level 2081–2100 (average rise relative to 1986-2005)
Extreme weather 2081–2100
Adaptation required
RCP 8.5
Low
Coal-fired power
Cars, trucks
3.7 °C
0.63 m
Large increase
High level at high cost
RCP 6.0
Medium
Mix
Mix
2.2 °C
0.48 m
Moderate increase
Medium level at medium cost
RCP 4.5
Medium
Renewable
Mix
1.8 °C
0.47 m
Moderate increase
Medium level at medium cost
RCP 2.6
High
Renewable
Emissions capture
Bicycles, public transport
1.0 °C
0.4 m
Small increase
Low level at low cost

Figure 49 Summary of RCPs pathways[98]

We can use the RCPs to plan for the future in the near future (2011-2040), mid-range century (2041-2070) and late century (2071- 2100) (see Figure 50). Scientists use the RCPs to model climate change and build scenarios about the impacts. You can use these scenarios to plan for the future. RCP 8.5 leads to much greater temperature increases, and this means greater impacts and greater costs. To adapt to these changes will also cost more. A balance must be struck between the cost of impacts and the cost of adaptation.

In Europe the EEA, Copernicus programme works with RCP 4.5 & 8.5.

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[98] https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-01-UPLOADED-WEB%2827Feb%29.pdf

9.1.3. Which climate scenario will SHELTER Project adopt?

Considering the natural hazards analysed in SHELTER and the CNH exposed, we are suggesting the following climate scenarios and time horizons.

In relation to climate scenarios and RCPs:

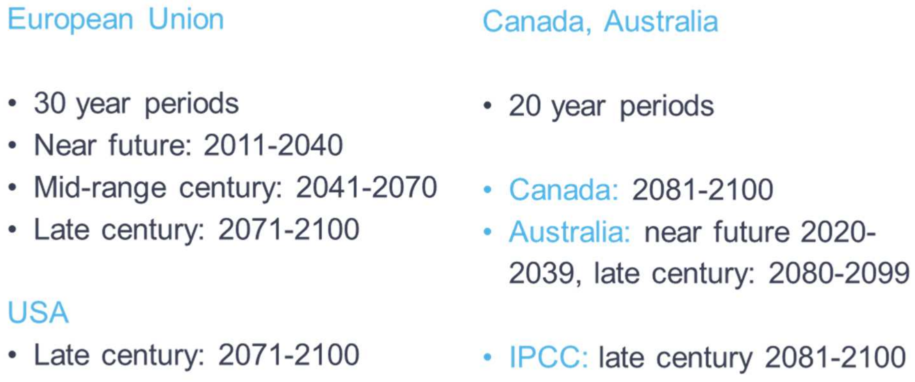
- RCP 8.5 (mandatory)
- RCP 4.5 (optional if resources available)

In relation to the time periods for the climate scenarios

- 30-year periods
- Near future: 2011-2040 (optional if resources available)
- Mid-range century: 2041-2070
- Late century: 2071-2100

Using climate scenarios and RCPs as well as time periods for near future, mid-range century and late century, would help harmonising the SHELTER project's results so that they may be comparable and to align them with the EU regular working procedures.

The **Figure 50** shows the periods more commonly used.



European Union

- 30 year periods
- Near future: 2011-2040
- Mid-range century: 2041-2070
- Late century: 2071-2100

USA

- Late century: 2071-2100

Canada, Australia

- 20 year periods

- Canada: 2081-2100
- Australia: near future 2020-2039, late century: 2080-2099

- IPCC: late century 2081-2100

Figure 50 EU & worldwide use of time periods[99]

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[99] https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

9.1.4. Summary of Copernicus Climate Change Service in Europe

The Copernicus Climate Change Service (C3S) supports adaptation and mitigation policies of the European Union by providing consistent and authoritative information about climate change. C3S offers free and open access to climate data and tools based on the best available science.

C3S is one of the six thematic information services provided by the Copernicus Earth Observation Programme of the European Union. Copernicus is an operational programme building on existing research infrastructures and knowledge available in Europe and elsewhere. C3S relies on climate research carried out within the World Climate Research Programme (WCRP) and responds to user requirements defined by the Global Climate Observing System (GCOS). C3S provides an important resource to the Global Framework for Climate Services (GFCS).

	Copernicus Climate Change Service Europe C3S
Data	• **Climate Reanalysis:** Climate reanalyses combine past observations with models to generate consistent time series of multiple climate variables. Reanalyses are among the most-used datasets in the geophysical sciences. They provide a comprehensive description of the observed climate as it has evolved during recent decades, on 3D grids at sub-daily intervals. • **Observations** • **Seasonal Forecasts** • **Sectorial indicators: River flow, Wind Capacity Factor, etc.** • **Long term climate projections** (WCRP Coupled Model Intercomparison Project Phase 5 CMIP5).
Maximum resolution	***Projections: 11*11 km (except some variables)*** ***Reanalysis ERA5-LAND (9km) or ERA5 (25 km)***
Variables	***Many. All those that are originally in CMIP5 (radiation, albedo, etc.)***
Indicators	***No***
Processing capacity	***Yes. Toolbox based on Python allows to generate "tailor-made" maps, graphs, etc.***
Data format	***netCDF/ GRIB***

Table 7 Summary of data offered by the Copernicus Climate Change Service C3S

Climate reanalyses combine past observations with models to generate consistent time series of multiple climate variables. Reanalyses are among the most-used datasets in the geophysical sciences.

	Copernicus Climate Change Service C3S		
Dataset	**ERA5**[100] is the latest climate reanalysis produced by ECMWF, providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty.	**ERA5-Land**[101] is a global land-surface dataset at 9 km resolution, consistent with atmospheric data from the ERA5 reanalysis from 1950 onward	For Europe regional reanalysis data for the European domain are provided to C3S by the Swedish Meteorological and Hydrological Institute (SMHI). Initially based on developments in the **FP7 UERRA project**[102], reanalysis data from 1961 to 2019 at 11 km horizontal resolution are available in the Climate Data Store. A new regional reanalysis system for Europe is currently being developed that will provide improved data at 5.5 km resolution by mid-2021.
Horizontal resolution	0.25°x0.25°	0,1°x 0,1° (9*9 km. Native)	5*5 km
Spatial Coverage	Global	Global	Europe
Variables	Many	Many, (e.g. soil temperature and water)	Temp, wind, HR, cloud, etc. But focused on precipitation
Temporal resolution/ climatology	Hourly data	Hourly data	Hourly data
Temporal coverage	1979-present	2001-present	1969-present

Table 8 Summary of the different reanalysis of climate and meteorological information offered in Copernicus Climate Change Service C3S

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[100] ERA5 hourly data on pressure levels from 1979 to present (copernicus.eu)
[101] C3S releases first instalment of ERA5-Land dataset for land-based studies and applications | Copernicus
[102] UERRA - Home

9.2. Importance of extreme events

The importance of the extreme events for natural hazards characterization has been argued all along this deliverable report.

This subsection provides a more detailed overview of the consideration of extreme events that builds on a depth review of the special report of the IPCC Managing the risks of extreme events and disasters to advance climate change adaptation, published in 2012. In the chapter 3 of that IPCC report, the authors address the changes in climate extremes and their impact on the natural physical environment. *S*everal observed and projected weather and climate extremes and expected impacts on the natural physical environment are analysed. The results of the analysis are scored against some attributes like confidence, low or medium confidence, likelihood and reference to available evidence.

The main findings of the IPCC report related to extreme events are summarized below:

- Temperature ([9] IPCC 2012: 133ff):
  Especially temperature is associated with extremes like heat waves and cold spells with huge impacts (e.g. increase health risk – social dimension, increase energy consumption – economical dimension). One result of the analysis is that there is an overall decrease of cold days and nights and an increase of warm days and nights on a global scale since 1950.

- Precipitation ([9] IPCC 2012: 141ff):
  Heavy precipitations may have huge impacts to infrastructures and cause flooding, crop failures or interruptions of lifelines (i.e. telecommunication, energy transportation). For the analysis the authors used the relative threshold as well as the absolute threshold of daily precipitation. There was also no difference between the trigger (rain or snowfall) of precipitation. One result is that there are more regions with increased heavy precipitation events than with decreased ones. Seasonal distinctions show that for Europe the trends are more consistent in wintertime than in summertime. For North America the trend is increasing. Unfortunately, there is no literature available to derive trends for hail events so far.

- Wind ([9] IPCC 2012: 149ff):
  Extreme wind events have negative impact to human safety, aviation, maritime transport and the integrity of infrastructures. Coastal sea levels can elevate due to wind events. Additionally, due to wind the wave climate can change and have a negative impact on coastline stability. Aeolian processes can change the surface of territorial over a longer period of time. Currently, there are less reports and data available so there are no clear trends to be identified so far. A trend for tropical cyclones was identified in the sense that there is an increase in mean tropical cyclone wind speed as well as that the frequency of the most intense storms will increase in some specific ocean areas. Especially in wintertime the risk increases for winter storms in some European regions.

In addition, the main findings of the IPCC report related to impacts on the natural physical environment are summarized below:

- Droughts ([9] IPCC 2012: 167ff):
  A drought is defined as *"a period of abnormally dry weather long enough to cause a serious hydrological imbalance ".* (IPCC 2012: 167)
  Less precipitation is the main trigger for droughts but there are also other reasons identified like increased potential evapotranspiration, wind speed or vapor pressure deficit. Unfortunately, there are less drought-related variables available. A drought has huge impacts to crop yields, availability of water, production of energy as well as to the general functioning of the ecosystem. A result of the analysis is that some regions of the world, especially in southern Europe and West Africa, there is a trend to more and longer droughts since 1950. Contrary to central North America and North-Western Australia with less intense, less frequency and less duration of droughts having been identified.

- Floods ([9] IPCC 2012: 175ff):
  A flood is defined as the overflowing of the normal confines of a stream or other bodies of water, or the accumulation of water over areas that are normally not submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods. (IPCC 2012: 175)
  Precipitation (long-lasting and or intense), snow and/or ice melt, suddenly dam break (e.g. glacial lake) or an intense local storm with heavy rainfall are amongst others trigger for floods. There are a lot of parameters of precipitation identified, which are relevant to increase the impact of a flood like intensity, duration, timing and phase. In addition, there are parameters identified like soil character and status, water levels, river basins, rate and timing of snow melting, urbanization as well as the existence of dams, dikes and reservoirs. The characteristics of floods are affected by climate change induced changes in parameters.
  Unfortunately, the availability of data is weak due to limited instrumental records at gauge stations. Therefore, there is just a medium evidence climate-driven changes in the magnitude and frequency of floods.

- Extreme Sea Levels ([9] IPCC 2012: 178ff):
  Severe weather events are – amongst tectonic events like tsunamis – the reasons for extreme sea levels. Storm surges are induced by strong winds and quick drop in atmospheric pressure. Another reason may be the rise of main sea level taking the long perspective into account. The result of the analysis is that the trend of mean sea level will rise. The coastal effects are combined with the rise of the sea level rather than storm events. An anthropogenic influence on increasing extreme coastal high-water levels via mean sea level contributions is identified as likely.

- Coastal Impacts ([9] IPCC 2012: 182ff):
  Especially in context of risk management coastal hazards like erosion and flooding may be influenced in long term by climate change. Tropical and extratropical

cyclones are the most common causes for high water sea levels. There is little confidence that anthropogenic climate change has been a major negative cause on coastlines due to limited evidence. On the other side there is solid evidence that the vulnerability of low coastlines is high due to rising sea levels and erosion.

- High-latitude Changes Including Permafrost ([9] IPCC 2012: 189):
  Permafrost is found in Arctic, subarctic and in ice-free areas of Antarctica as well as in high-mountain areas. Melting of permafrost can cause subsidence and change topography. In mountain areas the melting may cause instability of ground. The result of the analysis is that there is likely that days with permafrost temperatures will decrease continuously causing reductions of the area of permafrost in Arctic and subarctic.

- For the analysis of glaciers, geomorphological and geological impacts ([9] IPCC 2012: 186ff) as well as for sand and dust storms ([9] IPCC 2012: 190) the result is that there is still a serious lack of information. Changes in heat waves, permafrost degradation or glacial retreat will likely affect high mountain phenomena. Changes in heavy precipitation will affect landslides in some regions as well.

- Due to the scarcity of studies on waves no relation could be identified during the analysis of waves. So, due to insufficient state of research there is only low confidence that there is an anthropogenic influence on extreme wave heights.

In the IPCC report also reflect on the possibility of the climate becoming more extreme in the future. There are three approaches to answer this question and how to receive the relevant information for further analyses ([9] IPCC 2012: 124):

- Identification of the variation of specific climate variables in a defined area,
- Identification of significant changes in the frequency with which climate variables cross fixed thresholds that have been associated with human or other impacts,
- Identification and analysis of the increase or decrease of economic losses due to extreme events.

9.3. Influence of non-climate stressors and drivers on hazard frequency and intensity

It has already been argued in different sections of the present deliverable report that the consideration of climate variables and associated shifts in temperature and precipitation patterns due to climate change, is a crucial factor underlying potential changes in the severity and frequency of natural hazard events ([7] Feyen et al, 2012)

But it was also argued the importance to acknowledge that non-climate drivers, related to socio-economic issues, will also have a significant influence. Non-climate stressors and socio-economic drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of CNH (services, people/ citizens and infrastructures).

"Future socio-economic developments, such as changes in land use and demography, will play a central role in determining Europe's vulnerability to floods, droughts and water scarcity, with climate change being an additional factor" ([4] EEA 2012: 213)

Including a process to identify the non-climate stressors and drivers that may influence hazard characterization locally, is recognized in as a crucial element of adaptation and resilience planning. Recognizing these drivers could help to select, design and better shape fit-to-purpose and local solutions to build resilience against climate change.

These drivers could be generic, influencing to some extent the characterization of all kind of natural hazards (i.e. awareness, social capital). But more important is to recognize the locally explicit nature of these drivers, key local aspects that better help to comprehend the natural hazards, and in relation to CNH, and this understanding could help also in better shaping and prioritizing the local solutions.

Non-climate stressors and drivers have been structured under the six dimensions of Historic Areas Resilience established in SHELTER project (see **Table 9** below)

→ DIMENSIONS OF HA RESILIENCE		→ EXAMPLES
Historic areas environmental resilience	How the historic building environment addresses disruption, affordable comfort, structural security through traditional techniques, vernacular architecture and built/unbuilt environment relationships and its relevance as container and management unit for other CNH scales (as movable CNH)	Urban morphology, land use patterns and trends, geomorphology, territorial configuration
Cultural resilience	How HA addresses social inclusion and supports social and technical innovation through cultural identity, local knowledge, intangible CNH and openness to exploring novel pathways.	Local identity, local traditional practices
Social resilience	How individual's physical and psychological well-being are addressed within the HA and strong and healthy personal relationships, connection to culture and nature and learning and sharing new skills are enabled.	Social behaviour, social configuration, cohesion, inclusión/exclusion

Governance and institutional resilience	How links and partnerships are created and managed with support networks and across sectors (including public sector/government, research and business)	Policies/ politics (EU, national, regional, local) Sector planning, mechanisms and formal institutional instruments, urban planning, local legislation/regulations, standards, protected figures Governance structures and models
Economic resilience	How the creation of a different sort of local economy can positively stewards the local environment and resources to enhance biodiversity, cut carbon dependence and creates meaningful locally based livelihoods.	Socio-economic development mobility patterns supply/demand trends
Environmental resilience		Ecosystem based approach, environmental status, biodiversity

Table 9 Dimensions of Historic Areas addressed in SHELTER project

9.3.1. Investigating the non-climate stressors and drivers in SHELTER OLs

End-users and stakeholders in the SHELTER project OLs were outreached for contrasting the approach and for gathering information on intrinsic features that may condition hazard characterization locally. In close collaboration with WP3 SHELTER project, an exercise was undertaken in the context of a series of workshops organized for during December 2020 and January 2021. The stakeholders who participated in the working sessions had the chance to reflect on local drivers, conditions and stressors influencing in particular the behaviour, intensity and severity of the most significant natural hazard affecting their region/city context, as a basis to fine-tuned the solutions for increasing CNH resilience.

The main outcomes from the working sessions with OL are summarized in Table 10

→DIMENSIONS OF HA RESILIENCE	→FLUVIAL AND COASTAL FLOODING- DODRECHT
Historic areas environmental resilience	**Urban Morphology:** Channelled and underground water networks; Construction of the streets will increase or decrease risk depending on design; **Geomorphology:** Having a good bathymetry is crucial for modelling river floods and it is very difficult to have good information on that if there is no field work; River gets deeper every year at certain areas, decrease the change of flooding; **Asset/artefact:**

	Flood barriers at the coast protect Dordrecht from heavy flooding
Cultural resilience	Long history of flood management in Dordrecht
Social resilience	**Social behaviour:** Social cohesion within the neighbourhood, people warning and helping each other to prepare. **Demography patterns:** Many older people live in the city centre that is at risk from flooding
Governance and institutional resilience	**Sector planning:** Maintenance of rivers/riverbeds Land use at the upper part of the watershed affects most the fluvial flood Water dam management also plays an important role in fluvial floods Construction requirements for new developments **Urban Planning** In addition to the channels, any infrastructure built close to the river affects in the flood hazard, because they reduce the space to the river. Many older building were built in time of more frequent flooding, and are thus better prepared and designed
Economic resilience	Socio economic development: many CNH is privately owned, people may no longer invest in repairs and recovery, if they don't have perspective of a lower risk
Environmental resilience	Sea Level Rise; Climate change, more heavy rainfall and storm events

→ DIMENSIONS OF HA RESILIENCE	→EARTHQUAKE RAVENNA	→PLUVIAL FLOODING RAVENNA	SUBSIDENCE RAVENNA
Historic areas environmental resilience	**Urban Morphology:** Urban density level and distance between buildings and territorial development **Geomorphology:** Topographic **Asset/artefact:** Construction and structural characteristics Seismic safety level	**Urban Morphology** Level of aquifer Risk connected to the double pumping system, the one inside the area and the external one managed by Hera	**Urban Morphology:** Over-exploitation of groundwater resources for industrial water supply, but also for domestic use in rapidly expanding urban areas.

Cultural resilience	Local knowledge Training Activation of protocols for conservation and seismic adaptation (where possible)	Activation of protocols for the conservation and the control of the effects of a flood event	Activation of protocols for the conservation and the control of the effects of the event
Social resilience	**Social behaviour** Awareness of the seismic hazard Recognition of the heritage value by the community Involvement of associations for collaboration in the emergency phase	**Social behaviour** Involvement of associations to collaborate with in the emergency phase	
Governance and institutional resilience	**Sector planning** Building maintenance Improvement of seismic resistance Activation of protocols for the conservation and the control of the effects of the event National rescue programme under development **Urban Planning** Infrastructure health check and maintenance Assigned gathering spot and strategic buildings (ex. Hospital, parking, gym, etc.) Coordination among institutions based on shared prevention and emergency guideline National and local risk charts **Spatial Planning** Institutional coordination based on shared guide line about prevention and emergency	**Sector planning** Pumps Efficiency of the water pumping system Coordination between institutions Interventions protocols (emergency) Active preventive maintenance **Urban Planning** Permeability and land use Development of an integrated urban water (resources) management strategy Land use	**Sector planning** Active preventive maintenance **Urban Planning** Development of an integrated urban water (resources) management strategy Land use
Economic resilience	**Socio economic development** National Policy related to the quality of built heritage. Research project about	**Socio Economic development** Finding the right compromise in the design of hydraulic works	

	new seismic technologies		
Environmental resilience		Intensive rains due to climate change	

→ DIMENSIONS OF HA RESILIENCE	→WILDFIRES GALICIA
Historic areas environmental resilience	Configuration of the built up areas in the natural park- conditioning the accessibility to the area by the fire extinction brigades Protected area- formal protected figure regulated by law which conditions the land use distribution and land uses allowed in the area. Presence of water collection point for extinguishing Very rich and high valuable territorial
Cultural resilience	**Local identity** sense of belonging Divergencies in the wildfire risk management with Portugal Lack of Environmental and Heritage Education **Traditional practises** Forest management Extensive cattle Agricultural practices (machinery)
Social resilience	**Social behaviour** traditional agroforestry practices and local habits about fire Social capital **Demographic patters** Aging population and population decline within the protected area
Governance and institutional resilience	**Policies (European, National and Regional level)** Transnational conditions (Portugal) Lost of effort of coordination versus the results Data provision for decision making Biomass Management Stripes that are reflected in the current regional legislation **Spatial Planning** Plans of Natural Protection Natural Park Management Plans **Urban Planning** Relevance of the current Local Prevention Plans at municipal scale Poor coordination across the different planning instruments (scale) High level of bureaucracy that creates operational difficulties **Urban planning that are not updated (long term)** Natural Protection figures
Economic resilience	**Socio economic development** Exploitation of forest resources Temporality of the brigades

	Put into value of agrarian lands Communal management mountains Tourism as a determining factor in fire risk management **Demographic patters** Depopulation Mobility patters
Environmental resilience	Ecosystem conditions High value of the ecosystems Quality of environmental drivers Terrain with poor observation capacity Biodiversity High number of endemism's Territorial and soil already damaged which makes even harder the recovery after a wildfire event
→DIMENSIONS OF HA RESILIENCE	**→RIVER FLOODS SAVA**
Historic areas environmental resilience	Having a good bathymetry is crucial for modelling river floods and it is very difficult to have good information on that if there is no field work. In addition to the channels, any infrastructure built close to the river affects in the flood hazard, because they reduce the space to the river Uncontrolled dredging Channelled and underground water networks. In addition to the channels, any infrastructure built close to the river affects in the flood hazard, because they reduce the space to the river Lack of list of basic info about the CNH available and user friendly for fast and appropriate reaction (location, material, dimensions...) Tool to risk assess as well as the technical intervention needed
Cultural resilience	Relevant local knowledge Bad condition of CNH Neglect of cultural heritage Lack of solidarity for importance of resilience strengthening
Social resilience	lack of involvement of crowdsourcing in disaster management Lack of awareness regarding climate change impacts unidentified threat features (mapping) Urban / rural migration Globalisation / migration

Governance and institutional resilience	**Policies** From the point of view of flood defence, regulation of the arrangement of riverbeds for high waters Lack of public awareness about policies **Sector Planning:** Establishment and proper functioning of Early warning system for floods Agroforestry policies Hydro-energy production policies National Spatial Data Infrastructures integration Lack of policies related to dredging planning **Spatial Planning:** Low hazard and risk public awareness: GIS maps **Governance:** Uncoordinated spatial plans with the climate change forecasts Lack of coordination between Water management and institutions dealing with cultural heritage Insufficient coordination and harmonization during spatial planning with the water management sector Better coordination between institutions (related to CNH) on state and regional/local level (bringing the awareness) is needed Disruptions in communication and collaboration between stakeholders Need for procedural changes in DM Digital Literacy lack of standards/Guidance for CNH characterization and planning procedures
Economic resilience	Socio economic development, land use distribution, mobility patterns and demography patterns
Environmental resilience	Spatial data quality assurance Maintenance of rivers/riverbeds Water dam management also plays an important role in fluvial flood Land use at the upper part of the watershed affects most the fluvial flood

Table 10 Summary of non-climate drivers and stressors identified in OL.

The exercise undertaken with the OLs confirmed the theoretical model that was developed by desk research on non-climate drivers and stressors.

Land uses, landscape configuration, geomorphology and urban morphology are identified as a relevant driver influencing most hazards, due to the limited capacity for action and flexibility for defining adaptive solutions.

Social behaviour, awareness and social capital are identified as key drivers also conditioning heritage- led resilience.

Demographic patterns and vulnerability of the population groups and visitors profiles have been also highlighted in the OLs as relevant drivers particularly relevant when assessing social vulnerability.

Governance, spatial planning and sector policies have been also recognized by all OLs as utterly relevant drivers for hazard characterization, including in particular mechanisms (i.e. planning instruments, strategies, early warning systems) for DRR and the way policies deploy specific protocols from an operative point of view.

Financing and investment (i.e. nature conservation, ecosystem restoration, water management, CCA, infrastructures maintenance) influence the opportunities for CNH resilience and have being identified as utterly relevant driver.

10. Conclusions and next steps

The work done under Task 2.4, and materialized in the present report, reveals different uses of the term hazard appear in the literature in different ways by different disciplines which constitutes still a challenge when defining a methodological approach to characterize and assess natural hazards.

In SHELTER project, hazard is understood as a component of the overarching framework for risk assessment. Finding a common methodology for the characterization of all kind of natural hazards is a challenge since we must deal with climate related and non - climate related hazards. The generic approach for hazard characterization suggested by SHELTER project aims at overcoming this challenge. The risk assessment methodology to be developed in T2.5 should be customizable to all addressed hazards.

The literature review did not reveal any major gaps in relation to hazard-related European research of the past 25 years. Basically, all research questions that we raise within SHELTER project have already been addressed in one way or another in past research.

However, when trying to incorporate the climate change dimension, the characterization of each hazard may require applying different methods and modelling tools, particularly for flooding and heat waves, depending on the scale of the analysis. These methods and models could be forced using future climate projections to evaluate how the changes in certain variables (precipitation, temperature, wind, sea level rise) may affect certain hazards. Main shortcomings in research are those related to the evaluation of heat stress, heat waves and urban heat island. In comparison with other hazards, there is only limited research on heat waves.

Characterizing natural hazards requires the consideration of extreme events which are particularly relevant due to their expected devastating consequences on CNH. But the progressive changes of climate variables (i.e. temperature, precipitation, wind) due to climate change are equality relevant since these may also derive into negative impacts on CNH.

Despite the uncertainty linked to climate change projections and scenarios, applying a precautionary principle is very relevant for HA resilience. Uncertainties related to future hazard projections need to be acknowledged. Nevertheless, there is sufficient data available to make an informed judgement of potential future weather and climate hazards facing European areas to support adaptation planning and resilience strategies.

The characterization of HA is utterly relevant, as the key receptor of the potential direct and in-indirect impacts of the natural hazards. Impact chains are used in SHELTER project as a very valuable tool to define the scope of the risk assessment, describing the cause – effect relationships amongst the natural hazards and the potential CNH receptors exposed to such hazards and the expected consequences.

The spatial dimension of the CNH exposed constitutes a key element in the impact chains. In SHELTER, three macro-categories of CNH have been used in line with the work done by T2.3.:

- CNH at territorial level
- CNH at urban and historic city centre level
- CNH at building, site, artefact, mobile heritage

Different types of vulnerability are addressed in SHELTER project:

- Structural which refers to the potential affection to the static properties as well as the particular characteristics of a CNH (e.g. volume, style, decoration, interior and exterior architecture, territorial)
- Functional, which refers to the potential disruptions on the functions and operation of the use of the CNH (e.g. museum, education, residential, ecological corridor)
- Social and economic, which refers to the potential impacts on socio-economic activities (e.g. productivity, tourism, human comfort, etc.)

These terms as already argued in the methodology section, must still be agreed in the context of the overall risk assessment in SHELTER project T2.5

Natural hazards are very much dependant on the local context, idiosyncrasy and the socio-economic drivers, and must be incorporated into the hazard characterization as part of the risk assessment. Understanding the local context will also allow defining better shaped, fit-to- purpose solutions towards resilience.

Given the connection of non-climate drivers to certain hazard events, and to other processes connected to climate change adaptation and resilience, they should be included in the SHELTER operational framework for risk assessment (T2.5).

Non-climate drivers influence the frequency and intensity of some hazard events and enhance the level of exposure of the HA (and their citizens and infrastructures) to hazards such as pluvial flooding and heat stress. It is important to recognize this when developing responses to adapt and build resilience to climate change. SHELTER project WP3 should therefore encompass responses to address non-climate drivers.

Non-climate drivers can be both generic (e.g. demographic change) and locally specific (e.g. a specific urban development programme). Ideally, including a process to recognize non-climate drivers should be an element of adaptation and resilience planning. The WP5 Decision Support System could consider incorporating this, potentially via a scenario-based approach.

Spatial scale matters. SHELTER project should opt for a spatial approach to risk assessment. It is utterly important to have a spatially explicit assessment of hazards and related impacts to define *ad hoc*, precise and most effective measures to manage risk.

There is still an unresolved question of applying a multi hazard approach for CNH risk assessment and management The challenge of multi-hazard risk assessment in SHELTER project will be addressed in T2.5 in next steps of project development. The climate change research community has not yet achieved a consistent framework for assessment of complex climate change risks. Moreover, the IPCC notion of compound risk focuses most on the interaction of climate hazards determining a risk and complex risk terms were most often applied to the hazard determinant of a risk. This aligns with a growing research field on climate hazard interactions, such as heavy precipitation coinciding with a storm surge to increase likelihood of flooding, often termed compound weather or climate events.

CNH intrinsic value matters. Intrinsic and unique value of the CNH should be incorporated within the overall framework for risk assessment as part of the vulnerability component of risk.

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Appendices

Appendix 1 Overview of data sources for hazard characterization

1. Earthquakes

Seismic hazard Global maps

- GEM Global Earthquake Model *https://www.globalquakemodel.org/*
- Global Seismic Hazard Assessment Program (GSHAP). http://static.seismo.ethz.ch/gshap/global/caution.html
  - Name of indicator/variable: Homogenous seismic hazard map for horizontal peak ground acceleration (PGA) that is representative for stiff site conditions (Grünthal et al., 1999).
  - Resolution: Raster data (size 0.0833 degrees).
  - Time period: -
  - Unit: PGA (peak ground acceleration in proportion to acceleration of gravity (m/s2) with a 10% change of exceedance in 50 years).
  - Geographical coverage, limitations: global.
  - Data format: GRID
  - URL: http://static.seismo.ethz.ch/gshap/global/caution.html
  - Status: available.

Seismic hazard maps for Europe and the Mediterranean Basin region

- EFEHR European Facilities for Earthquake Hazard and Risk *http://www.efehr.org/en/home/*

- European Seismic Risk Service *https://eu-risk.eucentre.it/*

- EPOS European Plate Observing System *https://www.epos-ip.org/tcs/seismology*

- EMSC-CSME European Mediterranea Seismological Centre *https://www.emsc-csem.org/#2*

- ORFEUS Observatories & Research Facilities for European Seismology *https://www.orfeus-eu.org/*

- AHEAD European Archive of Historical Earthquake Data *https://www.emidius.eu/AHEAD/*

National seismic hazard maps

- National seismological institutes (i.e. Italian INGV, Spanish IGN)

European Projects

- SERA *www.sera-eu.org*

- RISE *www.rise-eu.org*

- SHARE *www.share-eu.org*
  Data source: SHARE Project.
  Name of indicator/variable: Harmonized Seismic Hazard Model (Giardini et al. 2013).
  Resolution: Raster data (size 0.0666 degrees).
  Time period: 1000-2007.
  Unit: PGA (peak ground acceleration in proportion to acceleration of gravity (m/s2) with a 10% change of exceedance in 50 years).
  Geographical coverage, limitations: Europe with Turkey.
  Data format: .shp and others.
  URL: http://www.share-eu.org/
  Status: available.

2. Subsidence

JRC European Soil Data Centre (ESDAC).
https://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus-v2

- Name of indicator/variable: JRC European Landslide Susceptibility Map version 2 (ELSUS v2).
- Resolution: 200 x 200 m.
- Time period: -.
- Unit: Landslide susceptibility (0=no data; 1=very low; 2=low; 3=moderate; 4=high; 5=very high).
- Geographical coverage, limitations: All European Union member states except Malta, in addition to Albania, Andorra, Bosnia and Herzegovina, Croatia, FYR Macedonia, Iceland, Kosovo, Liechtenstein, Montenegro, Norway, San Marino, Serbia, and Switzerland.
- Data format: geotiff.
- URL: https://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus-v2
- Status: requested and received

3. Flooding (fluvial)

River flood hazard maps for Europe and the Mediterranean Basin region

- The maps depict flood prone areas for river flood events for six different flood frequencies (from 1-in-10-years to 1-in-500-years). The extent comprises most of the geographical Europe and all the river basins entering the Mediterranean and Black Seas in the Caucasus, Middle East and Northern Africa countries. Cell values indicate water depth (in m). The maps can be used to assess the exposure of population and economic assets to river floods, and to perform flood risk assessments. NOTE: this dataset is based on JRC elaborations and is not an official flood hazard map (for details and limitations please refer to related publications)
- Data sets

  - https://data.jrc.ec.europa.eu/dataset/1d128b6c-a4ee-4858-9e34-6210707f3c81
- Report 2020
  - https://essd.copernicus.org/preprints/essd-2020-313/

Joint Research Centre: Flood Hazard Maps at European and Global Scale.

- Name of indicator/variable: Map Data is based on streamflow data from European and Global Flood Awareness System (EFAS and GloFAS) and computed using two-dimensional hydrodynamic models
- Time period: 21-year continuous discharge time series between 1990 and 2010.
- Unit: Water depth (m).
- Resolution: - 100 x 100 m.
- Geographical coverage, limitations: Uncertainty in the estimation of input data, limited data accessibility at trans-national level. Does not include Turkey and Iceland. Guyana, Martinique, Guadeloupe, and La Réunion are not covered.
- Data format: Geotiff image.
- URL: https://data.jrc.ec.europa.eu/collection/floods
- Status: available.

HANZE database of historical damaging floods in Europe, 1870-2016.

- Name of indicator/variable: The dataset is a compilation of past damaging floods in Europe, which contains information on dates, locations and losses for 1564 events (1870–2016).
- Resolution: NUTS3.
- Time period: 1870-2016.
- Unit: Area flooded, Flood losses.
- Geographical coverage, limitations: Lack of information.
- Data format: Excel.
- URL: https://data.4tu.nl/repository/uuid:5b75be6a-4dd4-472e-9424-f7ac4f7367f6
- Status: available.

Pan-European data sets of river flood probability of occurrence under present and future climate (Paprotny et al., 2017).

- Name of indicator/variable: River floods occurring in Europe under present and future climate. Includes gridded (GeoTIFF) datasets of river flood extents (in two variants, with or without flood protection) and water depths.
- Time period: -.
- Unit: water depth.
- Geographical coverage, limitations: Predictions.
- Data format: GeoTIFF.
- URL: https://data.4tu.nl/repository/uuid:968098ce-afe1-4b21-a509-dedaf9bf4bd5
- Status: available.

Global Active Archive of Large Flood Events.

- Name of indicator/variable: River floods occurring in Europe. Includes gridded (GeoTIFF) datasets of river flood extents and water depths. (Kundzewicz et al., 2013).
- Time period: 1985 – present.
- Unit: eg. Country, other country, dead, displaced, main cause, severity.
- Resolution: -
- Geographical coverage, limitations: Uncertainty if the input data.
- Data format: Excel, GIS Files.
- URL: https://www.dartmouth.edu/~floods/Archives/
- Status: available.

Additional

- MunichRe: Flood losses report: https://natcatservice.munichre.com/
- Copernicus emergency management: Rapid mapping. https://emergency.copernicus.eu/mapping/#zoom=2&lat=27.06375&lon=37.2948&layers=0BT00
- EFAS, European flood awareness system: Historical simulations of river discharge and precipitation. https://www.efas.eu/data-download
- The EU Floods Directive. https://ec.europa.eu/environment/water/flood_risk/links.htm
- “Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive now requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. With this Directive also reinforces the rights of the public to access this information and to have a say in the planning process.”
- Limitations: The flood hazard data and information is not presented consistently between countries. Data would have to be collected from each national source individually and compiled into one consistant database.

4. Wildfire

- **Copernicus emergency management service Fire danger forecast.** The European Forest Fire Information System (EFFIS) https://effis.jrc.ec.europa.eu/apps/effis_current_situation/index.html
- https://land.copernicus.eu/global/products/

5. Heat waves

Copernicus data

- Copernicus data on air temperature https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-urban-climate-cities?tab=overview
- COPERNICUS: Land surface temperature https://land.copernicus.eu/global/products/lst

Member States data and available local data in OL:

- European Drought Observatory (EDO) https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1111
- Climate ADAPT data for heat stress in Europe (2019) *https://maps.eea.europa.eu/EEABasicviewer/v4/?appid=e6f0c5adad4d445684c48312dbce2331&webmap=7c91ec6aa2c2445_a9a1684f54391f6a3&embed=false*
- SEFERIHISAR Turkish heat wave warning system: https://www.mgm.gov.tr/Meteouyari/turkiye.aspx

6. Storms

Data source:WISC Project.

- Name of indicator/variable: maximum 3-second gust speeds over a 72-hour period for significant winter storms between 1940 and 2014
- Resolution: 4 x 4 km.
- Time period: 1950-2016.
- Unit: m/s.
- Geographic coverage, limitations: ESPON space, Balkan area, Turkey. Does not include oversea areas, Acores, Madeira, Canarias.
- Data format: tiff and netcdf.
- URL: https://wisc.climate.copernicus.eu/wisc/#/help/products#footprint_download
- Status: available, requires registration.

EEA wind storms data.

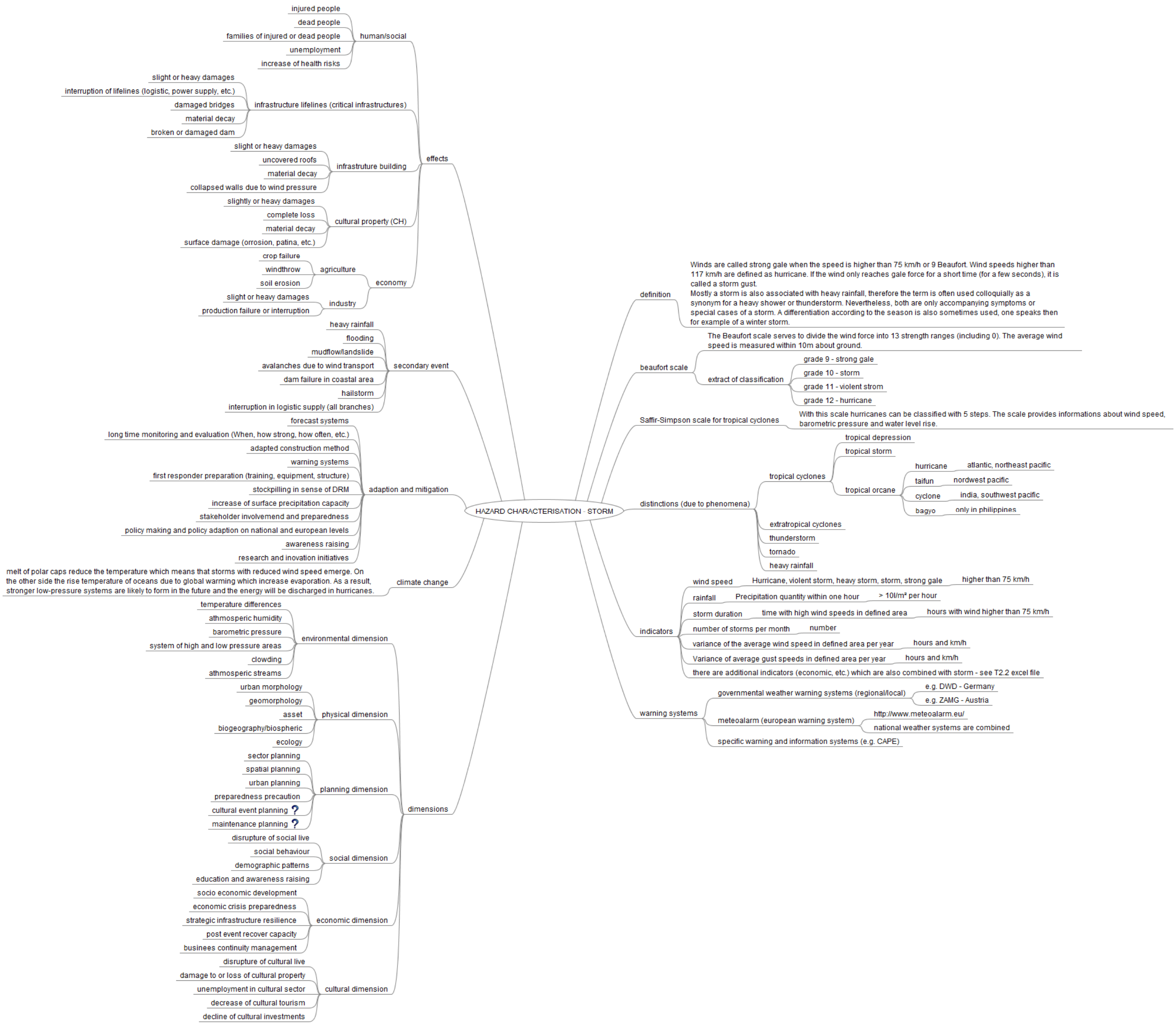
- Name of indicator/variable: Projected changes in extreme wind speed (98th percentile of daily maximum wind speed) based on GCM and RCM ensemble ([3] Donat et al., 2011).
- Resolution: 25 x 25 km.
- Time period: up to 2100.
- Unit: m/s.
- Geographical coverage, limitations: Data show projections based on climate models (GCMs and RCM).
- Data format: to be clarified after request of data.

- URL: https://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment
- Status: needs to be requested official from EEA.

NatCat Service, Munich Re.

- Name of indicator/variable: Approximate probability of having winter storms and for tropical storms probable maximum intensity.
- Resolution: NUTS3.
- Time period: 100 years.
- Unit: SS: Saffir-Simpson hurricane scale with an exceedance probability of 10% in 10 years (equivalent to a "return period" of 100 years).
- Geographical coverage, limitations: global, the affected areas in the reports or on NUTS 3 to NUTS 2 level.
- Data format: .pdf (as reports), no spatial data available.
- URL: https://www.munichre.com/en/reinsurance/business/nonlife/natcatservice/index.html
- Status: only overview reports can be created, no spatial data can be accessed, no free access to spatial data.

Appendix 2 Concept model for STORMS developed


HAZARD CHARACTERISATION - STORM
effects
human/social
injured people
dead people
families of injured or dead people
unemployment
increase of health risks
infrastructure lifelines (critical infrastructures)
slight or heavy damages
interruption of lifelines (logistic, power supply, etc.)
damaged bridges
material decay
broken or damaged dam
infrastruture building
slight or heavy damages
uncovered roofs
material decay
collapsed walls due to wind pressure
cultural property (CH)
slightly or heavy damages
complete loss
material decay
surface damage (orrosion, patina, etc.)
economy
agriculture
crop failure
windthrow
soil erosion
industry
slight or heavy damages
production failure or interruption
secondary event
heavy rainfall
flooding
mudflow/landslide
avalanches due to wind transport
dam failure in coastal area
hailstorm
interruption in logistic supply (all branches)
adaption and mitigation
forecast systems
long time monitoring and evaluation (When, how strong, how often, etc.)
adapted construction method
warning systems
first responder preparation (training, equipment, structure)
stockpilling in sense of DRM
increase of surface precipitation capacity
stakeholder involvemend and preparedness
policy making and policy adaption on national and european levels
awareness raising
research and inovation initiatives
climate change
melt of polar caps reduce the temperature which means that storms with reduced wind speed emerge. On the other side the rise temperature of oceans due to global warming which increase evaporation. As a result, stronger low-pressure systems are likely to form in the future and the energy will be discharged in hurricanes.
dimensions
environmental dimension
temperature differences
athmosperic humidity
barometric pressure
system of high and low pressure areas
clowding
athmosperic streams
physical dimension
urban morphology
geomorphology
asset
biogeography/biospheric
ecology
planning dimension
sector planning
spatial planning
urban planning
preparedness precaution
cultural event planning ?
maintenance planning ?
social dimension
disrupture of social live
social behaviour
demographic patterns
education and awareness raising
economic dimension
socio economic development
economic crisis preparedness
strategic infrastructure resilience
post event recover capacity
businees continuity management
cultural dimension
disrupture of cultural live
damage to or loss of cultural property
unemployment in cultural sector
decrease of cultural tourism
decline of cultural investments
definition
Winds are called strong gale when the speed is higher than 75 km/h or 9 Beaufort. Wind speeds higher than 117 km/h are defined as hurricane. If the wind only reaches gale force for a short time (for a few seconds), it is called a storm gust.
Mostly a storm is also associated with heavy rainfall, therefore the term is often used colloquially as a synonym for a heavy shower or thunderstorm. Nevertheless, both are only accompanying symptoms or special cases of a storm. A differentiation according to the season is also sometimes used, one speaks then for example of a winter storm.
beaufort scale
The Beaufort scale serves to divide the wind force into 13 strength ranges (including 0). The average wind speed is measured within 10m about ground.
extract of classification
grade 9 - strong gale
grade 10 - storm
grade 11 - violent strom
grade 12 - hurricane
Saffir-Simpson scale for tropical cyclones
With this scale hurricanes can be classified with 5 steps. The scale provides informations about wind speed, barometric pressure and water level rise.
distinctions (due to phenomena)
tropical cyclones
tropical depression
tropical storm
tropical orcane
hurricane
atlantic, northeast pacific
taifun
nordwest pacific
cyclone
india, southwest pacific
bagyo
only in philippines
extratropical cyclones
thunderstorm
tornado
heavy rainfall
indicators
wind speed
Hurricane, violent storm, heavy storm, storm, strong gale
higher than 75 km/h
rainfall
Precipitation quantity within one hour
> 10l/m² per hour
storm duration
time with high wind speeds in defined area
hours with wind higher than 75 km/h
number of storms per month
number
variance of the average wind speed in defined area per year
hours and km/h
Variance of average gust speeds in defined area per year
hours and km/h
there are additional indicators (economic, etc.) which are also combined with storm - see T2.2 excel file
warning systems
governmental weather warning systems (regional/local)
e.g. DWD - Germany
e.g. ZAMG - Austria
meteoalarm (european warning system)
http://www.meteoalarm.eu/
national weather systems are combined
specific warning and information systems (e.g. CAPE)

Appendix 3 Glossary of terms

Adaptation

The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects ([10] WGII, III IPCC, 2014)[103.]

Climate change

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1,defines climate change as: ‘a change of climate which is attributed directly or in-directly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes. See also Detection and Attribution. ([10] WGI, II, III, IPCC, 2014)[104.]

Climate change scenario

A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change ([10] IPCC, 2014)[105].

Cultural Heritage

Cultural heritage includes tangible cultural heritage, such as movable cultural heritage (paintings, sculptures, coins or manuscripts), immovable cultural heritage (monuments, archaeological sites, and so on) and underwater cultural heritage (shipwrecks, underwater ruins and cities) and intangible cultural heritage (oral traditions, performing arts, rituals) (SHELTER, Ontology)[106].

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[103] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Cli-mate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

[104] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Cli-mate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

[105] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Cli-mate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

[106] https://wiki.shelter-project.cloud/en/ontology/cultural-heritage

Disaster

Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery ([10] WGII, IPCC, 2014)[107].

Earthquake

An Earthquake is a sudden violent shaking of the ground caused by an abrupt release of energy accumulated inside the Earth, at a specific point called the hypocentrE. The point on the earth's surface, placed on the vertical of the hypocentrR, is called the epicentre. The earthquake can be classified by horizontal and vertical Peak Ground Acceleration (PGA) recorded on the ground and its intensity defined through the magnitude scale.

Exposure

The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. ([10] WGII, IPCC, 2014)[108].

Extreme weather event

An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season). ([10] WGI, II, IPCC, 2014)[109].

Flood

The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods and glacial lake outburst floods. ([10] WGII, IPCC, 2014)[110]. Flood pluvial refers to a flood event due to surface water runoff (m3/s). The flow of water that occurs when there is excess stormwater.

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[107] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

[108] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

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Frequency

The frequency of a natural hazard event is the number of times it occurs within a specified time interval ([1] Carter et al, 2015)[111]

Hazard

- 'The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.'([9] IPCC 2012: 560)[112]
- '…potentially damaging physical event, phenomenon or human activity characterized by its location, intensity, frequency and probability.' ([4] EEA 2012: 47)[113]
- unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins (SHELTER, 2019 ontology) [114].

Heat wave

A period of abnormally and uncomfortably hot weather ([10] WGI, II, IPCC, 2014)[115].

A period in which the maximum and minimum apparent temperatures are over the ninetieth percentile of the monthly distribution for at least two days. The impact of long heatwaves (more than four days) was 1.5–5 times that of short ones (WHO, 2020)[116]

Impacts (consequences, outcomes)

Effects on natural and human systems. In this report, the term impacts are used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of

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[112] IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/

[113] EEA Report n 12/2012 Climate change, impacts and vulnerability in Europe 2012 https://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012

[114] https://wiki.shelter-project.cloud/en/ontology/hazard

[115] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

[116] https://www.who.int/health-topics/heatwaves#tab=tab_1

climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of impacts called physical impacts. ([10] WGII, IPCC, 2014)[117].

Impact chain

An impact chain describes a cause-effect relationship between a hazard and an exposed receptor leading to potential direct and in-direct impacts. In the context of SHELTER project, the impact chains would help to systematise the assessment of vulnerability and risk of Cultural and Natural Heritage against several hazards. ([5] Erich et al, 2015)[118]

Magnitude and intensity

The magnitude of a natural hazard event is related to the energy released by the event. It is distinguished from intensity which is related to the effects at a specific location or area. ([1] Carter et al, 2015)[119]

Natural Heritage

Natural heritage includes natural sites with cultural aspects such as cultural landscapes, physical, biological or geological formations. (SHELTER, ontology)[120]

Resilience

The United Nations Office for Disaster Risk Reduction (UNDRR) defines resilience as: 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.' (UNDRR, 2009: 92)[121]

Risk

The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure. ([10] WGII, III, IPCC, 2014)[122].

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[117] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

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[120] https://wiki.shelter-project.cloud/en/ontology/natural-heritage

[121] https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction

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Storms

The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. ([10] WGI, II, IPCC, 2014)[123]. A terrestrial storm is an extreme weather condition, a violent disturbance of the atmosphere with strong winds measuring ten or higher on the Beaufort scale, meaning a wind speed of 24.5 m/s, which is 89 km/h or 55 mph or more.

Subsidence

Land subsidence is a gradual settling or sudden sinking of the Earth's surface. (EEA)[124] It is a potentially destructive hazard that can be caused by a wide range of natural or anthropogenic triggers but mainly results from solid or fluid mobilization underground. Subsidence due to groundwater depletion is a slow and gradual process that develops on large time scales (months to years), producing progressive loss of land elevation (centimetres to decimetres per year) typically over vast areas (tens to thousands of square kilometres) and variably affects urban and agricultural areas worldwide.

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. ([10] WGII, IPCC, 2014)[125].

Wildfire

Wildfire hazard is understood as the interaction among changing weather and climate, vegetation conditions and composition as well as human factors, that . Weather and climate define the composition and structure of vegetation fuels, which may help to predict the potential spread and intensity of fires once they are ignited. Wildfire hazard is usually computed or expressed as potential fire behaviour (e.g. fireline intensity) or fuel physical and chemical properties (e.g. loading or biomass). ([15] UNISDR,2017)[126]

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[123] IPCC (2014): Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

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