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D3.1 Science support plan and concept

WP3 – Science Support

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CLARITY Project Overview

Urban areas and transportation infrastructure are highly vulnerable to climate change. Smart use of existing climate intelligence can increase urban resilience and generate added value for businesses and society at large. Based on the results of FP7 (7th Framework Programme) climate change, future internet and crisis preparedness projects (SUDPLAN, ENVIROFI, CRISMA) with an average Technical Readiness LEVEL (TRL) of 4-5 and following an agile and user-centred design process, end-users, purveyors and providers of climate intelligence CLARITY co-creates an integrated Climate Services Information System (CSIS) to integrate resilience into urban and transportation infrastructure.

As a result, CLARITY provides an operational eco-system of cloud-based climate services to calculate and present the expected effects of Climate Change (CC)-induced and -amplified hazards at the level of risk, vulnerability and impact functions. CLARITY offers what-if decision support functions to investigate the effects of adaptation measures and risk reduction options in the specific project context and allow the comparison of alternative strategies. Four demonstration cases showcase CLARITY climate services in different climatic, regional, infrastructure and hazard contexts in Italy, Sweden, Austria and Spain; focusing on the planning and implementation of urban infrastructure development projects.

CLARITY provides the practical means to include the effects of CC hazards and possible adaptation and risk management strategies into planning and implementation of such projects, focusing on increasing CC resilience. Decision makers involved in these projects will be empowered to perform climate proof and adaptive planning of adaptation and risk reduction options.

Abbreviations and Glossary

A common glossary of terms for all CLARITY deliverables, as well as a list of abbreviations, can be found in the public document "CLARITY Glossary" available at CLARITY-H2020.eu.

The following table was generated from http://cat.clarity-h2020.eu/glossary?machine_name%5B%5D=abbreviations_and_acronyms on April 4th, 2018 and contains all the acronyms that are used in the project.

Name	Term description
AAO	Appraisal of Adaptation Options
ADM	Architecture Development Method
AHF	Anthropogenic Heat Flux
AJAX	Asynchronous JavaScript and XML
AR	Assessment Report
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BB	Building Block
BC	Bias Correction
C3S	Copernicus Climate Change Services
CA	Consortium Agreement
CBA	Cost-benefit-analysis
CC	Climate Change
CCA	Climate Change Adaptation
CCD	Consecutive Dry Days
CCH	Climate Change Hazards
CDD	Consecutive Dry Days
CERN	Conseil Européen pour la Recherche Nucléaire
CFS	Climate Forecast System
CKAN	Comprehensive Kerbal Archive Network
CLARITY	Integrated Climate Adaptation Service Tools for Improving Resilience Measure
CLC	CORINE Land Cover
Climate-ADAPT	European Climate Adaptation Platform
CMIP	Coupled Model Intercomparison Project
COSMO-CLM	COnsortium for Small-scale MOdelling - Climate Local Model
COTS	Commercial Off-The-Shelf
CRISMA	Modelling crisis management for improved action and preparedness
CRM	Continuous Risk Management
CS	Climate Service
CSIS	CLARITY Climate Services Information System
CSS	Cascading Style Sheets
CSV	Comma Separated Values
CSW	Catalogue Service for the Web
CTA	Constructive Technology Assessment
DC	Demonstration Case
DC	Dublin Core
DEM	Digital Elevation Model
DFO	Dartmouth Flood Observatory
DHI	Danish Hydraulic Institute
DM	Decision Maker

DMP	Data Management Plan
DoA	Description of the Actions (Annex 1 to the Grant Agreement)
DOI	Digital Object Identifier
DOM	Document Object Model
DPA	Data Protection Agency
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSM	Digital Surface Model
DV	Dynamic Vulnerability
DWD	Deutscher Wetterdienst
EC	European Commission
ECA&D	ECA&D European Climate Assessment & Dataset
ECMWF	European Centre of Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ECW	Enhanced Compression Wavelet
EE	Evaluation of Exposure
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
EFTA	European Free Trade Association
EGI	European Grid Infrastructure
EM	Exploitation Manager
EM-DAT	Emergency Events Database
EMSC	European-Mediterranean Seismological Centre
EO	Earth Observation
EPS	Ensemble Prediction System
ERA40	ERA 40-year Reanalysis
ERDDAP	Environmental Research Division's Data Access Program
ESD	Empirical Statistical Downscaling
ESDAC	European Soil Data Centre
ESGF	Earth System Grid Federation
ESM	Earth System Model
EU-GL	Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient (Document)
EU-MACS	European Market for Climate Services
FP7	7th Framework Programme
FRP	Fire Radiative Power
FTY	Forest Type
FUA	Functional Urban Areas
FWI	Fire Weather Index
GA	General Assembly
GCM	Global Climate Model
GDAL	Geospatial Data Abstraction Library
GDP	Gross Domestic Product
GeoJSON	geographical JavaScript Object Notation
GEOSS	Global Earth Observation System of Systems
GeoTIFF	Geographic Tagged Image File Format
GFAS	Global Fire Assimilation System
GFCS	Global Framework for Climate Services
GIS	Geographic Information System
GML	Geography Markup Language

GPM	General Project Manager
GPS	Global Positioning System
GPX	GPS Exchange Format
H	Human
HC	Hazard Characterisation
HRL	High Resolution Layers
HRU	Hydrological Response Unit
HTML5	Hypertext Markup Language, version 5
HTTP	Hypertext Transfer Protocol
HWMI	Heat Wave Magnitude Index
IA	Impact Assessment
IAAP	Integration of Adaptation Action Plan
IAO	Identification of Adaptation Options
ICMS	Integrated Crisis Management Middleware
ICT	Information and Communication Technologies
IFS	Integrated Forecast System
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual Property Rights
JMA	Japan Meteorological Agency
JRA-25	Japanese 25-year ReAnalysis
JRC	Joint Research Centre
JSON	JavaScript Object Notation
MCDA	Multi-Criteria Decision Analysis
MMU	Minimum Mapping Unit
MRU	Minimum Reference Unit
MUKLIMO_3	Mikroskaliges Urbanes Klimamodell 3D
NaTech	Natural Hazard Triggering Technological Disasters
NCEP	National Centers for Environmental Prediction
NDH	Natural Hazards
NDSM	Normalized Differential Surface Model
NetCDF	Network Common Data Format
NGO	Non-Governmental Organization
NWP	Numerical Weather Prediction
OAI-PMH	Open Archive Initiative – Protocol Metadata Harvesting
OGC	Open Geospatial Consortium
OGR	OpenGIS Simple Features Reference Implementation
OpenAIRE	Open Access Infrastructure for Research in Europe
OpenDAP	Open-source Project for a Network Data Access Protocol
ORFEUS	Observatories & Research Facilities for European Seismology
OSM	Open Street Maps
PDF	Portable Document Format
PDSI	Palmer Drought Severity Index
PHP	PHP Hypertext Preprocessor
POPD	Protection of Personal Data
PPEA	Precipitation Potential Evaporation Anomaly
QA	Quality Assurance
QAP	Quality Assurance Plan
R10mm	Heavy precipitation days (precipitation ≥ 10mm)
R20mm	Very heavy precipitation days (precipitation ≥ 20mm)
R95p	Very wet days

RA	Risk Assessment
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RDBMS	Relational Database Management System
REST	Representational State Transfer
RIA	Rich Internet Application
RS	Reference Scenario
S2D	Subseasonal-to-Decadal
SD	Statistical Downscaling
SMS	Scenario Management System
SOS	Sensor Observation Service
SPA	Single Page Application
SPBS	Stochastic back-scatter scheme
SPI	Standardized Precipitation Index
SPPT	Stochastically perturbed parameterized tendency
SPS	Sensor Planning Service
SQA	Software Quality Assurance
SQAP	Software Quality Assurance Plan
SQL	Structured Query Language
SSR	Seasonal Severity Rating
STL	Street Tree Layer
SU	Number of summer days
SUDPLAN	Sustainable Urban Development Planner for Climate Change Adaptation
SWD	Staff Working Document
SWICCA	Service for Water Indicators in Climate Change Adaptation
TC	Test Case
TCD	Tree Cover Density
TL	Task Leader
TM	Scientific & Technical Manager
TOC	Table of Content
TOGAF	The Open Group Architecture Framework
TR	Number of tropical nights
TRL	Technology Readiness Level
UN	United Nations
uncertML	Uncertainty Markup Language
UNGA	United Nations General Assembly
UNISDR	United Nations Office for Disaster Risk Reduction
UrbanSIS	Climate Information for European Cities
US	User Story
VA	Vulnerability Analysis
VC	Vulnerability Curve
VEI	Volcanic Explosivity Index
WFS	Web Feature Service
WHO	World Health Organization
WMO	World Meteorological Organization
WMS	Web Map Service
WMTS	Web Map Tile Service
WP	Work Package
WPL	Work Package Leader

The following table contains EU-GL Methodology terms used in the CLARITY project. Complete description can be found in the "CLARITY Glossary" available at http://cat.clarity-h2020.eu/glossary?machine_name%5B%5D=eu_gl_methodology_terms.

Name	Term description
Hazard	The potential occurrence of a natural or human-induced physical *event* or trend or physical *impact* that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, *service* provision, ecosystems, and environmental resources (IPCC, 2014). In the IPCC context, the term *hazard* usually refers to climate-related physical events or trends or their physical impacts. (IPCC, 2014).
Exposure	The presence of people, infrastructure, housing, production capacities and other tangible human assets in hazard-prone areas.
Vulnerability	The probability of a given element at risk, classified as part of a specific Vulnerability class, to be affected by a level of damage, according to a prefixed scale of damages, under a given hazard intensity (Glossary of the CLARITY Proposal).
Risk Analysis	Risk is 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 of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. (IPCC, 2014). Risk Analysis is a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences (CRISMA Project glossary).
Impact Scenario Analysis	In probabilistic terms choosing in a deterministic way one or more significant events, among actually occurred past events or as a result of numerical hazard simulation models, shall be obtained as damage evaluation following a specific event.
Adaptation Options	The array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social (IPCC, 2014).
Decision Support	Functions that help in evaluating the data and deciding what to do.
Action Plan	Functions that help in establishing the report / implementation plan / guideline.
Integration	Integration of adaptation plan into the project.

Executive Summary

This document is deliverable D3.1 "Science support plan and concept" of the CLARITY project (H2020, Contract number 730355). It presents a consolidated overview of scientific concepts behind CLARITY, detailed description of CLARITY workflow based on the methodology of the "Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient" (EU-GL [1]), as well as foreseen implementation in the Climate Services Information System (CSIS) and its application for the Demonstration Cases (DC).

The CLARITY project follows an agile and user-centred design process for co-creation of the Climate Services (CS). This deliverable aims to outline the scientific concept and methodological approach provided to support the development of CLARITY CSIS and the implementation of the DC. It is the first deliverable of the work package WP3 "Science Support" related to the task T3.1 "Scientific Background". Therefore, it describes the scientific concepts, methodology and previous research efforts constituting the CLARITY project background and how it will be used in the CLARITY CSIS.

The overall scientific concept follows the EU-GL methodology, which was adapted for CLARITY CSIS purposes. The report includes a detailed description of the background documents and the updated EU-GL methodology, which complies with the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) approach. The methodology applied in individual WP3 tasks, reflecting the workflow of different EU-GL modules, is described in separate sections.

This deliverable, as well as the work done in WP3 "Science Support", is closely related to the co-creation process in WP1 "CO-Creation". Therefore, the general methodological approach, described in the first part of the deliverable, is further developed in the second part of the deliverable relating to the specific DC user stories (US) and test cases (TC), which were collected and analysed in the co-creation process in WP1.

In addition, the implementation of the methodological approach for DCs is dependent on the data collection process. These activities are done in the scope of the WP2 "Demonstration and Validation" and the data collection methodology is further analysed in D2.1 "Demonstration and validation methodology". This deliverable provides a summary and gives examples of data necessary to support the methodological approach. It also indicates additional sources of information, such as available models, tools and background project results that are used in implementation of workflow and provided in the online CLARITY catalogue.

The document is largely based on the literature research and analysis of available results, data and tools from the previous projects and their usability for the CLARITY purposes. The implementation of modelling tools in CLARITY CSIS and definition of modelling workflow addressing specific DC user stories and test cases is still in progress. Moreover, the user stories and test cases are expected to be further developed in the follow up period, together with the development of the CLARITY architecture in WP4 "Technology Support". Therefore, the updated version of the workflow e.g. by including further user requirements for the particular demonstrator cases within the co-creation process will be presented in the deliverable D3.2 "Science support report v1".

1 Introduction

This deliverable aims to outline the scientific concept and methodological approach provided to support the development of CLARITY Climate Services Information System (CSIS) and the implementation of the demonstration cases (DC). It includes inputs from all WP3 "Science Support" tasks and is partly related to the co-creation process in WP1 "CO-Creation", as well as the data collection process in WP2 "Demonstration and Validation".

Section 1 presents the structure of this deliverable and summarizes the main objectives of WP3 "Science Support". Section 2 provides the scientific background, including a literature research on climate change (CC) impacts in Europe, as well as global and EU guidelines for Climate Services. Section 3 describes the methodology adopted within CLARITY by introducing an updated version of the EU-GL approach in the context of climate and risk sciences. Section 4 reviews the knowledge database (previous projects, models, tools and datasets) that are relevant for CLARITY and explains their intended use within the project. Finally, Section 5 gives a detailed overview of the scientific support and application of the scientific concepts behind the general ICT Climate Services and the Expert Climate Services, based on test cases (TC) and user stories (US).

1.1 CLARITY Science Support

The main objectives of WP3 (Science Support), manifested through the work package (WP) Tasks T3.1 – T3.5, are described in the following.

Task 3.1 (Scientific Background) contributes to the initial WP activities in terms of providing the scientific base (literature overview, models, datasets, and algorithms) needed for the realization of the CLARITY climate services, while continually referring to the EU-GL methodology. The main outcome of T3.1 is reflected in the current deliverable (D3.1 "Science Support Plan and Concept").

Task 3.2 (Climate Intelligence) provides climate and environmental data for reference scenarios in accordance with end-user requirements. Downscaled climate projections, based on IPCC scenarios, are used to perform impact assessment. To improve the projections of environmental variables, customized models and algorithms are used for applying the downscaling procedures and bias-correction methods. T3.2 integrates available local data and aims to determine the environmental response to CC forcing (with and without adaptation measures). The main output from T3.2 will be used for Risk Assessment and Impact Scenario Analysis in T3.3 "Risk Assessment and Impact Scenario Analysis".

Task 3.3 (Risk Assessment and Impact Scenario Analysis) discusses and applies indicators for risk and impact assessment, manifested through an interplay of the three variables Hazards, Exposure and Vulnerability, based on the output from the previous tasks and referring to the EU-GL methodology. This includes the quantification and evaluation of risk under the consideration of CC, characteristics of the most relevant climate hazards (e.g. based on statistical parameters) and the assessment of exposure and vulnerability parameters likely to be affected by the considered hazards (e.g. by using a number of climate models and vulnerability functions). For this purpose, concepts and methods from previous European and national projects will be included. The former name of this task (Vulnerability and Risk Assessment) has been changed due to an updated version of the EU-GL steps.

Task 3.4 (Adaptation Strategies and Decision Support) provides models and algorithms to evaluate adaptation strategies, based on the information from Risk Assessment and Impact Scenario Analysis. The implementation of the adaptation measures leads to a modified impact scenario assessment due to the modification of input parameters.

Task 3.5 (Economic and Societal Impact) appraises economic and societal consequences of the implementation of different adaptation strategies with the aim of identifying the most efficient options (e.g. by applying cost-benefit analyses). This enables an evaluation and comparison of alternative adaptation scenarios and allows for an 'optimal' selection of mitigation/adaptation options.

2 Scientific Background

The latest report from the Intergovernmental Panel on Climate Change (IPCC) sets the scope of observed trends in global climate and future climate projections for this century and further [2]. According to the "Climate Change 2013: The Physical Science Basis" report [2], the observed large-scale changes include an increase in atmospheric and oceanic temperature, a reduction in snow and ice cover, a sea level rise and increased greenhouse gas concentrations in the atmosphere, with the latter being the main driver for anthropogenic climate change.

The global mean near-surface temperature between 2006 and 2015 has increased between 0.83°C to 0.89 °C compared to pre-industrial values. This was shown by three independent analyses [3] [4] [5]. During the same period, the European land temperatures rose by approximately 1.5°C compared to pre-industrial levels. 2014 and 2015 have been the warmest years since monitoring records began and it is likely that anthropogenic climate change has increased the probability of recent extreme events [6]. Annual precipitation has increased in northern parts of Europe and decreased in the South, while the mean sea level is increasing with regional variations [7].

Future climate projections indicate that the change in global temperature varies significantly depending on the model and emission scenario. However, all models and scenarios show a warming over Europe in the 21st century. The strongest warming is expected in Southern Europe in summer and in Northern Europe in winter [7]. Projections of mean precipitation show an increase in annual precipitation in central and northern parts of Europe and a decrease in the southern Europe, which is consistent with the observed patterns [6]. Apart from the general trend mentioned above, climate change also "leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events". Thus, climate change can severely affect human and natural systems, depending on their exposure and vulnerability [8].

Actions to mitigate greenhouse gas emissions are crucial to avoid "worst effects over the long term" as stated in EU-GL [1, p. 10]. The Paris Agreement, which was adopted in 2015, is a big step forward regarding the global effort to mitigate climate change. The signed nations committed to the aim to keep the global temperature increase this century below 2 degrees Celsius above the pre-industrial levels. However, some change in climate cannot be avoided anymore and impacts can already be felt today. Thus, adapting to a changing climate is crucial in order to reduce the negative impacts on human health, infrastructure, the environment etc. The Paris Agreement therefore also acknowledged the need to enhance climate change adaptation abilities of countries [9], and the Synthesis Report to the Fifth Assessment Report (AR5) of the IPCC highlights that "adaptation and mitigation are complementary strategies" [7, p. 17].

Climate research and modelling efforts provide a large amount of data and knowledge on how the climate will change in different regions of the world. This knowledge is crucial to find appropriate measures for climate adaptation in each region and on the national and local level. However, translating the available information such that decision-makers can incorporate the information into their decisions proves to be difficult [10].

Climate services are supposed to bridge the gap between data and the users. In the context of the European Commission's climate service initiative the term "Climate Services" has a broad meaning, "which covers the transformation of climate-related data – together with other relevant information – into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessments), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services include data, information, and knowledge that support adaptation, mitigation and disaster risk management (DRM)." With this perspective, "climate services have the potential to become the intelligence behind the transition to a climate-resilient society" [11].

CLARITY aims to develop such a tool, an integrated Climate Services Information System (CSIS) for urban areas and traffic infrastructure, to transfer knowledge about climate change and its implications for urban areas and infrastructure to decision-makers. To provide an EU-wide climate services information system, it is crucial to base the CLARITY development on existing guidelines and to define common data and system requirements. This section therefore comprises information about observed and projected Climate Change Impacts in Europe, as well as global and EU guidelines for Climate Services.

2.1 Climate Change Impacts in Europe

As the climate is changing, an increase of certain extreme weather and climate events is expected which may enhance the impacts of several hazards across Europe [7]. Managing the risks of climate extremes – also in the context of a changing climate – is challenging and many different factors have to be taken into account. Therefore, it is particularly important to carefully develop adaptation strategies based on a broad foundation of investigations.

The following section provides a literature research on climate change impacts in Europe. At this point, it has to be noted that the terminology used within this section (see, for example, the term "Risk" or "Hazard") might differ from the definitions proposed within CLARITY project (see "CLARITY Glossary").

The World Meteorological Organization (WMO) has published an Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2012) which provides a worldwide collection and analysis of disaster risk information and describes weather, climate and water-related disaster impacts [12]. According to this analysis, floods and storms were the most reported hazards in Europe with the largest economic losses, while the highest proportion of reported deaths was caused by extreme temperatures, e.g. 72 210 deaths during the 2003 European heat wave or 55 736 lives lost during the 2010 heat wave in the Russian Federation [12, p. 30]. In addition to the aforementioned disasters, Europe has to cope with a range of other hazards, like wet mass movements, wildfires or droughts [12] (see **Figure 1**).

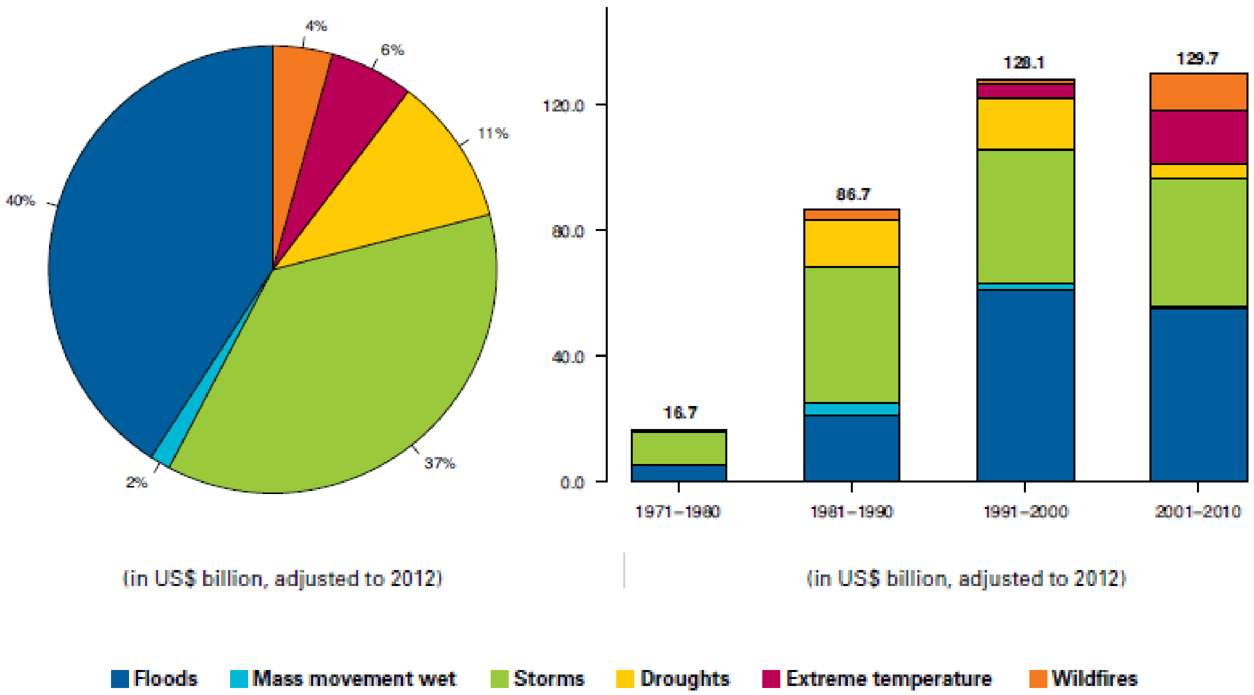


Figure 1: Distribution of the reported number of disasters in Europe by hazard type, per decade [12].

In order to assess changes in weather and climate events leading to extreme impacts and disasters, the following categories have been proposed within the IPCC special report "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" [8, p. 115]:

- Extremes of atmospheric weather and climate variables, e.g. temperature, precipitation and wind
- Weather and climate phenomena that influence the occurrence of extremes in weather or climate variables or are extremes themselves, e.g. monsoons, El Nino, tropical and extratropical cyclones
- Impacts on the natural physical environment, e.g. droughts, floods, extreme sea level, landslides etc.

Extreme impacts and disasters can also be a result of specific conditions that occur simultaneously (i.e. compound events) or of an accumulation of moderate weather or climate events that do not qualify as 'extreme events' themselves (e.g. droughts, floods). Impacts of weather and climate extreme events are largely influenced by non-climatic factors like exposure and vulnerability and the interactions between climatic and non-climatic factors can be rather complex. Besides that, not all extreme climate events are leading to extreme impacts [8].

Extreme weather events and extreme climate events may be distinguished based on their time-scales (the former being associated with changing weather patterns and their respective time scales and the latter being related to longer time scales, e.g. the accumulation of several weather events), although this distinction is not precise and, as mentioned in IPCC [8] and European Environment Agency (EEA) [6] reports, both of them are often referred to as 'climate extremes'. Extreme events can be defined quantitatively either based on their probability of occurrence or based on a specific threshold (e.g. depending on possible impacts) [8, p. 117].

The level of confidence (regarding observed or projected changes in extreme events) strongly depends on the type of event (i.e. on the involved processes or the amount of evidence available) [8, p. 120]. Moreover, it is difficult to attribute a specific extreme event to a single factor, like human-induced climate change. Thus, it can be helpful to use a likelihood-based approach, i.e. to attribute the changed probability of the occurrence of an extreme event to a specific cause [8, p. 127].

In the following section are described main findings about key hazards in Europe as listed in **Figure 1** and related extremes of climate variables such as temperature, precipitation and wind. The wet mass movements are described with a more general term "landslides", while temperature extremes relate primarily to heat hazards.

I. **Heat / Extreme Temperature**

Climate change has contributed to an increase in high-temperature extremes in Europe since 1950, i.e. in an increased number of hot days, tropical nights and number and longer duration of heat waves. On the other hand, there has been a decline in low-temperature extremes [7].

Several studies have pointed out that an increasing global surface temperature will affect both magnitude and frequency of extreme events like heat waves, also in Europe (e.g. [13]) Heat extremes often come along with droughts due to a reduction in evaporative cooling effects [14], but in some cases, they may also favour heavy precipitation events [15].

Russo et al. [16] introduced the *Heat Wave Magnitude Index daily*, which is a measure for the duration and magnitude of heat waves and an improvement of the former *Heat Wave Magnitude Index* [13]. Based on this index, 11 intense and long heat waves had occurred in the period 1950-2010 in Europe, whereby most of them happened after the year 2000. Furthermore, it is likely that anthropogenic climate change has contributed to an increased probability of recent heat extremes [6, p. 77].

Simulations with multi-model ensembles show an increase in both frequency and magnitude of heat waves in most parts of Europe for all emission scenarios. Considering the Representative Concentration Pathway

(RCP) 8.5 scenario, an increase in the occurrence of very extreme heat waves (HWMI > 8, see [13]) up to every two years in the second half of the 21st century is projected (see **Figure 2**).

Heat waves can have severe effects on human health and they have caused tens of thousands of premature deaths in Europe since 2000. Besides that, they can affect society (e.g. by negatively influencing labour productivity), ecosystems (e.g. by increasing the risk of forest fires) and agriculture [6].

According to the World Health Organization (WHO) and WMO, besides climatic factors like heat wave frequency, there are additional risk factors that may enhance the impacts of heat extremes. Elderly people, younger adults and children, people having particular diseases, people living alone, working outdoors or working indoors close to industrial heat sources may be more vulnerable to heath waves than the rest of the population [17]. Furthermore, people living in urban areas, where urban heat island effects play a role, may experience additional risk from heat extremes [8].

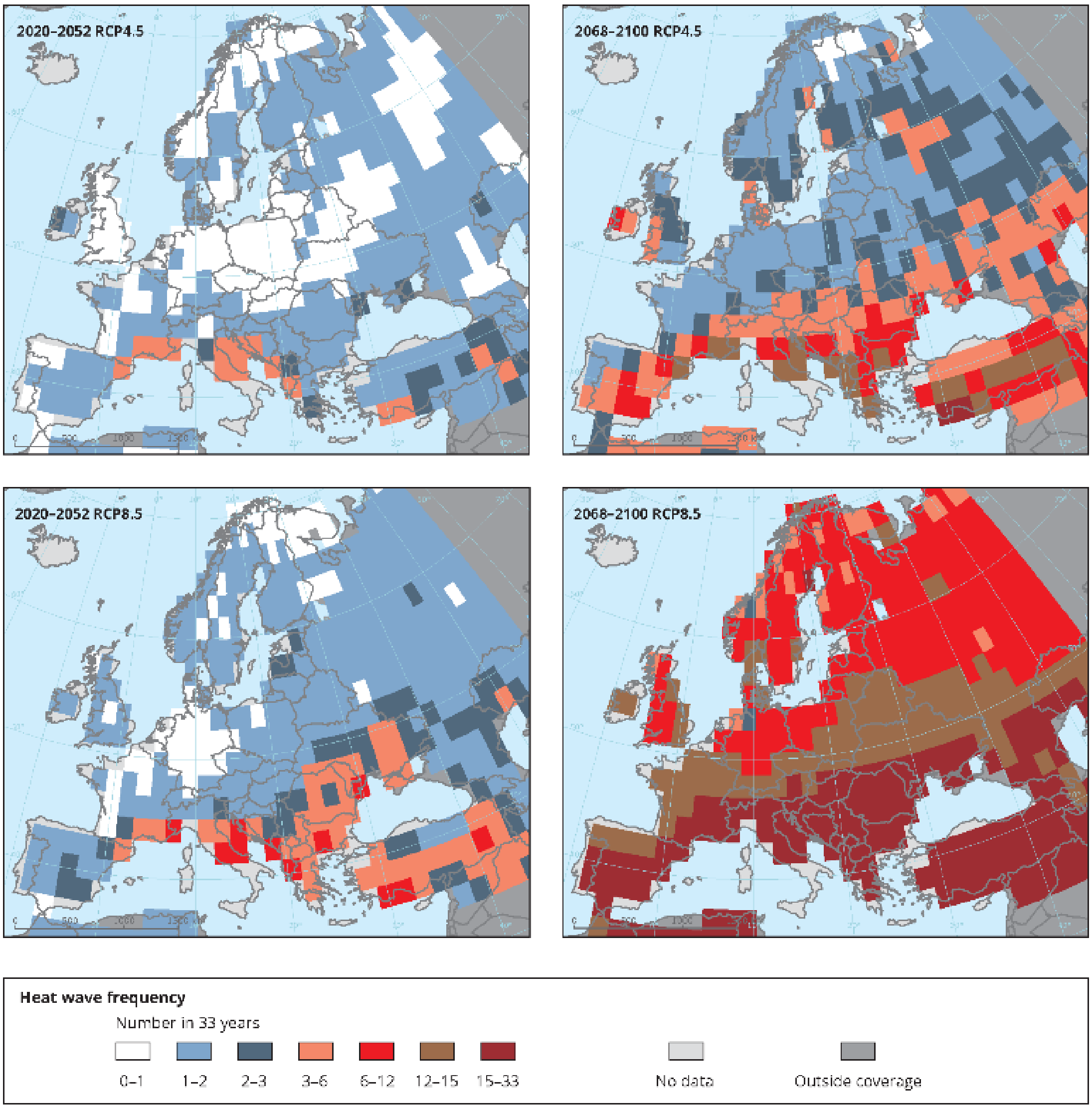


Figure 2: Projected number of very extreme heat waves in a multi-model ensemble for two future periods and two emission scenarios ([6] based on [13]).

II. **Floods / Precipitation Extremes**

Studying trends and changes of heavy precipitation events is challenging, due to inadequate data basis, (i.e. daily records of mean precipitation) and to the large regional variations. However, studies on heavy precipitation generally agree that, since 1950, heavy precipitation events have become more intense in northern and north-eastern Europe [6, p. 82].

Regarding future scenarios, an increase in daily heavy precipitation in most parts of Europe (up to 35%) in winter can be expected. A less uniform picture is presented for the summer season, where an increase in heavy precipitation events is projected for most parts of Europe, but on the other hand, decreases are projected for some southern and south-western regions [18] (see **Figure 3**).

The spatial resolution of the regional climate models used for studying climate change impacts is still problematic for adequately resolving local heavy precipitation events (e.g. [19]).

Precipitation extremes can be quantified by a series of indices, like the *Heavy Precipitation Days index (R10mm)* or the *Very Heavy Precipitation Days index (R20mm)*[1], indicating the number of days with precipitation amount ≥ 10 mm and ≥ 20 mm, respectively. Some other indices are based on a percentile threshold, as, for example, the *Very Wet Days (R95p) index*, indicating days with a precipitation amount > 95th percentile of daily amounts[2].

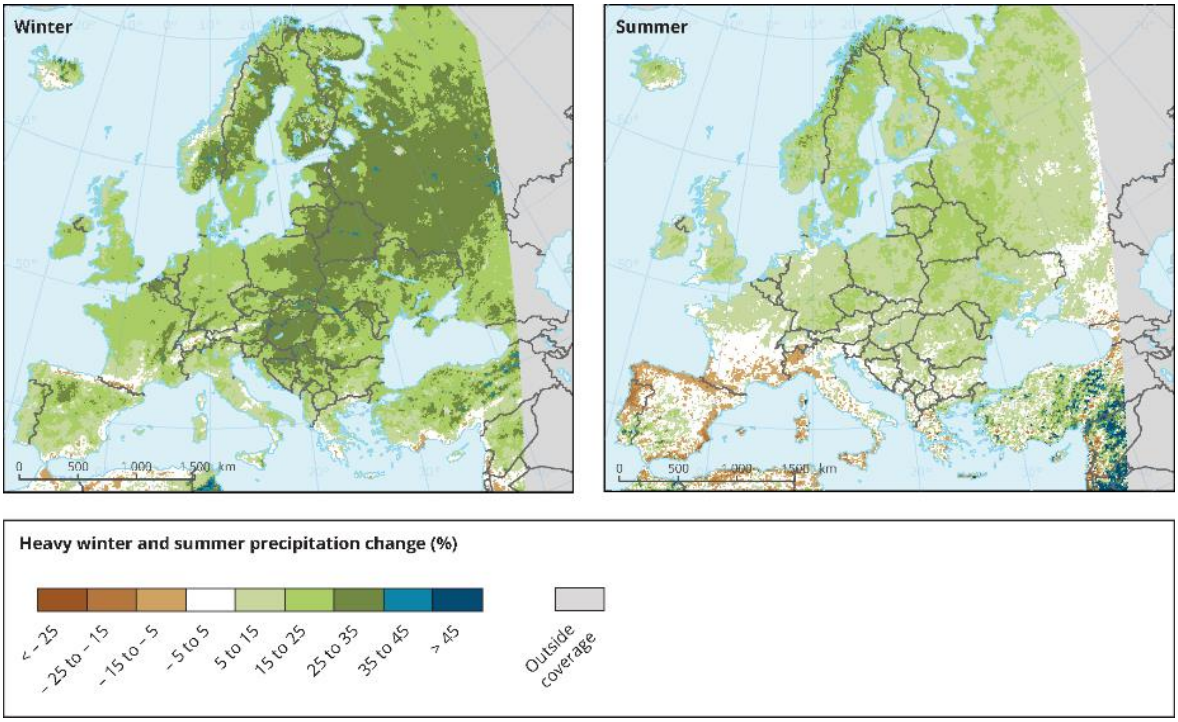


Figure 3: Projected changes (ensemble mean) in heavy precipitation from 1971-2000 to 2071-2100 for the RCP 8.5 scenario ([6] based on [18]).

Heavy precipitation events can cause several hazards, like **floods (**also flash floods) and **mass movements** (see Landslides). This can have severe impacts on society dependent on factors like population density, land-use changes etc. The changes in heavy precipitation strongly depend on region, season and climate scenario [6].

[1] http://etccdi.pacificclimate.org/list_27_indices.shtml
[2] https://www.ecad.eu/indicesextremes/indicesdictionary.php#1

A flood is defined as "[…] the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged." [20]. There are various types of floods, depending on their drivers and impacts, like river floods, flash floods, coastal floods, urban floods etc.

The main drivers leading to flooding events are intense and/or long-lasting precipitation, snow or ice melting, dam break or local intense storms. There are various factors that influence the formation and development of floods, including precipitation characteristics (intensity, duration, phase etc.) but also water levels, presence of snow/ice, soil condition and urbanization, amongst many others [8].

Flood events, especially river floods (along with storms) account for the most important natural hazards in Europe with regard to economic damage. Since 1980, almost 1500 flood events have been reported, more than a half of them after the year 2000 [6, p. 140].

Based on a combination of data from global datasets like the Dartmouth Flood Observatory (DFO)[3] and the Emergency Events Database EM-DAT [21] and data reported by EU Member States and EEA members, it was found out, that the number of very severe flood events increased between 1980 and 2010, although with great inter-annual variability [6, p. 134]. However, it remains unclear how this increase can be linked to (the changing) climate, because of limited data records and also because of other flood-related factors like increased exposure of people and property in flood risk areas [7].

Estimates for future risks of river floods in Europe with a hydrological model that is driven by an ensemble of climate simulations show a projected increase in Q100 (i.e. one-in-a-century) flood events in large parts of Europe, but a decrease in parts where snow accumulation during winter may be reduced due to global warming [22] (see **Figure 4**).

Flood-related impacts involve several risks for various areas, including human health, agriculture, transport and economic sectors. Flooding can affect people and human health immediately, i.e. through drowning or serious injuries, but it may have indirect consequences as well, for example through destruction of buildings, financial loss and furthermore, it may lead to infectious diseases or mental health issues that often persist long after the event [6] [23]. Without any additional adaptation measures the number of people annually affected by flooding, is projected to increase to 775.000 – 5.5 million people by the year 2080 – depending on the emission scenario [24]. Besides the tremendous effects on human health, floods may cause damages to infrastructure, property, transportation systems and agriculture.

[3] http://floodobservatory.colorado.edu/

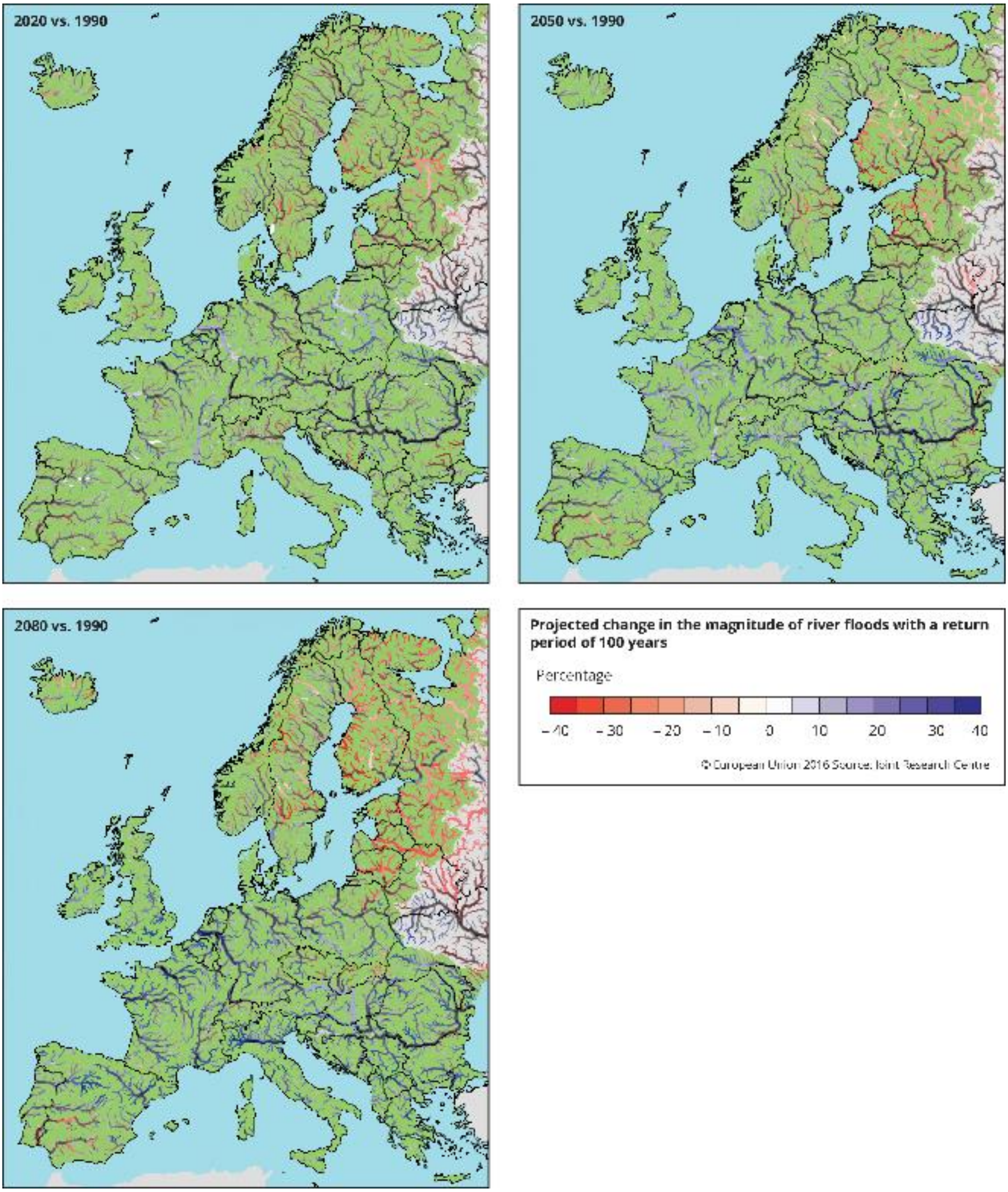


Figure 4: 100-year daily peak flow. Projected change for the time slices 2006-2035, 2036-2065 and 2066-2095 compared to an ensemble mean of the baseline (1976-2005), based on EURO-CORDEX RCP 8.5 scenarios ([6] based on [22]).

III. Storms / Extreme winds

Due to the large variations in storm location and intensity over the past century across Europe, no significant long-term trends are available [6]. There has likely been a poleward shift in extratropical storm tracks during the last 50 years [8].

Regarding future projections, modelling studies generally agree on "[…] increases in the strongest, most damaging storms in most European regions." [6]. Winter storm activity is projected to increase over the North Atlantic and Western Europe [25] and autumn storms with a tropical origin are expected to increase in Europe under global warming [26].

Projected changes in extreme wind speed based on a study with GCM (Global Climate Model) and RCM (Regional climate model) model ensembles [27] are shown in **Figure 5**. In this case, the *98th percentile of daily maximum wind speed* has been used to quantify extreme wind speed.

Wind storms – often accompanied by heavy precipitation and/or wind gusts – can have harmful and destructive effects on human health and many other systems and may lead to structural damage, floods and storm surges [6, p. 85]. Based on a natural catastrophe loss database from Munich RE, storms accounted for the natural hazard with the highest insured losses in Europe during the period 1980 – 2013 (Munich Re NatCatSERVICE data cited [28] in [6]).

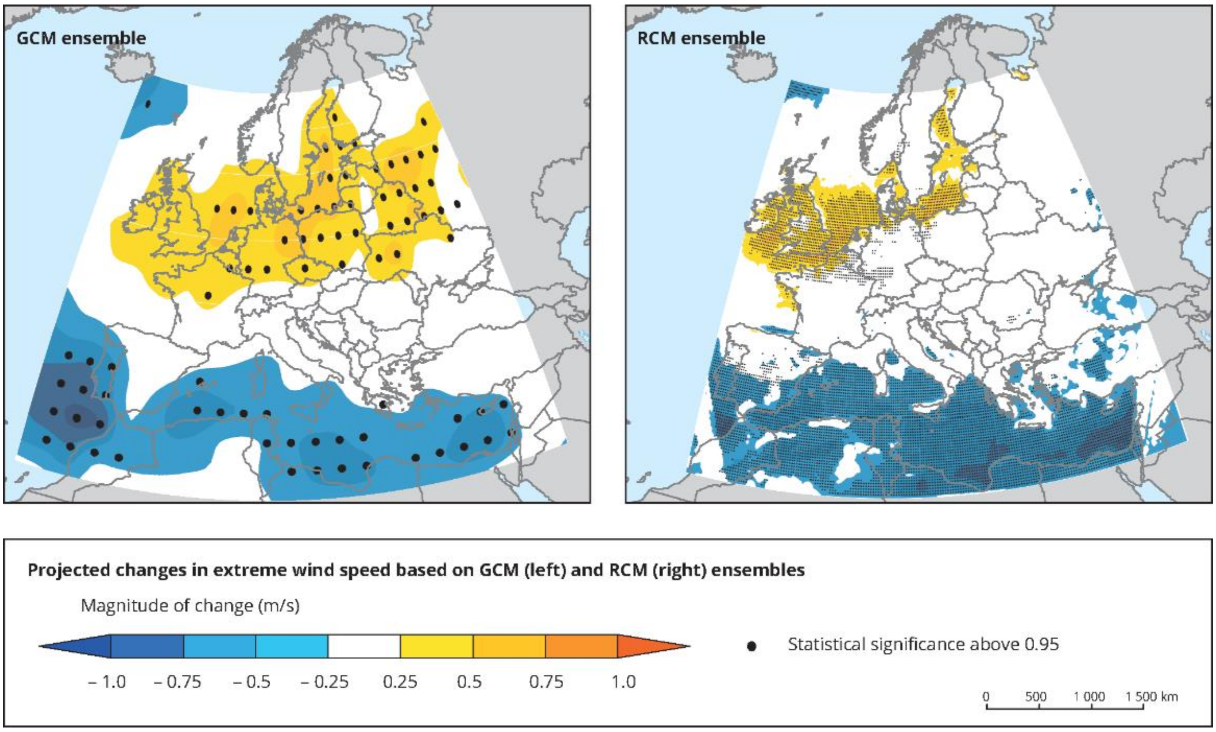


Figure 5: Ensemble mean of changes in extreme wind speed (98th percentile of daily maximum wind speed) for scenario A1B for the period 2071-2100 relative to 1961-2000, based on 9 GCMs (left) and 11 RCMs (right) ([6]; adapted from [27]).

IV. Droughts

There are various definitions of drought, depending on the context and the respective subject. A meteorological drought generally refers to a deficit of precipitation, often associated with high temperatures and therefore high evapotranspiration. Indices like the *Standardised Precipitation Index (SPI)* are usually used to describe droughts statistically [6, p. 144 f.]. However, droughts can also be defined from a hydrological or agricultural perspective, considering parameters like groundwater levels or soil moisture [8, p. 179]. The variety of definitions for the term drought together with a lack of long-term observations makes an analysis difficult [7, p. 1279]. In the CLARITY project several indices will be considered for hazard evaluation and the appropriate indices will be selected dependent on the respective subject and data availability.

An example for a drought index that is based on precipitation data only, is the aforementioned SPI, which is defined as "[…] the difference of precipitation from the mean for a specified time divided by the standard deviation, where the mean and standard deviation are determined from the climatological record." [29]. SPI values are -0.5 to -1 for mild droughts, while they are below -2 for extreme droughts [8]. Another index that is used to characterize droughts is the *Consecutive Dry Days (CDD)* index, which accounts for the maximum consecutive number of days without rain within a certain period [8, p. 180]. There are also indices that additionally provide estimates of actual or potential evapotranspiration, like the *Palmer Drought Severity Index (PDSI)* [30] or the *Precipitation Potential Evaporation Anomaly (PPEA)* [31].

Since 1950, meteorological droughts have become more frequent in parts of southern and central Europe, whereas they have become less frequent in Northern and partly Eastern Europe [32]. Meteorological droughts are projected to occur more frequently and more intensely in Central and Southern Europe, as well as in the Mediterranean [2, p. 1279].

Based on a EURO-CORDEX model ensemble, the frequency and duration of extreme meteorological droughts (based on the SPI index) is projected to significantly increase in the future, especially at the end of the 21st century, with the largest increases in parts of the Iberian Peninsula, southern parts of Italy and the Eastern Mediterranean [33] (see **Figure 6**).

Droughts come along with a series of consequences for European citizens and various sectors. They may affect agriculture (e.g. due to decreased crop yields), energy production (due to limitation of available cooling water), industry and public water supply, including an increased competition between different water users [6].

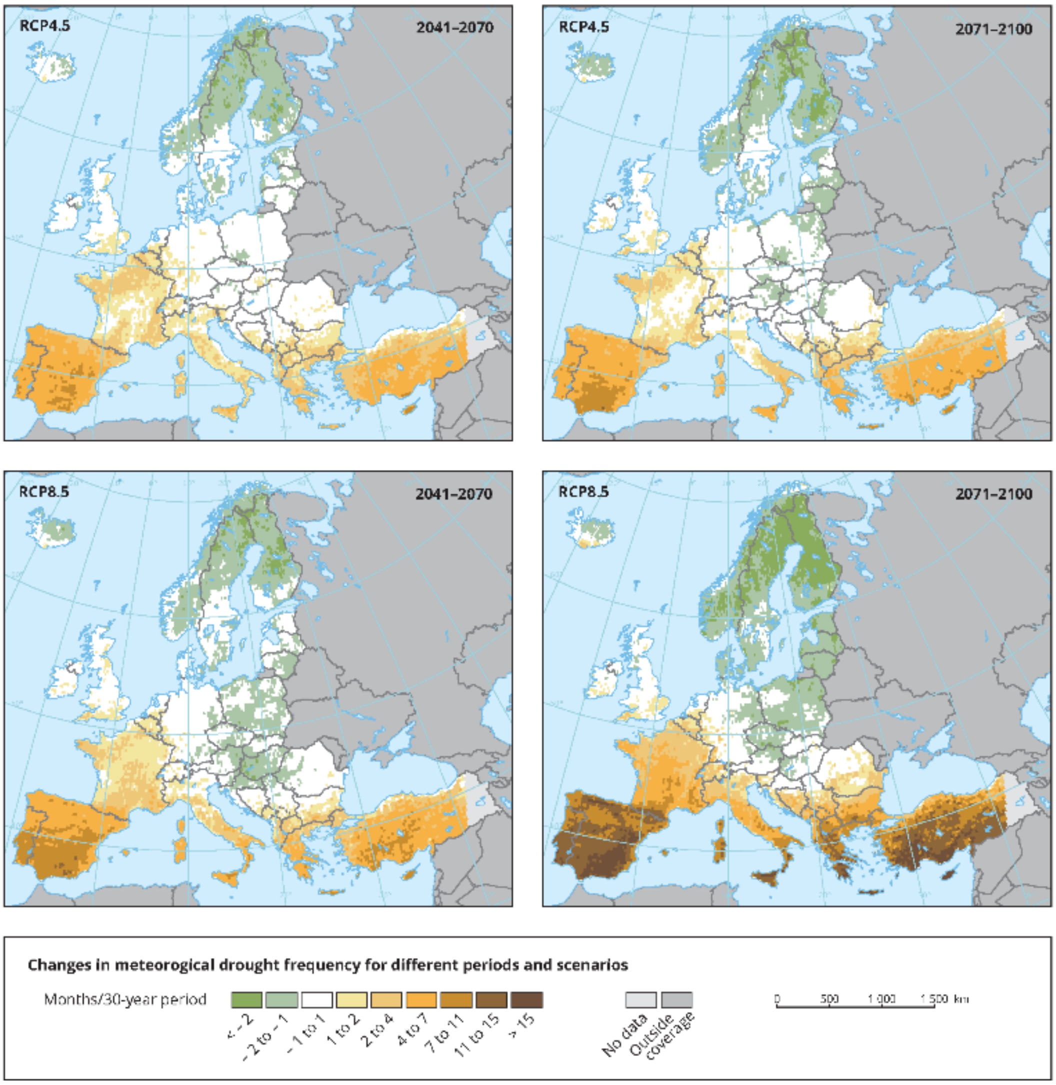


Figure 6: Projected change in the frequency of extreme meteorological droughts for two future periods and two emission scenarios. Definition of drought frequency: number of months in a 30 year period with the SPI index accumulated over 6 months ([6] based on [33]).

V. Forest fires

The occurrence of forest fire events strongly depends on various factors, like climate and weather conditions, vegetation, land-use practises etc. While human activities are the major cause for the ignition of most of the wild fires in Europe, weather conditions and fuel accumulation strongly impact changes in probability of fire events over time [34] and thus, climate change may influence forest fire regimes across Europe in the future, due to an increasing number and intensity of droughts and heat waves.

The European Forest Fire Information System (EFFIS)[4] collects and shares near real-time and historical information about forest fire events in Europe, Middle Eastern and North Africa. However, analysing and determining trends in the frequency of historical fire events is challenging due to a lack of long-term comparable datasets and changes in reporting systems [6, p. 177].

The Global Fire Assimilation System (GFAS)[5], produced by the ECMWF, generates daily estimates of biomass burning emissions, based on an assimilation of *Fire Radiative Power (FRP)* observations.

Meteorological fire danger indices, like the *Canadian Fire Weather Index (FWI)* as well as the *Seasonal Severity Rating (SSR)* index, which is an extension of the FWI, are used to compare fire danger across regions and time [35].

Past trends of forest fire danger have been analysed based on the SSR index, computed over the period 1981-2010. These trends show a significant increase in the forest fire danger in many regions across Europe (see **Figure 7**). The SSR was computed based on ECMWF (European Centre of Medium-Range Weather Forecasts) data, such as temperature, relative humidity, wind and precipitation [6, p. 177].

Recent forest fires have affected regions that are usually not at risk. Sweden, for example, experienced a strong forest fire – the largest in Sweden's recent history – in 2014, where large areas of forest land have been damaged [36]. Climate projections indicate an increase of extreme events like droughts, heat waves and dry spells across most parts of southern Europe and therefore, an increase in duration and intensity of wildfire events can be expected [37].

Figure 7 (right) shows the projected trend in forest fire danger change in terms of the SSR index for the period 2071-2100 compared to 1961-1990.

[4] http://effis.jrc.ec.europa.eu/
[5] http://apps.ecmwf.int/datasets/data/cams-gfas/

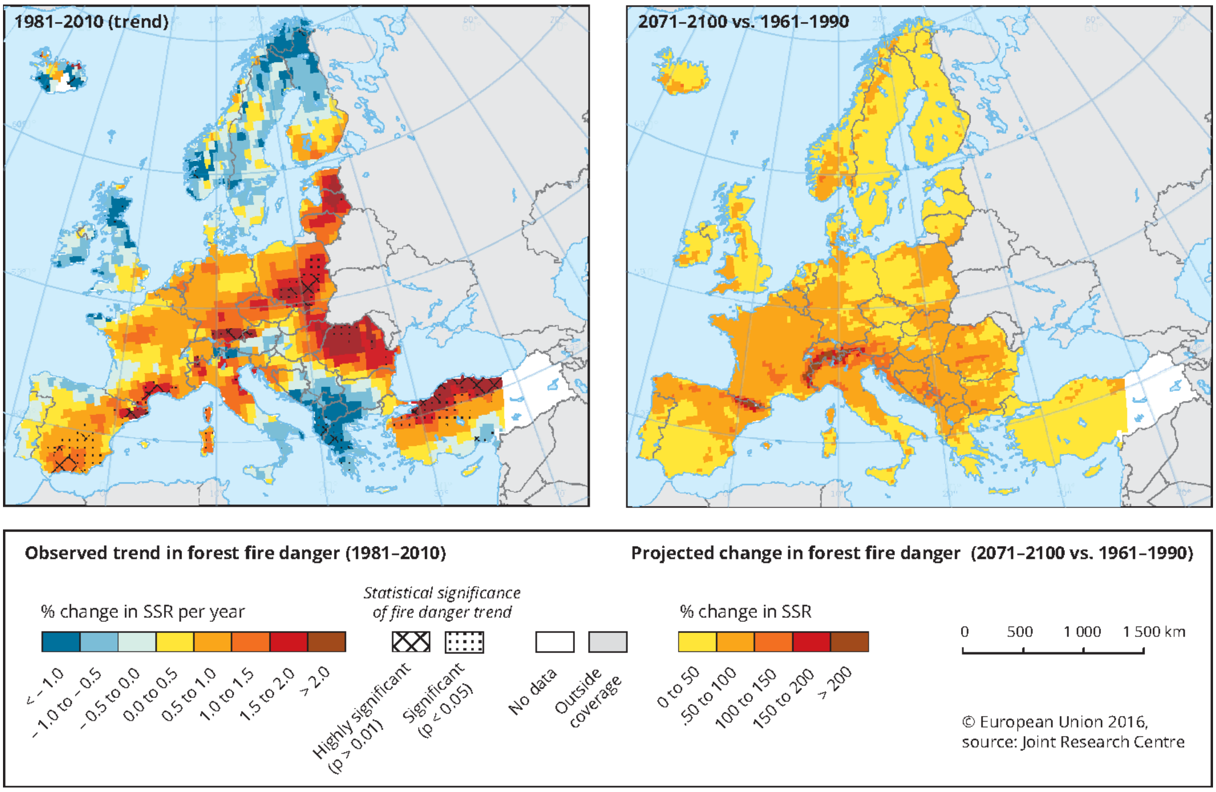


Figure 7: Projected change in forest fire danger in terms of the SSR index (observed and projected changes) ([6]based on [38]).

VI. Landslides

Landslides represent a major hazard to many areas across Europe, with the most affected area being mountainous regions. A landslide is defined as "[…] a mass of earth material (soil, rock, etc.) moving down a steep slope." [39].

Landslide events may be triggered by rapid changes in groundwater level and/or flow, precipitation, natural erosion, river banks, snowmelt, earthquakes or volcanic processes. Besides that, several additional factors, like topography, geological properties, slope morphology, lithology and land cover play an important role. Furthermore, human activities – for example construction works – may favour the conditions for landslide occurrence, sometimes in combination with natural activities [40].

According to Haque et al. [40], "Recently, triggered by increasingly frequent extreme weather events, mass movements in many European countries have become common natural phenomena and have caused considerable damage and economic losses." They investigated the spatio-temporal distribution of deadly landslides for 27 countries in Europe for the period 1995-2013 and found out that 476 landslide events accounted for 1370 deaths and 784 injuries within the investigated period. They also showed a pronounced increasing trend of fatal landslides during the period 2008-2014, the events being mostly triggered by phenomena such as storms (in combination with heavy rainfall), earthquakes and floods.

Lopez Saez et al. [41] found an increase of the frequency of landslide events since 1990 for a region of the French Alps. Stoffel and Huggel [42] pointed out that "[…] changing mean and extreme temperature and precipitation are likely to be widespread and to influence both the occurrence (in terms of temporal frequency) and the magnitude of future mass movements in mountain regions around the globe."

A similar statement has been made by [6, p. 299] which says that the probability of mountain-specific natural hazards like landslides are likely to increase due to different factors, like "[…] changes in precipitation patterns, increased soil erosion, permafrost degradation and the destabilisation of mountain slopes."

However, “Quantification of possible trends in the frequency of landslides and ice avalanches in mountains is difficult due to incomplete documentation of past events […]” [8, p. 199].

Landslides – depending on their size and speed – can affect various sectors and may seriously damage buildings, agriculture, roads, railways etc. Furthermore, large landslides can lead to river blocking, especially in mountainous areas. There is also an indication that “[…] most statistics on natural disasters underestimate the impacts from landslides as they often do not separate them from other triggering or concurrent natural hazards such as storms, floods or earthquakes [43].

2.2 Global Framework and Guidelines for Climate Services

The scope of this section is to summarize main concepts, global framework and guidelines for Climate Services as background information that might be relevant for development of CLARITY CSIS.

The **Global Framework for Climate Services (GFCS)** was established in 2009 at the World Climate Conference-3 in Geneva, Switzerland. The vision of the GFCS is "To enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale." [44]. The five priority areas of the GFCS are (1) Agriculture and food security, (2) Disaster risk reduction, (3) Energy, (4) Health, and (5) Water [44].

The report "Climate Knowledge for Action: A Global Framework for Climate Services" [45], which forms the basis of the GFCS, proposes five components of the Framework (**Figure 8**):

(1) **The User Interface**, which enables users, climate researchers and climate service providers to interact in order to maximise the usefulness of climate services.

(2) **The Climate Services Information System**, which is a system that protects and distributes climate data and information based on the needs of the users.

(3) **The Observations and Monitoring component**, which ensures that needed climate observations are generated.

(4) **The Research, Modelling and Prediction component**, which assess and promotes "the needs of climate services within research agendas" [45].

(5) **The Capacity Building component**, which "will support systematic development of the necessary institutions, infrastructure and human resources to provide effective climate services" [45].

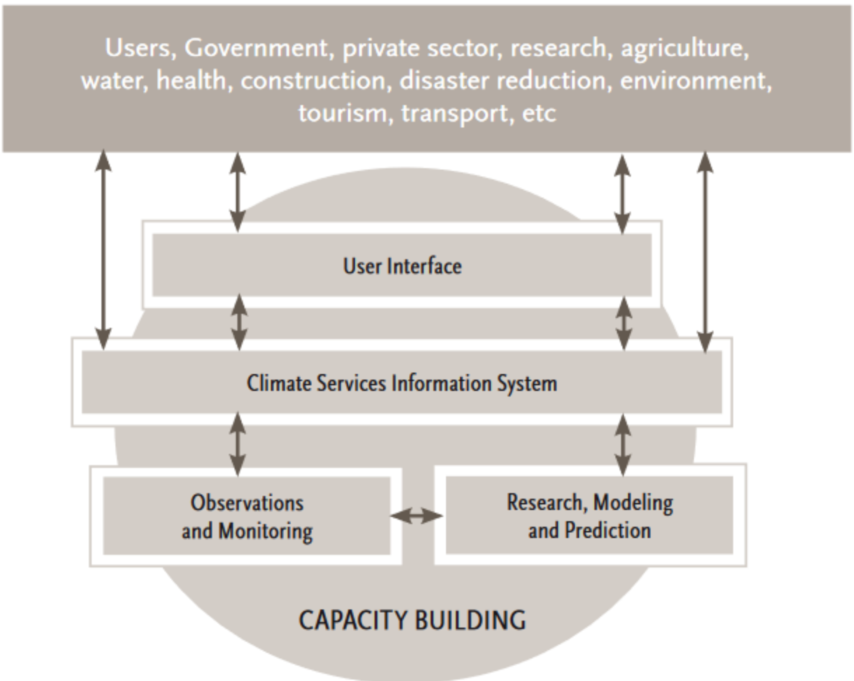


Figure 8: Components of the Global Framework for Climate Services [45, p. 9].

The Implementation Plan from 2014 [46] formulates 5 goals and adopted the eight key principles proposed in [45].

The five goals, as listed in [46, pp. 4-5] are:

1. Reducing the vulnerability of society to climate-related hazards through better provision of climate services;
2. Advancing the key global development goals through better provision of climate services;
3. Mainstreaming the use of climate information in decision-making. Promoting better uptake, understanding and awareness of the need for climate information and climate services; and demonstrating the value of the services in socio-economic, safety and sustainability terms;
4. Strengthening the engagement of providers and users of climate services. Building relationships between providers and users of climate services at both the technical and decision-making levels;
5. Maximizing the utility of existing climate service infrastructure. Improving coordination and strengthening and building this infrastructure where needed.

Eight Principles should be followed to achieve the above stated goals [46, p. iv]:

1. All countries will benefit, but priority shall go to building the capacity of developing countries vulnerable to the impacts of climate change and variability;
2. The primary goal will be to ensure greater availability of, access to and use of enhanced climate services for all countries;
3. Activities will address three geographic domains: global, regional and national;
4. Operational climate services will be the core element;
5. Climate information is primarily an international public good provided by governments, which will have a central role in its management;
6. Promote the free and open exchange of climate-relevant data, tools and scientifically based methods while respecting national and international policies;
7. The role of the Framework will be to facilitate and strengthen, not to duplicate;
8. The Framework will be built through user–provider partnerships that include all stakeholders.

The implementation plan also suggests first steps for the priority areas. It should be noted that the priority area “Energy” was later included in the Implementation Plan [44].

The **Sendai Framework for Disaster Risk Reduction 2015 – 2030** is a UN (United Nations) Framework and was adopted by UN Member States in March 2015 at the Third UN World Conference on Disaster Risk Reduction. It is the follow-up instrument of the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. The following materials support the interpretation and implementation of the Sendai Framework:

– Reading the Sendai Framework for Disaster Risk Reduction 2015-2030, 2015
– Coherence and mutual reinforcement between the Sendai Framework for Disaster Risk Reduction 2015-2030 and international agreements for development and climate action [47]
– Words Into Action: Implementation Guides for the Sendai Framework [48]

The goal of the Sendai Framework is to “Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience” [49, p. 12].

As pointed out by the [50], disaster risk management is not a sector itself. The Sendai Framework rather provides a disaster risk management paradigm which should be applied “across international and national agendas and sectors” [50, p. 6]. Reading the Sendai Framework [50] furthermore mentioned that the Sendai Framework constitutes a shift from disaster management to disaster risk management, focusing not only on managing the event but on “managing the process which creates the risk”. The following guiding principles as defined in the Sendai Framework, support states and other stakeholders to implement the Sendai Framework:

- “Each state has the primary responsibility to prevent and reduce disaster risk”
- Responsibilities need to be shared by “central governments and relevant national authorities, sectors, stakeholders, as appropriate to their national circumstances”
- Disaster risk management aims to protect people and their property, while promoting and protecting all human rights, “including the right to development”
- An “all-of-society engagement and partnership” is needed, including empowerment and non-discriminatory participation
- Disaster risk reduction requires coordination mechanisms within and across sectors, with relevant stakeholders at all levels, with clear articulation of responsibilities
- Empowerment of local authorities and communities, e.g. through resources, incentives, responsibilities.
- A multi-hazard approach and risk-informed decision-making, based on open exchange, accessible, up-to-date, comprehensible, science-based information is required
- Coherence of policies, plans, practices and mechanisms across sectors is important
- Local and specific characteristics of disaster risks need to be understood to determine measures
- Underlying disaster risk factors need to be addressed through informed investments to enable sustainable development
- “Building Back Better” and increasing public education and awareness should aim to prevent the creation of risks and to reduce disaster risk
- Strengthening international cooperation and the fulfilment of commitments are crucial for disaster risk management
- Developing countries and countries with specific disaster risk challenges need support from developed countries, which should be tailored to their needs

The Sendai Framework identified seven global targets and four priorities for action. The seven targets include:

1. A substantial reduction in global disaster mortality by 2030
2. A substantial reduction in the number of affected people globally by 2030
3. A reduction in direct disaster economic loss by 2030
4. A substantial reduction of disaster damage to critical infrastructure and disruption of basic services by 2030
5. A substantial increase in the number of countries with national and local disaster risk reduction strategies by 2020
6. Improved international cooperation to developing countries through adequate and sustainable support

7. A substantial increase in the availability of and access to multi-hazard early warning systems and disaster risk information and assessments by 2030

The four priorities for action that are defined in the Sendai Framework are listed below:

Priority 1: Understanding disaster risk

“Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment.” [49, p. 14].

Priority 2: Strengthening disaster risk governance to manage disaster risk

“Disaster risk governance at the national, regional and global levels is vital to the management of disaster risk reduction in all sectors and ensuring the coherence of national and local frameworks of laws, regulations and public policies that, by defining roles and responsibilities, guide, encourage and incentivize the public and private sectors to take action and address disaster risk” [49].

Priority 3: Investing in disaster risk reduction for resilience

“Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment. These can be drivers of innovation, growth and job creation. Such measures are cost-effective and instrumental to save lives, prevent and reduce losses and ensure effective recovery and rehabilitation.” [49, p. 18]

Priority 4: Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction

“The steady growth of disaster risk, including the increase of people and assets exposure, combined with the lessons learned from past disasters, indicates the need to further strengthen disaster preparedness for response, take action in anticipation of events, integrate disaster risk reduction in response preparedness and ensure that capacities are in place for effective response and recovery at all levels.” [49, p. 21]

For each priority, the framework lists key activities at the national and local levels as well as on the global and regional levels, which should be considered and implemented.

To address Priority 1 at the national and local level, for example, the Sendai Framework suggests, among other things, to (1) encourage the collection, analysis, management, use and dissemination of relevant data and information, (2) to strengthen baselines and to “periodically assess disaster risks, vulnerability, capacity, exposure, hazard characteristics and their possible sequential effects” [49, p. 14], (3) to develop, periodically update and disseminate disaster risk information like risk maps to decision-makers, (4) to use geographic information systems (GIS) and innovative communication technologies to improve measurement tools and the collection, analysis and distribution of data and (5) to strengthen education and awareness in disaster risk reduction. On the global and regional level, the Sendai Framework e.g. (1) encourages the development and knowledge exchange of science-based methods and tools, (2) suggests surveys on multi-hazard disaster risks and to develop “regional disaster risk assessments and maps, including climate change scenarios” [49, p. 16],(3) promotes international cooperation, data sharing and the development of user-friendly systems and services to exchange information about best-practices, disaster risk reduction technologies, plans and measures. The Sendai Framework also refers to the existing networks and instruments to build on, like the “Making Cities Resilient: My city is getting ready” campaign (see below).

Addressing Priority 4 at the national and local level, the Sendai Framework points out the need to periodically update disaster preparedness and contingency policies and plans, also considering climate change scenarios and their impact and the need to “promote resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide live-saving and essential services" [49, p. 21]. The Sendai Framework furthermore encourages the use of multi-hazard, multi-sectoral forecasting and early-warning systems, and calls for the development of capacities in the post-disaster phase in order to reduce disaster risk in the short, medium and long term e.g. through land-use planning and relocation of infrastructure.

The Sendai Framework also acknowledged the Global Platform for Disaster Risk Reduction and regional platforms for disaster risk reduction "as mechanisms for coherence across agendas, monitoring and periodic reviews". The Global Platform for Disaster Risk Reduction is a meeting held every two years to enable knowledge transfer, discussions and partnership-building. An important function is "to share experience and formulate strategic guidance for the implementation of global disaster risk reduction agreements" [51], now namely the Sendai Framework.

The UNGA (United Nations General Assembly*)* and UNISDR (United Nations Office for Disaster Risk Reduction) "Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction", which was published in December 2016 [52], defines disaster risk terms and presents indicators for each global target that enable the assessment of the global progress in the implementation of the Sendai Framework. On 2. February 2017 the UN member states adopted the indicators and terminology [53].

The **Making Cities Resilient Campaign** was launched in 2010 and is led by the UNISDR. It aims to support sustainable urbanisation, knowledge exchange and provides support for implementing the Sendai Framework. The toolkit section provides cities and stakeholders with useful tools that help to identify risks and to prepare cities for sustainable development. The UNISDR guidance document "Ten Essentials for Making Cities Resilient" aims to support the implementation of the Sendai Framework at the local level [54]. For every Essential a rationale and suggestions, as well as examples, tools and resources are given to support users to take action.

The Disaster Resilience Scorecard for Cities from May 2017 is built around the UNISDR 10 Essentials for Making Cities Resilient and aims to "assist countries and local governments in monitoring and reviewing progress and challenges in the implementation of the Sendai Framework" and "to enable the development of a local disaster risk reduction strategy (resilience action plans)" [55]. A preliminary and a detailed assessment tool are provided for this purpose. The preliminary assessment tool is intended to be used within a 1 to 2 day multi-stakeholder workshop, while the detailed assessment tool comprises a multi-stakeholder exercise that can take up to four months. The latter can be the basis for a detailed city resilience action plan. The Disaster Resilience Scorecard for Cities is meant to be used together with the Quick Risk Estimation (QRE) tool, which is available on the UNISDR – Making Cities Resilient website [56]. The QRE aims to identify and understand current and future risks and thus to improve risk awareness.

2.3 EU Guidelines and Actions for Climate Services

On the EU level, several guidelines and documents are relevant when addressing Climate Services, like the Roadmap for Climate Services [11] and the EU Adaptation Strategy [57] with its accompanying documents. While the Staff Working Document (SWD) 134 'guidelines on developing an adaptation strategy' [58] provide 6 steps to guide users through the process of developing an adaptation strategy, the EU-GL [1] are more specific, lay out how climate aspects can be incorporated into project planning and give more detailed information on how to evaluate exposure to climate hazards, assess vulnerabilities and risks. The EU-GL [1] also present key climate variables and climate-related hazards that should be considered when addressing climate change. The SWD 137 'Adapting infrastructure to climate change' [59] provides a more detailed set of climate impacts on infrastructure, regarding different sectors as well as different regions.

Roadmap for Climate Services

The European Research and Innovation Roadmap for Climate Services was published in March 2015 [11]. It provides a framework and the basis for discussion about ways to develop the market for climate services, which offers benefits to society. The roadmap identified three main challenges: (1) enabling market growth,

(2) building the market framework and (3) enhancing the quality and relevance of climate services. Nine activities and 25 specific actions were proposed to address these challenges.

As pointed out by the Roadmap for Climate Services [11] gaps exist in the underlying science as well as (or even more) in the field of transforming data/ knowledge / information in a way that society/policy makers etc. can use it within their decision-making process. A stakeholder analysis was performed to assess the drivers and constraints for incorporating information on climate change in decision making. While long-term climate change appears to be less relevant and / or difficult to integrate into decision making, short-term weather forecasts and extreme events are considered very relevant. Economic benefit, positioning the organisation to be attractive for customers (branding, green labelling) and policy requirements are the main drivers for organisations to incorporate information about climate change into their decision-making process. The main constraints are the difficulty to incorporate/ combine available climate information with the organisation's logics/ processes, the different timeframes for climate change impact and for planning cycles (especially evaluating investment and return), and to translate climate change impacts for organisations into economic/monetary terms [11, pp. 15-16]. The following requirements for climate services were outlined: Climate services need to be reliable, from trustworthy sources, "fit-for-purpose" and usable.

Based on the stakeholder survey and literature analysis the following priorities for climate services were identified: (1) "stronger focus on demand-side and on provider-user interface". (2) "Multidisciplinary approach and innovation" meaning to encourage more cooperation between providers, purveyors and users, as well as between scientists from different fields, practitioners, software designers. (3) "integrating climate information with multiple sources and with user organisation logics, practices, (4) improving regional modelling capabilities, and the capacity to provide regional and sectoral assessment of changes, risks and impacts at timescales relevant for decisions to businesses, industry and local authorities, (5) building capacities and "communities of practice", (6) quality control, certification and standards [11].

Results from the stakeholder consultation as well as the analysis of relevant literature, the assessment of outputs from climate service related projects and discussion sessions led to the development of the Roadmap for Climate Services. The gathered information was used to identify the main challenges mentioned above and to more specifically define actions necessary to enhance the use and usefulness of climate services. Beside the collaboration with users and the incorporation of climate data with other data (e.g. socioeconomic, land-use data), the development of higher resolution data and the integration and presentation of uncertainty are important aspects.

EU Strategy on Climate Adaptation

In response to current and projected impacts of climate change in the EU, the EU released the White Paper 'Adapting to climate change: Towards a European framework for action' [60], which proposed a number of actions to tackle climate change impacts. Based on the White Paper [60], an EU Strategy on adaptation to climate change was adopted in April 2013 [57], aiming to foster a "systematic exchange of best practices" within the EU and to "help the EU move towards a low-carbon and climate resilient economy" [57].

The objectives of the strategy are to (1) promote action by Member States, (2) to enable better informed decision-making and (3) to climate-proof EU actions, "promoting adaptation in key vulnerable sectors" [57].

Eight Actions are outlined in the EU Adaptation Strategy 2013 to help achieve these objectives.

1. Action 1: Encourage all Member States to adopt comprehensive adaptation strategies […]
2. Action 2: Provide LIFE funding to support capacity building and step up adaptation action in Europe. (2013-2020) […]
3. Action 3: Introduce adaptation in the Covenant of Mayors framework (2013/2014) […]
4. Action 4: Bridge the knowledge gap […]

5. Action 5: Further develop Climate-Adapt as the “one-stop shop” for adaptation information in Europe […]
6. Action 6: Facilitate the climate-proofing of the Common Agricultural Policy (CAP), the Cohesion Policy and the Common Fisheries Policy (CFP). […]
7. Action 7: Ensuring more resilient infrastructure […]
8. Action 8: Promote insurance and other financial products for resilient investment and business decisions […]” [57]

Actions 1, 2 and 3 are designed to help promoting action by Member States. Guidelines for adaptation strategies, including cross-border issues and the incorporation of national disaster risk management plans, are provided. LIFE funding will give incentives for adaptation actions in vulnerable areas and the Covenant of Mayors framework is supposed to help cities to adopt adaptation strategies.

In order to improve informed decision-making, the following knowledge gaps were identified (The list below is taken from the [57], Action 4):

- information on damage and adaptation costs and benefits;
- regional and local-level analyses and risk assessments;
- frameworks, models and tools to support decision-making and to assess how effective
- the various adaptation measures are;
- means of monitoring and evaluating past adaptation efforts.

Addressing these gaps and developing the European Climate Adaptation Platform (Climate-ADAPT) to bundle all information are the core elements of actions 4 and 5. Actions 6 to 8 are targeted to climate-proof EU action in vulnerable sectors.

The Climate-ADAPT portal is considered a key element of the EU Adaptation Strategy and was launched in March 2012 [57]. The Climate-ADAPT portal is a webpage that bundles information and data about (a) climate change in Europe, (b) adaptation strategies, (c) projects and case studies to support society, decision-makers and citizens to make informed-decisions, to adopt climate adaptation strategies and to move towards a more resilient Europe. The Climate-ADAPT portal enables users to access and share data, information and tools and thus fosters knowledge exchange.

The EU Adaptation Strategy comprises several documents that support the implementation of the strategy. The Commission SWD 134 ‘Guidelines on developing adaptation strategies’ [58] and the Commission SWD 137 ‘Adapting infrastructure to climate change’ [59] are especially relevant for the CLARITY project. The EU-GL: non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient is a related document that is also part of the EU effort to mainstream climate change adaptation [1]. The EU Adaptation Strategy is currently being evaluated and results are supposed to be available in 2018 [57].

The EEA ‘Climate change, impact and vulnerability in Europe 2016’ report [6] “aims to support the implementation and review process of the 2013 EU Adaptation Strategy” [61]. The report provides a comprehensive overview on climate change, its impacts and vulnerability in Europe, also with regards to climate change impacts on cities as well as on energy and transport.

The document ‘Opinion of the European Committee of the Regions – Towards a new EU climate change adaptation strategy – taking an integrated approach’ [10] mentioned and appreciated the release of the covenant of majors monitoring [62] and reporting templates [63] and of the adaptation preparedness scoreboard, whose development was part of Action 1 of the EU Adaptation Strategy 2013. These efforts help to assess the preparedness of member states and municipalities, help to collect and analyse data in a structured way and will help to assess the impact of adaptation measures [64]. Thus, the knowledge gap concerning the monitoring and evaluation of adaptation efforts, as listed in [57] Action 4, was addressed.

However, Hertell [10] also states that “local and regional authorities regularly point out 1) the lack of (access to) useful and understandable climate information and 2) the lack of expertise and experience in interpreting this information as barriers to adaptation action. Further assistance — through documentation and good practice sharing — is therefore required to first guide them through the already-existing information, and secondly to help them in the exercise of downscaling and interpreting impacts at a city/region scale” [10]. These challenges are directly addressed by the CLARITY project.

Guidelines on developing adaptation strategies (SWD (2013) 134 final)

The Commission SWD 134 ‘Guidelines on developing adaptation strategies’ [58] accompanies the EU Adaptation Strategy [57] and lays out 6 steps to develop an adaptation strategy. For each step, the guidelines provide additional subsequent steps, which should be considered during the preparation of an adaptation strategy. Real world examples and links to potential information sources further assist users to build an adaptation strategy. The guidelines on developing adaptation strategies also provide a check-box list ([58], Annex 2) to guide users through the process of developing an adaptation strategy. These steps as well as the check-box templates are incorporated in the Adaptation Support Tool that is available on the Climate-ADAPT website.

The Commission SWD 137 ‘Adapting infrastructure to climate change [59] accompanies the EU Adaptation Strategy [57], which highlighted the need to promote adaptation in vulnerable sectors and specifically mentioned the need for more resilient infrastructure in Action 7. Climate proofing infrastructure is considered crucial given the long life-span of our infrastructure. Adapting infrastructure in urban areas is mentioned specifically because a large part of important infrastructure is located in cities, is highly interlinked and covers several sectors ([59], Section 1.3). In addition, a large part of EU’s population lives in cities and is therefore directly affected.

In general, climate change related threads are damage or destruction of infrastructure due to extreme events; “coastal flooding and inundation from sea level rise; changes in patterns of water availability; and effects of higher temperature on operating costs, including effects in temperate and/or permafrost” ([59], Section 1.3).

In cities climate change impacts can be accentuated (e.g. urban heat island effect). Climate change induced challenges are higher temperatures in summer (more extreme and frequent heat waves), floods, and “ensuring energy and water supply during consumption peaks (e.g. cooling in “hotter” summers and heating in “cooler” winters)” [59]. Old infrastructure, e.g. in the transportation sector or energy sector, might be more susceptible to extreme events and can lead to increased casualties and disruptions.

Coastal areas will be especially affected by sea level rise, changes in ocean currents and coastal erosion ([59], Section 2.2.2). Referring to the Thematic Assessment Marine and Coastal Environment EEA study [65], the SWD 133 [66] mentioned that integrated coastal zone management and ecosystem-based adaptation, like forest rehabilitation and dune restoration, proved to be more suitable to protect coastal infrastructures than hard structures historically used. The Commission SWD 133 "Climate change adaptation: marine and coastal issues" [66] provides further information for coastal areas.

In mountainous regions “increasing ambient temperature, which leads to a loss of glacier mass […], reduced snow cover, thawing of permafrost and changing precipitation patterns” ([59], Section 2.2.3) might lead to more frequent and intense natural hazards like landslides, rock fall or floods [59]. These changes can lead to destruction of infrastructure and to changes in the water cycle, which would affect e.g. the water availability for hydropower plants. Reduced snow cover and increasing temperatures will also have adverse effects on winter activities and the regional economy [59]. In addition, EU’s outermost regions are recognized to be specifically vulnerable to climate change ([59], Section 2.2.4).

The Annexes 1 to 3 of the [59] document summarise the climatic pressures and associated risks for transport infrastructure, energy infrastructure and the buildings and constructions sector specifically relevant for CLARITY.

Dealing with Uncertainty

Dealing with uncertainty is unavoidable in climate-science and communicating uncertainty is critical in order to enable sensitive decisions and trust into climate data and services. The Roadmap for Climate Services [11] explicitly included uncertainty in one of their proposed specific actions. Otto et al. [67] initiated a 3-day workshop with participants from 10 European Union projects in February 2016 to share information about uncertainty in climate science and to discuss how to best handle uncertainty in climate services in order to enhance trust. The lessons learned from the workshop are presented below [67, p. S268]:

Transparency: The need to maintain traceability about sources of uncertainty was emphasized across all groups. While information about uncertainty may need to be condensed when it is communicated from provider to subsequent users, a traceable chain of documentation is necessary for full transparency. This assumes documentation of all processing steps.

Layering: A layered approach allows tailoring the amount of information on uncertainty under different decision frameworks. This can only be achieved by bidirectional communication between providers and users, to ensure that the user's needs are understood and that appropriate and accurate information is provided and appropriately interpreted.

Disclosure: A tailored approached is not meant to hide uncertainty but rather aims to detect and document all known components of uncertainty, including knowledge gaps and issues relating to the methodology and processing of data. When communicating uncertainty, it is important to emphasize what we understand and to recognize that as research improves knowledge, some uncertainty sources may be reduced."

Uncertainty is a major challenge when working with predictions about future climate change and its impacts. However, uncertainty should not lead to inaction, but rather calls for "win-win, low-cost, and no-regret adaptations" [57].

The EU-GL [1], directly address this challenge: "Uncertainties in climate variability, future society, the scale of future greenhouse gas emissions, and scientific knowledge on how components of the climate system interact, all lead to uncertainty in climate projections. Outputs from different climate models can disagree on both the degree and sign of change in a climate variable, presenting users with a wide range of possible climate futures to deal with." [1, p. 13]. In addition, information necessary to assess asset integrity and safety issues, like extreme values e.g. the 1-in-10-year rainfall event, might not be available from climate model outputs. The EU-GL [1] therefore propose to define "climate-related thresholds for the project and evaluate whether existing climate trends are threatening to exceed them on an unacceptably frequent basis".

"The key objective in the face of uncertainty is therefore to define and implement design changes (adaptation options) which both provide a benefit in the current climate as well as resilience to the range of potential future climate change" [1, p. 15].

2.4 EU Non-paper Guidelines for Project Managers

The EU Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient [1] (see Annex I for a summary of the content), identified as "EU-GLs" in the context of CLARITY, have been published with the aim to help project managers to account for current climate variability and future climate change within their infrastructure project developments (ranging from urban planning to civil buildings, critical infrastructures design), in order to make investments climate resilient. The guidelines make reference to a number of relevant EU policies or guidelines that are relevant to assets and infrastructure, like e.g. the "Guidance on integrating climate change and biodiversity into environmental impact assessment", published in March 2013 [68].

The EU-GLs are structured so as to provide a toolkit to incorporate climate resilience into a conventional project cycle. The logic and the terminology adopted in the document reflects the state of the art knowledge in the field of climate change adaptation at the moment of the document release in 2013, represented by the Fourth Assessment Report (AR4) of IPCC [69]. The significant methodological shift introduced by the AR5 [7], which reconnects the climate risk/impact modelling to the more consolidated modelling framework from DRR (Disaster Risk Reduction) domain, requires an update of the EU-GLs approach to be adopted within CLARITY framework (see **Figure 9**, **Figure 10**). According to a number of studies (see, among them, EU-H2020 Resin project [70]) the AR5 report has moved from a vulnerability-centred approach to a risk-based approach (see **Figure 11**).

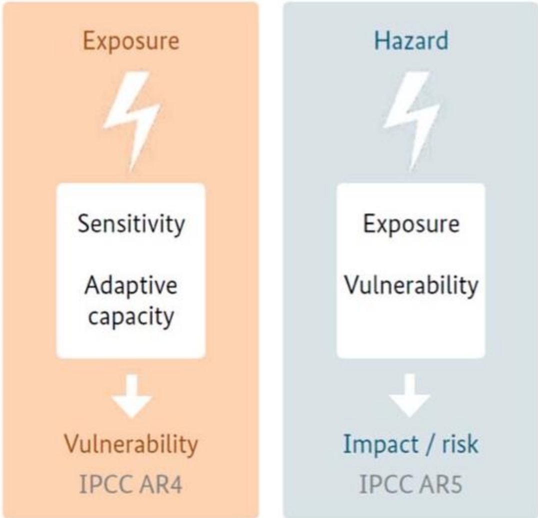


Figure 9: Differences in assessment approaches between AR4 [69] and AR5 [7].

Climate Change 2007 (AR4): Working Group II: Impacts, Adaptation and Vulnerability

Adaptive capacity: *the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.*

Exposure: *refers to the character, magnitude, and rate of climate change and variation to which a system is exposed.*

Sensitivity: *is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.*

Vulnerability: *is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.*

Climate Change 2014 (AR5): Working Group II: Impacts, Adaptation and Vulnerability

Adaptive capacity: *is the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.*

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.*

Hazard: *the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources*

Risk: *the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.*

Sensitivity: *the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct or indirect.*

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.*

Figure 10: Differences in terminology between AR4 [69] and AR5 [7].

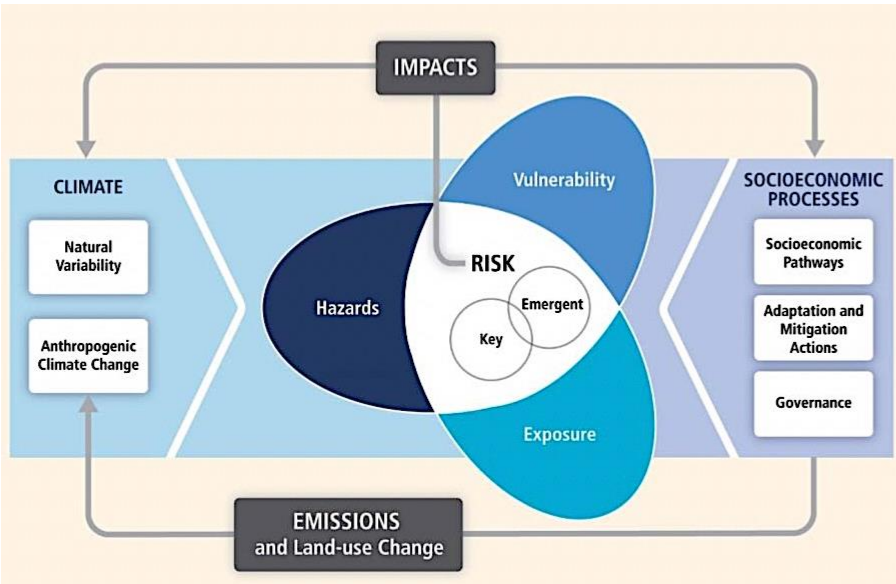


Figure 11: Methodological approach of IPCC AR5, where the risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure [7].

Indeed, the IPCC itself underlines that the approach has been updated compared to the previous AR4 report, also in consideration of the common agenda developed with UNISDR and the Sendai Framework for DRR, to promote an integrated modelling approach of DRR and Climate Change Adaptation (CCA).

In light of the new methodology, the risk (R) is therefore identified as a probabilistic convolution of the climate hazard (H), exposure (E) (of human and natural systems) and vulnerability (V), meant as sensitivity and adaptive capacity (R = HxExV), in line with the consolidated definition in the field of risk science (see Section 3).

It is important to note that risk can change over time driven by the change of factors that influence climate hazard, exposure, and vulnerability (e.g. climate signals modification, changes in land use and population distribution due to urbanization processes, and socio-economic capability for setting actions etc.). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability and/or increase resilience or adaptive capacity. Embedding effective risk reduction and adaptation strategies within the design and implementation of development and infrastructure projects then imply to consider the dynamics of vulnerability and exposure in relation to the relevant hazards affecting the area of the interventions. At the same time, effective adaptation strategies need to tackle issues which are often broader than climate risk reduction, with significant linkages with socioeconomic processes and sustainable development goals, which represent important co-benefits of adaptation, to be considered as relevant selection criteria when defining the design strategies of the project at hand.

Section 3.1 describes the updating process of EU-GLs carried out in the context of CLARITY to comply with the most recent methodological approaches in the field of climate and risk sciences, as well as within adaptation policies at EU level, increasingly aiming at integrating DRR and CCA strategies.

3 Methodology

This section outlines the working methodology adopted within CLARITY, identifying the background scientific approach in the field of climate and risk sciences at the base of the CSIS logic and its relation with the procedures identified by the EU-GL.

Section 3.1 describes the update of the EU-GL methodology in relation to the IPCC-AR5 framework; Sections 3.2 to 3.4 are devoted to the specification of scientific background in relation to the modelling of climate hazards, exposure, vulnerability, risk and impact (also in relation to the need of producing assessments and simulations referring to multi-risk conditions), to the assessment of the effects of adaptation measures and their integration within Decision Support Systems and tools; Section 3.5 focuses on the economic and social implications of climate risks and the expected benefits arising from the integration of adaptation measures within planning and design of urban development and or infrastructure interventions.

Figure 12 illustrates the EU-GL workflow as envisaged within CLARITY. The 7 steps from updated EU-GLs correspond to 4 steps needed to simulate climate risk/impact scenarios and 3 additional steps needed to assess the effect of adaptation measures and integrate them in the planning/design process (the back arrow from step 6 to step 1 indicate the need of producing alternative scenarios which simulate the effect of adaptation options and measure the variation in terms of risk/impact deriving from their implementation).

Each step is fed by different types of datasets and connected with the others in terms of input and output.

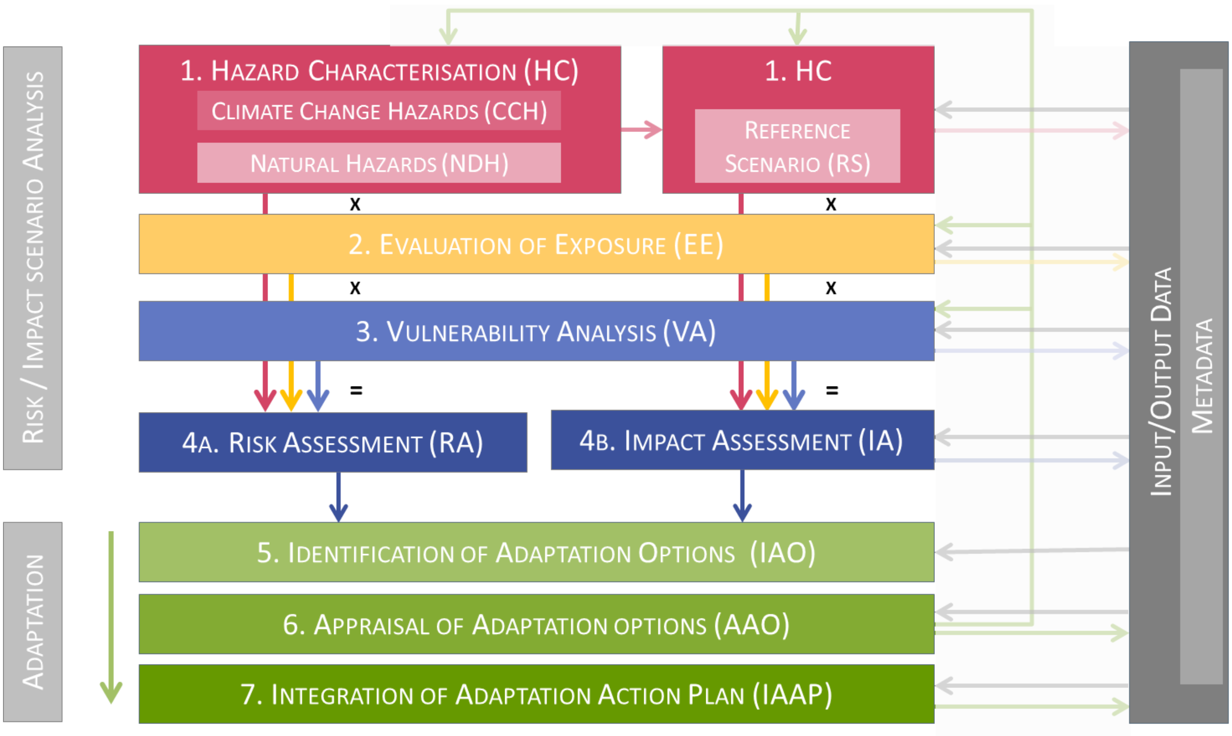


Figure 12: Schematization of the CLARITY modelling workflow in relation to the 7 steps of the EU-GLs.

3.1 Update of EU-GL Methodology

In relation to the objectives of CLARITY, the EU-GLs have been updated to comply with the IPCC-AR5 approach, adapting the corresponding content both in relation to the scientific methodological shift, and the original objectives underlying the "steps" of the Climate Resilience Toolkit (**Table 1**).

Table 1: Comparison of the 7 modules from the Climate Resilience Toolkit as presented in the EU-GL non-paper guidelines for project managers [1] and the 7 modules adapted for the CLARITY project.

Guidelines for Project Managers, 2013: Climate Resilience Toolkit	CLARITY
1. Identify Climate Sensitivity 2. Evaluate Exposure 3. Assess Vulnerability 4. Assess Risks	1. Characterize Hazard (HC) 2. Evaluate Exposure (EE) 3. Vulnerability analysis (VA) 4. Assess Risks and Impact (RA & IA)
5. Identify adaptation options	5. Identify adaptation options (IAO)
6. Appraise options	6. Appraise adaptation options (AAO)
7. Implement	7. Implement/Integrate Adaptation Action Plans (IAAP)

In the following, the 7 steps of the Climate Resilience Toolkit from EU-GLs as applied within CLARITY project, are illustrated.

1. Characterize Hazard (HC)

The first step to build an adaptation strategy is to identify **hazard conditions** in the project area, in relation to a range of climate variables and natural hazards. This has to be done both for the baseline/observed climate and for the predicted future climate in the project area.

Climate variables and hazards related to baseline/observed climate, can be modelled by processing historical datasets. As first step the relevant climate variables are selected and serve as a base to derive climate indices necessary for the hazard analysis. For each climate-related hazard one or more relevant indices, such as probability of occurrence, exceedances over threshold values, are identified. The indices are calculated for a defined climatic period and climate variables can be combined with other parameters to evaluate characteristics of more complex natural hazards, such as landslides or floods. Given a defined hazard scale, the hazard conditions in the project area can be quantified.

In dealing with climate change conditions, it is essential to determine for each climate variable or hazard considered how this may evolve in the future, by examining the outputs of climate models. Uncertainty in climate model projections should be acknowledged and recorded by presenting a summary of climate model outputs using appropriate downscaled data.

Therefore, hazard analysis focuses on three main characteristics: intensity, frequency, and size or location of the natural hazard.

- Intensity is the observed or potential magnitude of a given natural hazard.
- Frequency relates to how often a natural hazard of a particular intensity is likely to occur, or has occurred, in a given location. This probability is often expressed in return periods.
- Location refers to the affected geographical area. A careful analysis must be made of the actual area to be considered in any project, given that on the one hand the intensity of an event may be related to the evolution of a climatic episode in nearby areas, and on the other hand the

modification of e.g. drainage and land use conditions in the project area may modify the intensity of threats from adjacent areas.

Concerning hazard assessment and the needed downscaling of climate models in the area of interest, it is of outmost importance to take into account the environmental variables affecting the addressed area in different ways (e.g. urban morphology, surface types, green cover), especially when dealing with urban development and building/open spaces design.

2. Evaluate exposure to climate hazards (EE)

Once the **hazard characterization** in the project area has been assessed, the next step is to evaluate exposure to climate hazards of the elements at risk considered (e.g. population, buildings, infrastructures, etc.) relevant at the project location(s).

The exposure is the quantitative distribution, in space and time, of elements exposed (people, buildings, infrastructures, etc.) grouped on the base of their behaviour under effect of the hazard into categories (called "vulnerability classes"), defined on the base of specific characteristics (i.e., age for people, structural-typological characteristics for buildings, etc.), able to influence the damageability of the elements exposed against hazards.
Due to differences in assessment approaches between AR4 [69] and AR5 [7] (see Section 2.4), the nature of the EU-GL modules 2a and 2b changes in CLARITY, resulting in:

- **Module 2a - Baseline exposure**, that is based on the current distribution of the elements at risk in the area of interest. Baseline exposure can be estimated by combining the available data on e.g. population distribution, land use and land cover (see Section 4.3). Exposure must be calculated separately for each element at risk type.
- **Module 2b – Future exposure**, that is based on the planned distribution of the elements at risk in the future. In CLARITY, this will usually correspond to the planned project and the expected distribution of the elements at risk will have to be provided by the user or by an expert working on their behalf.

Due to a combination of ethical and technical considerations, in the CLARITY project will not be specified individual elements at risk. Instead, all elements at risk of a certain type in a certain area will be grouped together, resulting in a per element at risk exposure map.

3. Vulnerability Analysis (VA)

In addition to exposure, the vulnerability of the elements at risk to the current and to the expected future climate needs to be assessed.

The vulnerability is the probability that a given exposed element of assigned characteristics is damaged by a given hazard intensity.

EU-GL foresees two sub-modules here, one for assessing the vulnerability to the current climate and one for assessing the vulnerability to the future climate. However, AR5 [7] defines the vulnerability is an inherent function of the elements at risk. Therefore, the EU-GL classification of modules 3a and 3b is obsolete and what needs to be done at this stage is to **assess the vulnerability of all element at risk types** that are present / expected to be present in the area of interest (from 2a/ab) **to the significant climate-induced hazards**[6].

Following the methodology that is presented in Section 3.3, we intend to work with "vulnerability classes" rather than allocating individual vulnerability function to each element at risk. Thus, an element at risk of the type "residential building" might belong to one of a few vulnerability classes for each of the significant

[6] "Significant" hazards are those that are either already present in the area or that are expected to become gain significance due to the future climate change (from module 1).

hazards (e.g. "low" for fire, "high" for flood, "medium" for heath waves etc.) and the vulnerability analysis proceeds in two steps:

1. Define the vulnerability classes for all relevant element at risk types. E.g. low/medium/high vulnerability classes for buildings; "children/adults/elderly" classes for people etc.
2. Define the vulnerability functions for all relevant element at risk type/hazard combinations.
3. Allocate all the elements at risk in the area of interest (from exposure analysis 2a/ab) to vulnerability classes, for each hazard type.

Since the elements at risk of a certain type in a certain area are be grouped together in exposure assessment step, their vulnerability will have to be expressed as a vulnerability matrix that indicates which percentage of the elements of risk of a certain type belongs to which vulnerability class for which hazard in this area. An example of such matrix, for a generic element at risk category, is shown in **Figure 13**.

VULNERABILITY CLASS i				
	Hazard Intensity (HI)			
Level of damage	**HI 1**	**HI 2**	**HI 3**	**...**
Low	5%	20%	50%	...
Medium	10%	30%	70%	...
High	20%	50%	80%	...

Figure 13: Example of a vulnerability matrix of a specific vulnerability class of a given element at risk under effect of a specific hazard.

The uncertainty, inherent in the assessment, should also be acknowledged in the final vulnerability classification, which is tricky as various uncertainties come together (modelling uncertainty resulting in hazard, uncertainty in projecting share and distributions of elements at risk, uncertainty in capability to better adapt and coping with the expected exposure.

4. Assess Risks and Impact (RA & IA)

This module provides a structured method of analysing climate hazards and their impacts to provide the fundamental information for decision-making.

In line with the updated approach as outlined in the IPCC-AR5, this evaluation is derived by the general relation R=H x E x V.

The risk and impact assessment[7] process work through taking into account the magnitudes and likelihoods of the impacts associated with the hazards identified in Module 2 - Evaluate exposure to climate hazards and assessing the significance of the assessed risks to the success of the project. Risk and impact assessment may well identify issues which have not been picked up in the vulnerability analyses.

- **Risk assessments**: aim at defining a synthetic index/coefficient, representing the convolution of the probabilities of different hazard intensities (H), in relation to the exposure (E) and vulnerability (V) conditions in a given area. Such a risk index is useful to allow high-level comparisons between alternative project options but does not allow detailed quantification of impacts on considered elements at risk.
  To produce reliable results that can be a sound basis for decision making in the field of infrastructure development, risk assessment should be always based on numerical modelling procedures (see Section 3.3). Probabilistic quantitative risk assessments can be undertaken in the early phases of the asset lifecycle, with different levels of detail (including the spatial resolution of the models' output) depending on the availability of exposure and vulnerability. This requires running various scenarios and comparing

[7] Risk is a probabilistic measure that relates to a cumulative effect of all (likely) hazard occurrences, whereas the impact merely indicates the effects of specific reference events.

the results with respect to the frequency of event occurrence and event magnitude by means of a probability distribution.

- **Impact scenario analysis**: as a complement to the risk assessment, by choosing in a "deterministic" way one or more reference events (among actually occurred past events or as a result of numerical hazard simulation models) the corresponding "impact scenario analyses" can be performed using numerical impact models, providing detailed damage evaluation on selected elements at risk following specific event(s) (Here again one has to consider the uncertainty delivered by the risk-modelling, and vulnerability modelling and the exposure modelling with respect to future distribution of the elements at risk..

  Unlike the risk assessment, the impact scenario analysis represents a simulation of the expected impacts of a specific hazard (in terms of intensity, location, etc.), derived from the application of an impact model able to correlate hazard (H), exposure (E) and vulnerability (V) characteristics to produce a detailed quantification of damage on elements at risk considered (e.g. population, buildings). An analysis based on the output of the impact models can be used to support decision-making, e.g. by applying multi-criteria and/or cost-benefit analyses on a number of relevant impact scenarios.

  Probabilistic assessment and uncertainty evaluation are provided also in relation to impact scenario analyses, mainly related to the probability of occurrence of the hazard type and intensity at the location of the analysis.

The detailed risk assessment and/or scenario analysis is divided into 3 steps: (1) It involves an analysis (e.g. refinement of hazard properties, exposure distribution, and algorithms to model the relations between H, E, V) by specialists to quantitatively evaluate risks while taking into account climate (and socio-economic) change. (2) Aspects and characteristics of the most relevant climate hazards need to be defined (e.g. magnitude and direction of change, statistical basis, averaging period and joint probability events). In addition, it is also essential to determine the aspects and characteristics related to exposure and vulnerability parameters relevant for the elements at risk considered in the area of interest. (3) The ability of the project to cope with existing climate variability and with future climate hazards should be assessed. This typically involves the use of numerical models (e.g. climate impact models), that describe some element of the project, namely the relevant exposure and vulnerability parameters likely to be affected by the hazard(s) considered (e.g. spatial and technical characteristics of ground and underground floors of a building in a flood-prone area). The assessment should involve a number of climate models (e.g. hydrological, flood risk, heat wave models, etc.) as well as specific vulnerability functions in relation to the hazard(s) and element(s) at risk considered. A range of future climate scenarios should be investigated based on a number of climate models and a range of greenhouse gas emissions scenarios, such as RCP4.5 and/or RCP8.5.

5. Identify adaptation options (IAO)

In order to take into account climate vulnerabilities and risks that have been identified through application of Modules 1 to 4, it is necessary identify adaptation options, followed by a detailed qualitative and quantitative assessment of the options.

The application of an adaptation option within the project implies a variation in the risk assessment or in the impact scenario analysis compared to the "baseline" of the project, since it:

- modifies relevant microclimate variables (e.g. albedo, runoff, etc.),
- modifies exposure of elements at risk (e.g. delocalization of residential areas),
- modifies the vulnerability function of a given element at risk (or of its component) in relation to the hazard parameter considered (e.g. improved thermal efficiency of the building envelope)
- modifies the exposure level (e.g. extending the flood plain of a channel reduces the flood level and consequently the exposure of the elements at risk).

Thus, the selection of one or more adaptation options allows performing an “alternate run” of risk and impact models and their comparison in terms of impacts.

Identifying adaptation options typically involves diverse fields of expertise and stakeholders’ domain, to allow project managers to gain a more detailed understanding of the pros and cons for each option. Technical experts and external stakeholders should attend such workshop to realistically estimate potential effects. To be well prepared for the workshop, project managers should make themselves familiar with respective guideline documents, best practice adaptation examples, engineering standards etc.

After identifying available adaptation options, the next step is to select a shortlist from the available options for the specific project. This shortlist should contain a clear benchmarking of the benefits of the adaptation options, both in terms of hazard, exposure and vulnerability reduction (see Module 5 Identify adaptation options), both of related socio-economic co-benefits (such as increase in liveability, biodiversity, and selection ability to respond to multiple hazards, etc.)

6. Appraise adaptation options (AAO)

In essence, this module comprises a cost-benefit-analysis (CBA) of climate change adaptation measures. The objective of any standard CBA is to select efficient and ‘optimal’ options i.e. those maximising net benefits. The methodology requires an economic appraisal, i.e. from the perspective of the country as opposed to the financial appraisal which covers project promoter relevant impacts only.

The main steps outlined in the EU-GL [1] are summarized below to provide an overview:

- Determine the project boundary: This step involves the definition of climate-related impacts and stakeholders that should be included. “The impacts are defined in qualitative terms over the project forecast period” [1] and should be evaluated under at least one future climate change scenario.
- Define the forecast period and depreciation discount rate: “The project forecast period […] should reflect the economic life of the investment project as a whole.” [1].
- Establish project baseline(s): The project baseline is represented by scenarios without implementing climate change adaptation options.
- Identify costs and benefits of the various options: Draw up a short list of technically and legally feasible adaptation options/option mixes.
- Value costs and benefits of adaptation options: Determine investment and operating costs of the options. “Establish unit values for benefits.”
- Assess impact and effectiveness of options.

7. Implement/Integration of Adaptation Action Plan (IAAP)

It is necessary to integrate adaptation action plan into the project development cycle.

Based on the previous steps, make decisions about modifications to technical project design and management options and develop an implementation plan for the selected adaptation measures. The implementation should clarify roles and responsibilities for the relevant stakeholders who are involved, as well as clear descriptions of how the adaptation option(s) should be implemented and what they will require in terms of resources to implement and identify actions that need cooperation and thus specific communication channels.

3.2 Climate Intelligence

The role of Climate Intelligence within CLARITY is to provide climate data for the reference conditions and the scenarios (including urban planning) driven by end-user needs; to provide downscaled climate signals based on the IPCC climate scenarios; to implement models and algorithms that use available local data and models for improving the projections of environmental variables by further downscaling and bias correction; and to connect selected environmental variables to meteorological signals by providing fit-to-purpose hazard models. In order to comply with the requirement of CLARITY towards a multi-risk assessment, a multi-model approach is considered that delivers climate data for reference and adaptation scenarios at different time and spatial scales (and inherently with different degrees of spatial resolution) focusing at the defined demo cases. CLARITY´s concept builds upon existing climate data and information, and specifically existing climate services, such as the Copernicus Climate Change Services (C3S) projects SWICCA[8] and UrbanSIS[9]. The purpose of this sub-section is to provide a generic background description of current techniques for climate prediction (or forecast) and climate projection, which are behind the climate data that will be available in the CSIS.

3.2.1 Climate modelling: historical period and future scenarios

The modelling workflow envisaged by CLARITY (see **Figure 12**) is based on a four modelling steps process needed to simulate climate risk/impact scenarios, assess the effect of adaptation measures and integrate them in the planning/design process. In particular, the simulation of the effect of specific adaptation options will provide knowledge-based data needed for the quantification of the variation in terms of risk/impact deriving from their implementation. Underlying this concept is the need to attain a set of scenarios that establish the basis for adaptation measure comparability built on existing (historic to present) data sets that characterise the reference conditions. These scenarios are projected into future climate conditions with the full chain of elements required to perform an impact assessment, from climate forcing over local conditions to climate-related hazards and impacts. The comparison between reference and projected hazard impact indicates the effect of climate change. When using future climate data on an impact assessment it is thus necessary to guarantee that the user driven sectoral scenarios are consistent with the global or regional development scenarios (e.g. the RCPs) underlying the climate projection.

The simulation of a pre-defined historical period establishes also the control conditions needed to evaluate the overall ability of the model to simulate meteorological and climatological processes. Reanalyses techniques offer estimates of historical atmospheric, hydrographic or other climate relevant quantities, by processing past climate data using fixed state-of-the-art weather forecasting or ocean circulation models with data assimilation techniques. Global reanalysis datasets are produced by several agencies, such as the ECMWF, the National Centers for Environmental Prediction (NCEP), or the Japan Meteorological Agency (JMA). ECMWF´s reanalyses products (see **Table 2**) are of particular interest for CLARITY purposes to evaluate historical climate on European scale.

Figure 14 provides a good example of the global climatology analysis for a 25-year period based on multi-model ensemble and reanalysis data. Here, the multi-model annual mean air temperature (2 m) is shown to agree with the reanalysis within 2°C in most areas, despite several locations where the biases are much larger (high elevations over the Himalayas and parts of both Greenland and Antarctica, near the ice edge in the North Atlantic, and over ocean upwelling regions off the west coasts of South America and Africa). The uncertainty within observations is visible in the inconsistency across the three global reanalyses.

[8] http://swicca.climate.copernicus.eu/
[9] http://urbansis.climate.copernicus.eu/

Table 2: List of reanalysis datasets available for download at ECMWF[10].

Dataset	Time period	Atmosphere	Atmospheric composition	Ocean waves	Ocean sub-surface	Land surface	Sea Ice
ERA5	2010-present	✔		✔		✔	
ERA-Interim	1979-present	✔		✔		✔	
ERA-Interim/Land	1979-2010					✔	
CERA-SAT	2008-2016	✔		✔	✔	✔	✔
CERA-20C	1901-2010	✔		✔	✔	✔	✔
ERA-20CM	1900-2010	✔		✔		✔	
ERA-20C	1900-2010	✔		✔		✔	
ERA-40	1957-2002	✔		✔		✔	
ERA-15	1979-1993	✔				✔	
ORAS4	1958-2015				✔		
ORAP5	1979-2013				✔		✔
MACC	2003-2014	✔	✔				

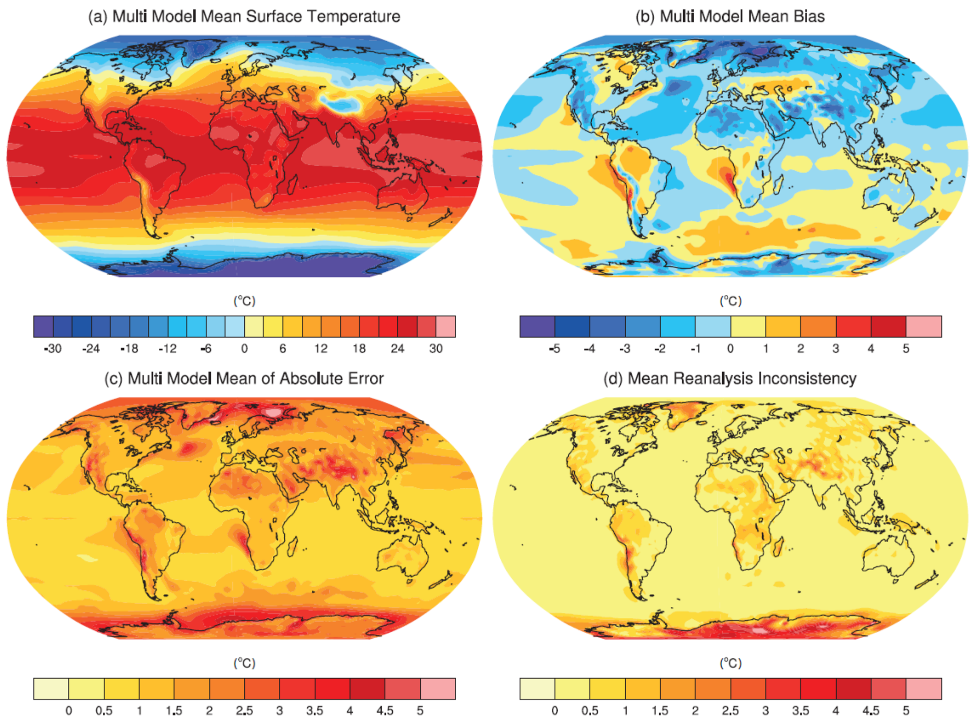


Figure 14: Annual-mean surface (2 m) air temperature (°C) for the period 1980–2005. (a) Multi-model (ensemble) mean constructed with one realization of all models available in CMIP5. (b) Multi-model-mean bias as the difference between the CMIP5 multi-model mean and the climatology from ERA-Interim. (c) Mean absolute model error with respect to the climatology from ERA-Interim. (d) Mean inconsistency between ERA-Interim, ERA 40-year reanalysis (ERA40) and Japanese 25-year Reanalysis (JRA-25) products as the mean of the absolute pairwise differences between those fields for their common period (1979–2001) (source: [71]).

[10] https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets, accessed in January 2018

Because the global reanalyses datasets may not provide the users with the needed spatial resolution there have been efforts to deliver higher resolution reanalysis products, such as the EC-funded project "European Reanalysis and Observations for Monitoring" (EURO4M[11]), or its successor "Uncertainties in Ensembles of Regional Reanalyses" (UERRA[12]). In the C3S project UrbanSIS, the UERRA-ALADIN reanalysis dataset [72], with an horizontal resolution of 11 km, was used to provide the necessary meteorological lateral boundary conditions to the dynamical downscaling with HARMONIE-AROME [73], that will be extensively used in CLARITY within DC2 (see Section 3.2.4).

It is known that climate variability exists both in reality and in climate simulations. Therefore, climate change projections require multi-model ensembles, which span a range of effects of e.g. different emission and land use scenarios defined in the RCPs. The Coupled Model Intercomparison Project (CMIP) established a standard experimental protocol for studying the output of global models, providing a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. CMIP Phase 5 (CMIP5[13]), ended in 2013, promoted a standard set of model simulations targeted at evaluating how realistic climate models are in simulating the recent past, providing projections of future climate change, and understanding some of the factors responsible for differences in model projections. The concept for the upcoming CMIP6[14] includes assessments of model performance during the historical period and quantifications of the causes of the spread in future projections.

3.2.2 Global Climate Models

Climate models constitute a numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties. These are the primary tools for investigating the response of the climate system to various forcings, for making climate predictions on seasonal to decadal time scales and for making projections of future climate. The complexity of these computational tools ranges from simple energy balance models to complex Earth System Models (ESMs), based on a number of aspects, such as spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Naturally, computational cost is a distinctive feature.

Global Climate Models (also referred to as General Circulation Models, both abbreviated as GCMs, or more specifically Atmosphere-Ocean General Circulation Models, AOGCMs), set the 'standard' climate models assessed in the AR4. These models describe the dynamics and interactions between the components of the global climate system: atmosphere, ocean and a simplified description of the land surface. Examples of GCMs include EC-EARTH, ECHAM, HadGEM, CCSM4, JPSL, among others.

[11] http://www.euro4m.eu/
[12] http://www.uerra.eu/
[13] https://pcmdi.llnl.gov/mips/cmip5/
[14] https://pcmdi.llnl.gov/CMIP6/

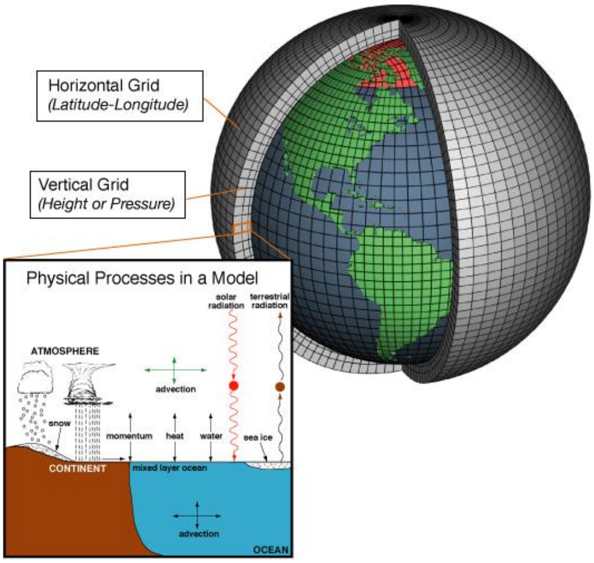


Figure 15: Schematics of a GCM concept (source: NOAA[15]).

With the increase in scientific knowledge, as well as available computational resources, GCMs have evolved to more complex and detailed systems. The most comprehensive tools currently available for simulating past and future response of the climate system to external forcing are designated as ESMs, which incorporate the interaction of biogeochemical cycles with the climate system. The EC-funded coordination and support action Climateurope[16] has published a report [74] with the purpose of explaining and illustrating the abilities and limitations of ESMs in relation to the potential for climate services. With particular interest for the understanding of the climate data driving CLARITY´s CSIS is the assessment in the cited document of the ability of climate models and ESMs to perform long-term climate projections and seasonal-to-decadal predictions in relation to uncertainties and opportunities for climate services. In this context, an overview of the main features of the AOGCMs and ESMs participating in CMIP5, and specifically the increase in complexity compared to CMIP3 is subject of analysis in AR5 IPCC´s report [71].

Many end-users of climate data look for information at the regional or even local scale. Although global climate models (GCMs or ESMs) are unable to provide data at the spatial scale required, higher resolution modelling systems can be driven by the large-scale circulation and physical conditions from the global models at their lateral boundaries. This downscaling process is an important component of the user-oriented climate data delivery in the CSIS and will be briefly analysed in Section 3.2.4.

3.2.3 Seasonal to decadal climate prediction

While time scales shorter than one month are manageable within weather and sub-seasonal forecasting, there has been a growing need from end-users and stakeholders for more accurate climate information at time scales ranging from a month to a decade into the future that, supported by advancements in climate science, have triggered the development of Subseasonal-to-Decadal (S2D) prediction [75] [74].

Currently there are available two main systems for the seasonal forecasting: Integrated Forecast System (IFS) provided by the ECMWF and Climate Forecast System (CFS) model developed by the National Centers for Environmental Prediction (NCEP).

In particular, the NOAA CFS is a fully coupled model representing the interaction between the Earth's atmosphere, oceans, land and sea-ice. It uses 4-time initializations for each prediction. On the other hand,

[15] http://www.noaa.gov/
[16] https://www.climateurope.eu/

the ECMWF uses the last version of the IFS (model cycle 36r4). Atmosphere model uncertainties are simulated using the 3-time level stochastically perturbed parameterized tendency (SPPT) scheme and the stochastic back-scatter scheme (SPBS) operational in the Ensemble Prediction System (EPS).

All these predictions have some skill in horizons of between 1 and 3 months, but the skill is very limited to forecast annual and multiannual anomalies. That is, from the third month on, forecast ensembles tend to show practically equivalent values to the climatic averages for each day, with a range equal to the typical climate variability (when this happens, it is said that there is "no signal" in the prediction). However, any signal prediction albeit small is welcome, since it may provide some benefits in planning of certain activities that depend on climatic anomalies. Although these forecasts are experimental, so at this early stage of development it is needed to go deeper into the verification of the models.

In contrast to climate projections, S2D prediction rests on initialized simulations of observed conditions, which means that the first critical step when applying this technique is the model initialization with the best estimate of the initial state of the atmosphere, ocean, sea-ice cover, snow, soil moisture, etc. For this reason, S2D prediction combines aspects of both an initial condition problem, in which uncertainties arise due to estimating the initial state of the atmosphere, ocean, cryosphere and land surface, and a boundary condition problem, which suffers from uncertainties in the forcings and feedback processes that play a central role in constraining climate projections [76], as illustrated in **Figure 16**.

There are basically two methods to perform climate predictions. Dynamical S2D prediction systems have been developed, with a strong basis on model intercomparison projects such as ENSEMBLES[17] and CMIP5[18], with a focus on simulating responses to external forcing factors and on initialisation of model simulations using observations. Empirical forecast models based on a statistical representation of the physical mechanisms between the atmosphere and oceans have also been used as a simpler and less computationally demanding alternative to process-based dynamical models [76].

However, with the exception of sectors such as energy, water, insurance, and transport, the use of S2D prediction across Europe has been limited. Perceived barriers to the uptake of climate forecasts by end-users are related to the accessibility, relevance, and usability of these datasets [75].

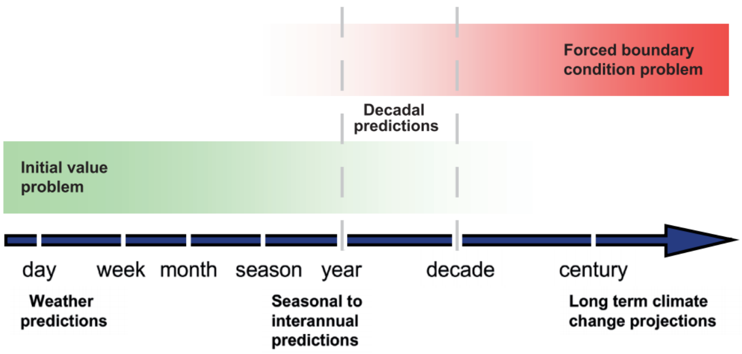


Figure 16: Schematic of the progression from an initial-value based prediction at short time scales in daily weather forecasts at one end, to multidecadal to century projections as a mainly forced boundary condition problem at the other, with S2D prediction standing in the middle time range (source: [77], based on [78]).

[17] https://ensembles-eu.org/
[18] https://pcmdi.llnl.gov/mips/cmip5/

3.2.4 Downscaling

CLARITY concept streams from the strong increase in the demand for regional to local-scale adaptation strategies and plans to deal with the impacts of a changing climate, which have triggered the interest in user-tailored climate services. Although global models (ESMs and GCMs) provide credible large-scale simulations of the past climate and projections for the future, the resolution at which these tools operate limits their ability to capture small scale and short timescale phenomena, such as extreme meteorological events (e.g., flash flood caused by short-term heavy precipitation) or landscape heterogeneities (e.g., complex mountainous terrain or urban areas). Dynamical downscaling with RCMs and Empirical Statistical Downscaling (ESD) can be applied over limited areas, providing information on smaller scales that can support more detailed impact and adaptation assessment and planning. Outputs provided by RCMs applied over limited-area domains (and using boundary conditions either from reanalyses or global models) will be extensively used in CLARITY to provide the detail required by the user-driven DCs.

In addition to extract directly from the GCM results, a large-scale overview of the expected climate signals, regional modelling cascades can be applied to enable the required regionalization [79]:

- GCM→RCM: the GCM serves as external forcing at the lateral boundaries of a nested window in the RCM;
- GCM→SD: the GCM serves as the source for predictor fields climatological information upon which a ESD builds its empirical relationships and transfer functions with respect to the climatological information obtained at local scale (from point observatories)
- GCM→RCM→ESD: the RCM´s dynamical downscaling results are the basis for generating the transfer function of the ESD.

As an example of the application of a dynamical downscaling process within the climate services provision, **Figure 17** illustrates the modelling flowchart for the generation of selected Essential Climate Variables (ECVs) and Sectoral Impact Indicators within Copernicus. In this process, the convection-permitting numerical weather prediction (NWP) model HARMONIE-AROME [80] is fed with input data that is basically composed of: high-resolution physiography compiled from different land use databases, lateral boundary conditions provided by the UERRA-ALADIN reanalysis [72], and surface observations retrieved from the ECMWF MARS archive. In the next step the initial states for the atmospheric and surface model are generated, where the previous 6-hour forecast serves as input. Finally, the forecast model is run and produces a 12-hour forecast as output. The latter is used in the post-processing of the ECVs, and also as input to impact assessment with air quality and hydrological models [73].

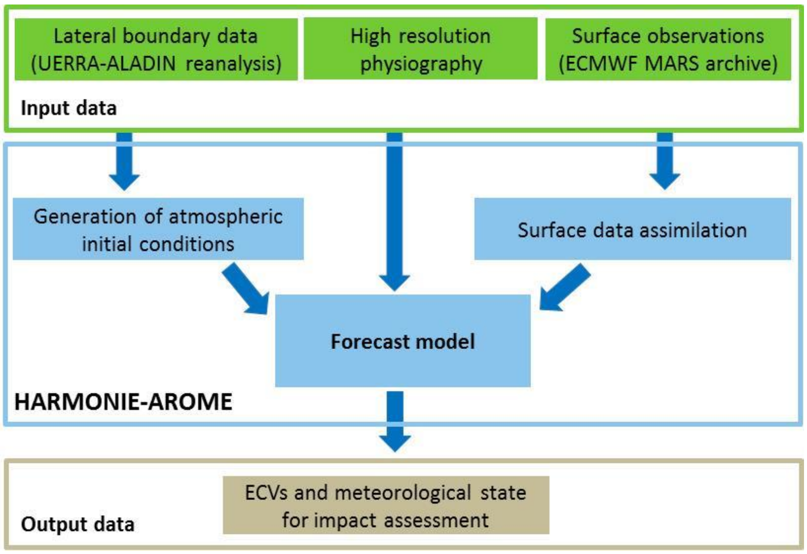


Figure 17: Flowchart of the dynamical downscaling process within the C3S project UrbanSIS (source: adapted from [73]).

Research has shown that RCMs are capable of adding value[19] over the global models outputs (e.g., [81]), for example over landscapes, inducing strong spatial gradients such as urban areas as it has been shown in the C3S project UrbanSIS (see example in **Figure 18** and more information in [73] [82] [83]).

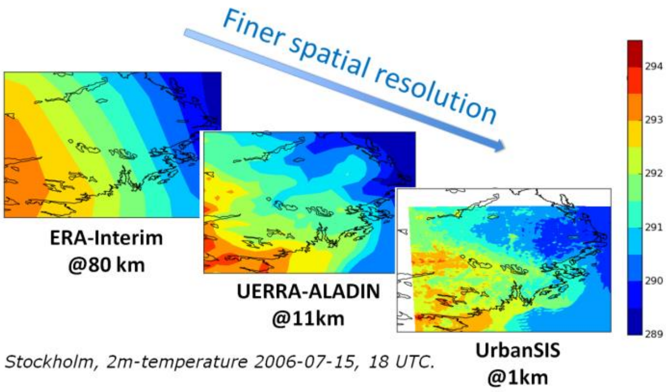


Figure 18: Illustration of the urban climate downscaling performed within the C3S project UrbanSIS (source: [84]).

Use of finer computational meshes in climate model simulations generally reduces numerical truncation error in the discretization of the field equations and permits the explicit representation of small-scale processes. However, the added value provided by RCMs over the global models depends on the model, variable, scale, region, experiment set-up including boundary conditions [81]. **Figure 19** shows the several factors that can ultimately affect the amount, kind and meaning of value added by an RCM during the design of an RCM experiment or in the selection of the climate statistics, as proposed by Di Luca et al. [85].

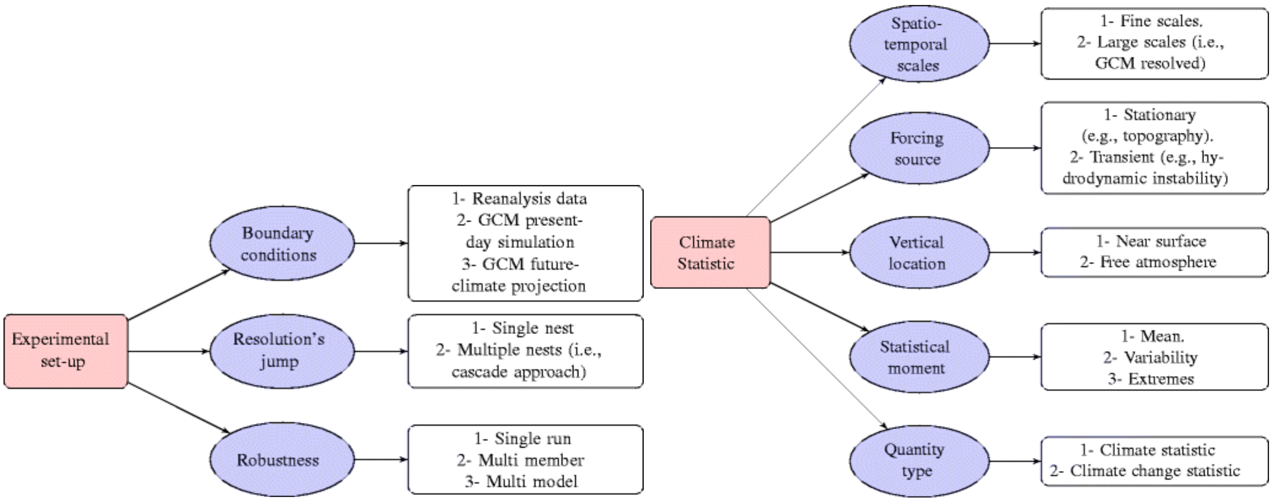


Figure 19: Choices in the design of the experimental setup and in the choice of the climate statistics that can potentially influence the added value of RCMs (source: [85])

While RCMs are a tool to accomplish a more correct and reliable description of the regional and local climate for both mean values and extremes, and an improved representation of physical and dynamical processes, there remain barriers to realising their full potential for climate services. Among the major

[19] The 'added value' is a measure of the extent to which the downscaled climate is closer to observations than the model from which the boundary conditions were obtained [71].

limitations to achieving robust estimates (across models, model versions and climate state) of added value are limited ability to represent internal variability, regional model errors, and incorrect global model fields at the lateral boundaries of the RCM. As a result, added value can be seen in some regions, but can be absent for others [74].

There are strong indications that the main errors in state-of-the art RCMs are due to incorrect energy balance closure, its feedback to the convective and stable atmospheric boundary layer and the resulting formation of clouds and precipitation, which is strongly controlled by the choice of the microphysical scheme. Furthermore, with respect to precipitation, it is important to consider that the overall bias depends on a timevariant combination of effects leading to precipitation events involving different combinations of model physics [86]. Associated to model errors related to uncertainty in representation of processes (parameterizations), error propagation is also pointed out by IPCC [71] as a cause of model bias. In the scope of model performance evaluation, sensitivity to resolution is of particular relevance, since some phenomena or aspects of climate are found to be better simulated with models run at higher horizontal and/or vertical resolution. Despite the indications that model skill increases with higher resolution, this is not a linear effect since downscaling skill varies with geographic location and choice of model domain, season and synoptic situation, parameter, boundary conditions and sea surface information (SSTs and sea ice). The quality of RCM results may be affected by the forcing, namely the uncertainties in specified greenhouse gases, aerosols emissions, or land use change. In addition to the issues mentioned above, errors can potentially arise also from observational uncertainty in evaluation data and parameterizations.

Statistical downscaling (SD)

In the case of SD, sources of model errors and uncertainties depend on the choice of method, including the choice of the predictors, the estimation of empirical relationships between predictors and predictands from limited data sets, and also the data used to estimate the predictors [71]. According to Ribalaygua et al. [87], the selection of predictors should be undertaken based on theoretical considerations, rather than using empirical analyses which could result in non-physically based relationships that may be not applicable in the future due to the stationarity problem. The predictors should be physical forcings of the predictands, or at least, should be physically linked to the predictands. Furthermore, the identified relationships between predictors and predictands should be those which best reflect the physical links between them - again in order to assure so far as possible the stationarity of these relationships. If these requirements are fulfilled, a good diagnostic capability should be obtained at the daily scale. Thus, this daily skill should be analysed since it is required to ensure the stability of statistical relationships for the future.

The main advantages of the statistical approaches are two. The first is the low computational cost, which allows the downscaling of many GCM outputs and several greenhouse gas emission scenarios in order to quantify uncertainties [88]. The second is that specific information is provided for point locations with observations, and in these observations the microclimatic features of these points are implicit. This local detail is relevant as the same future climate may bring changes with respect to the current climate which could be quite different for points which are a few km apart. This supposition has been confirmed with the results obtained when local future climate scenarios are produced using this methodology. Dynamical approaches typically provide spatial resolutions of up to 25 km, which are still insufficient to resolve topography with enough detail and to show differences in the projected changes for points located close together.

However, the statistical approaches show some disadvantages compared to dynamic downscaling: (1) historical observations of the studied variables are needed; (2) they have possible spatial or inter-variable inconsistencies; and (3) there may be a possible problem of non-stationarity in the relationships between predictors and predictands particularly due to weak physical linkages.

Use of downscaling methods in the CLARITY project

In the paper by Kreienkamp et al. [79] on "Good practice for the usage of climate model simulation results", it is recommended, in order to ensure the quality of subsequent analyses using the downscaled results, to employ at least two different downscaling methods: the use of RCMs, nested into GCMs for an area of interest as well as employing ESDs. If possible both model types, a RCM and an ESD, should be considered as well as a range of scenarios.

Therefore, despite the fact that downscaling constitutes a critical component and basis for the downstream development of climate services such as CLARITY, scientific questions remain on how to obtain robust estimates of regional climate. These knowledge gaps have triggered international cooperation targeted at further improving climate modelling, related processes and information integration methods [74]. As a branch of the "Coordinated Regional Downscaling Experiment" (CORDEX[20]), the EURO-CORDEX[21] initiative provides regional climate projections for Europe at 50 km and 12.5 km resolution. Compared to other coordinated ensembles of regional climate simulations at high spatial resolution over Europe (e.g., Prudence[22], ENSEMBLES[23]) EURO-CORDEX offers increased spatial resolution for selected emission pathways (RCP26, RCP45, RCP85). The EURO-CORDEX simulations are openly available through the Earth System Grid Federation (ESGF) under the CORDEX project[24]. The EURO-CORDEX community recently released a valuable guide for using climate projections data aiming at providing background information, best practices and links to further information for users of RCM data, such as researchers in impacts communities, engineers in industry and the public sector, or small and medium enterprises [89]. Helpful advice on how to use climate model output can also be found in Kreienkamp et al. [79].

Another example for the downscaling process incorporated in CLARITY project is a dynamical-statistical approach that combines different regional and urban climate models and statistical methods to provide high resolution climate information. For example, statistical methods based on analogue/regression techniques present a good performance comparing with other downscaling methods ([90], [88], [91], [87]). **Figure 20** illustrates the applied model chain – without the models being fully coupled among each other – to obtain climate information at various scales, from low to very high resolution. Regional climate models (simulations from EURO-CORDEX project (~12.5 km) and COSMO CLM (Climate Limited-area Model) simulations (1 km)) are used for regional climate analysis and serve as input for local climate modelling. On an urban scale, the urban climate model MUKLIMO_3 is applied for high-resolution climate analysis on city level (~100m), while the micro-scale model ENVI-MET is applied on district level (~10m). More details about the modelling tools are given in Section 4.2.

[20] http://cordex.org/
[21] http://www.euro-cordex.net/
[22] http://prudence.dmi.dk/
[23] https://ensembles-eu.org/
[24] http://www.data.euro-cordex.net

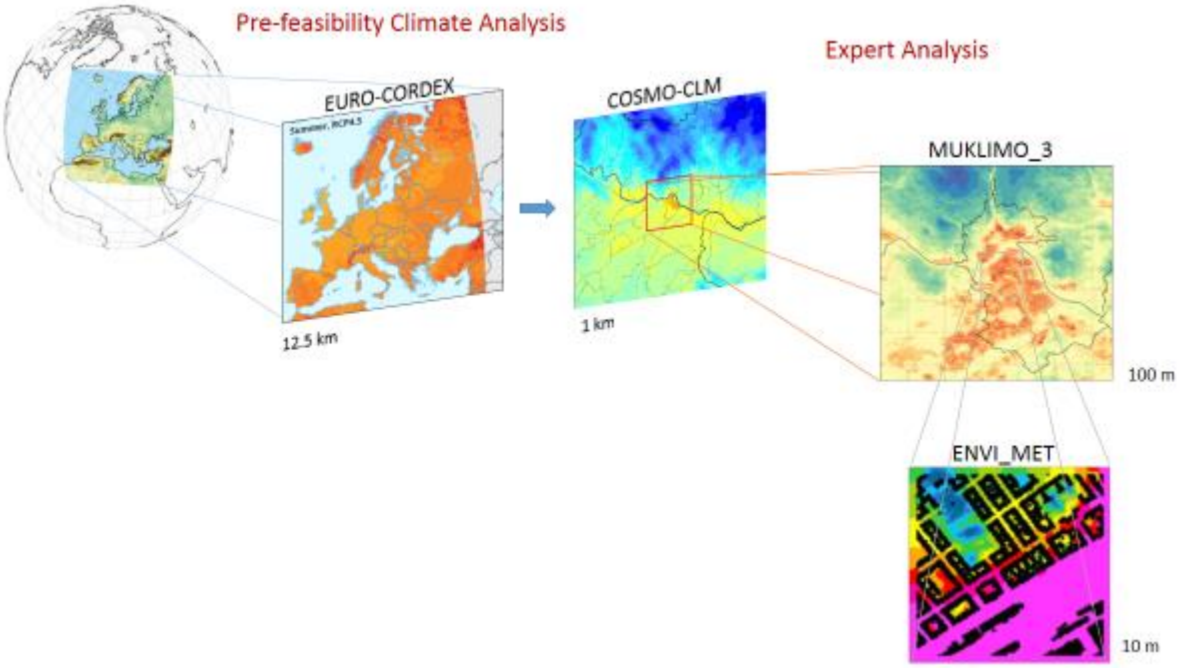


Figure 20: Proposed downscaling process for urban climate analysis on pre-feasibility level to expert analysis, considering different models at various scales.

3.2.5 Refinement techniques

Despite continuous improvements over the past decades climate models may still be affected by considerable systematic errors (biases) when compared to observations, which limit the direct use of their outputs as input data for the impact models. Statistical post-processing techniques, referred to as bias correction (BC, also bias adjustment or bias reduction), can be applied to potentially reduce the bias.

Bias correction is a method of reducing model bias with respect to a "true" reference dataset, which is often an observational dataset or reanalysis product. Several bias correction methods are available, from the most simple 'delta change' approach, through the mathematically similar but conceptually different 'direct methods' (such as 'linear scaling'); to more flexible methods that employ a quantile-based transformation of distributions, referred to as 'quantile mapping'; or even to more sophisticated 'multivariate bias correction' methods that also correct the dependence between variables ([74], [92], [93]) .

BC methods have been shown to successfully reduce errors in RCM outputs, especially in hydrological impact studies (e.g., [94] [95]). However, and according to IPCC´s AR5 group on bias correction [96], this computationally inexpensive and pragmatic tool is also prone to misuse due to its mathematical simplicity. One of the issues to take into consideration when using a BC method is that it cannot correct for incorrect model representations of dynamical and/or physical processes [97]. Ehret et al. [86] argue that BC is often used in an invalid way when added to the GCM/RCM model cascade, which may hide rather than reduce uncertainty, ultimately leading to forejudging of end users and decision makers. For example, BC methods often impair the advantages of circulation models by altering spatiotemporal field consistency, relations among variables and by violating conservation principles. The simple choice of the BC method can be considered as an additional source of uncertainty [97]. Also, BC methods currently in use still show a limited ability to further downscale the model output since sub-grid day-to-day variability cannot be generated, and feedbacks altering the sub-grid climate change signal cannot be represented [92].

3.3 Risk Assessment and Impact Scenario Analysis

The different backgrounds of Disaster Risk and Climate Change domains – the first emerging from risk sciences and emergency management fields, the latter from earth sciences and only recently recognized as a global challenge affecting society as a whole – limit so far, the establishment of an integrated methodological and operational approach to DRR and CCA in a multi-risk modelling and resilient design-oriented perspective. Effective emergency planning and adaptation measures design in the context of climate change require preliminary assessments of potential risk and impacts due to climate-related hazard, including the potential technological hazards induced by cascading failures of interconnected infrastructure systems (e.g. transport network; power distribution network, etc.).

The novel approach adopted by IPCC in the AR5 (see Section 3.1) represents a significant opportunity to align the modelling approaches in relation to the different hazard typologies, thus framing climate risk modelling in the perspective of “all-hazards” and “multi-risk” approaches.

In risk science, different types of assessments can be distinguished, based on Risk Assessment and Impact Scenario Analysis.

The risk is the likelihood that a predetermined level of damage on elements at risk, caused by a certain event, will arise within a given time period in a certain geographic area. Therefore, risk should be understood as a cumulative assessment that takes into account the total potential damage that can be generated in the same area from different events in a predetermined time span.

The scenario, on the other hand, represents the probabilistic distribution, in a certain geographic area, of the damage caused by a single event with a probability of occurrence assigned (assumed as a reference scenario). Both risk and scenario involve three aleatory variables, hazard, exposure, and vulnerability, through the convolution (1).

Risk [Scenario] = Hazard x Exposure x Vulnerability (1)

In this relation, the Hazard is the probability of occurrence of all the possible events (or of a single event for the scenario analysis) of a given severity, in a specific area and in a specific time period. Exposure is the probable quantitative and qualitative geographic distribution of the various elements at risk that characterize the area, whose conditions and / or operation may be damaged, altered or destroyed due to the occurrence of the Hazard event. Vulnerability is the probability that the exposed element of a certain typological characteristic (vulnerability class) undergoes a certain degree of damage or state changes, with reference to an appropriate scale, due to a Hazard event of assigned intensity.

To specialize the relationship (1), the risk of reaching a certain level of damage can be determined through the relationship (2).

$$\text{Risk}_{\text{l}} = \int_m E_m \left[\int_i \ (H_i) \cdot (V_{l,i,m})\right] \ (2)$$

where: H_i is the probability of occurrence of an event of severity level "i" over a period of time and on a certain site; $V_{l,i,m}$ is the probability of occurrence of an assigned damage level "l" following the event "i" for a certain category "m" (vulnerability class) of elements at risk; E_m is the percentage of elements for the "m" category.

The scenario for a certain damage "l" level, due to a single intensity event "i", can instead be determined through the relationship (3).

$$\text{Scenario}_{\text{l,i}} = \int_m E_m[(H_i) \cdot (V_{l,i,m})] \ (3)$$

In emergency and adaptation planning, both risk analysis and scenarios can be used, in response to different purposes: risk assessments allow comparative evaluations of risk-prone areas to take strategic decisions on preparedness and response intervention strategies (e.g. evacuation) and for the definition of priority areas for adaptation actions; scenario analyses, by providing a detailed impact assessment following the reference hazard event(s) selected, allow a much more fine-tuned quantification of the expected damage in a given territorial area, thus enabling a proper estimation of (human and financial) resources required for emergency management and resilience-based urban design and planning.

This approach, based on a consolidated scientific framework in the field of risk science and theory of decisions (from UNDRO, 1979 [98] to IPCC, 2014 [7]), has been recently formalized in the framework of EU-FP7 projects CRISMA[25] and Snowball[26], as a theoretical model to address multi-risk and cascading effects through a scenario assessment methodology [99]. The methodology expands the logic of the scenario assessment described above to propose a holistic approach to perform impact scenario analyses in an "all-hazards" perspective. The different *elementary bricks*, Space (s); Time (t); Hazards (H); Initial Exposure (E); Initial Vulnerability (V); Dynamic vulnerability (DV); Human behaviour influence; Damage (D), are defined in relation to the required inputs of the models and can be schematized in **Figure 21**.

Space and Time constitute the reference frame of other bricks. Hazards, Exposure and Vulnerability identify the input data of the "impact model" at initial time (in peace time). Dynamic vulnerability identifies the routine that updates the response (vulnerability) of a specific element exposed induced by sequence of two or more hazards. The human behaviour is a variable able to influence the hazard chains (in the case of cascading effects and NaTech - Natural Hazard Triggering Technological Disasters), the exposure, the vulnerability and the damage induced (e.g. in relation to preparedness measures such as evacuation or other self-protection measures). Its effect is considered through the introduction of an opportune influence factor (α). Damage on element exposed (in time and space) is the output data of the impact model(s) applied.

[25] http://www.crismaproject.eu
[26] https://snowball-project.eu

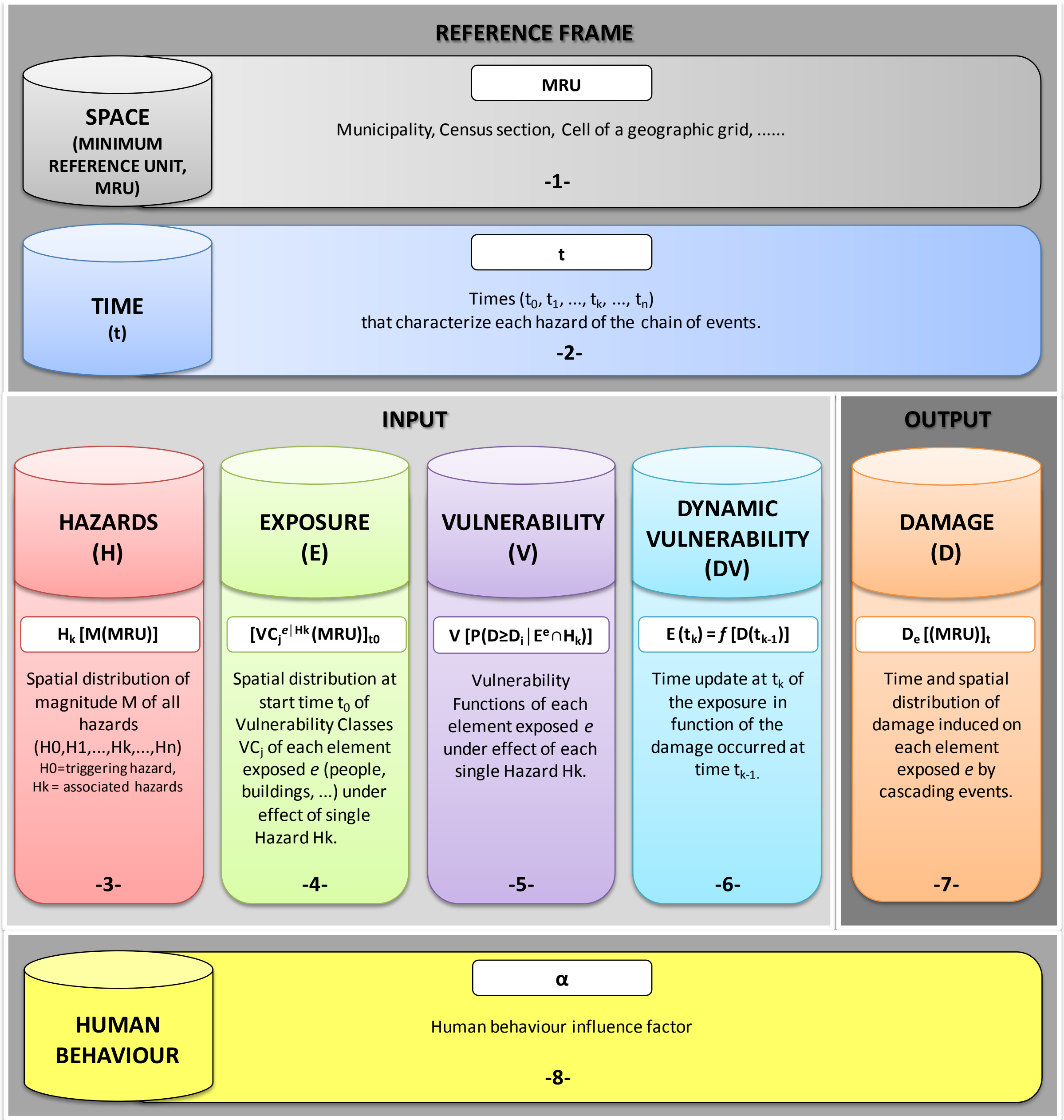


Figure 21: Elementary bricks of the CLARITY theoretical model (adapted from CRISMA and SNOWBALL).

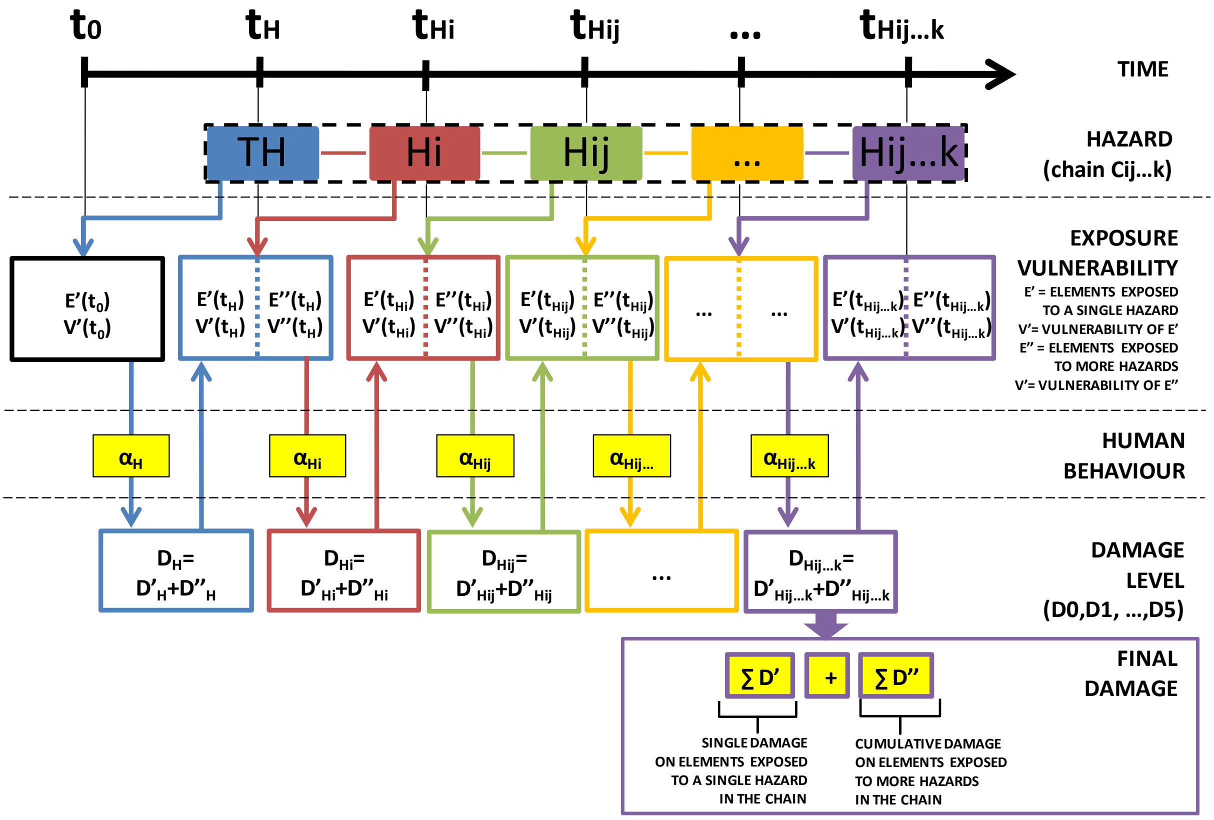


Figure 22: Flow chart of the theoretical model (adapted from CRISMA and SNOWBALL).

In the case of a multi-risk prone area (which may include the concurrent presence of climate and geophysical hazards, but also the presence of multiple climate risks in different seasons of the year), or the need of modelling a sequence of interconnected hazards within a cascading effects (such as a landslide triggered by an extreme precipitation event) or NaTech (such as power outage following a storm) timeline of events , due to the extreme complexity of a full probabilistic risk assessment approach when dealing with multiple hazards (both independent and interconnected), the proposed modelling methodology considers the “scenario analysis” approach, which allows the assessment of damage induced on the elements at risk (e.g. people, buildings, critical infrastructures, service networks, economy, etc.) by a series of single hazards (e.g. earthquakes, floods, landslides). Thus, the “scenario analysis” consists in the measure of the damage induced (space- and time-dependent) by a single event (hazard) or a single chain of events of assigned intensity and probability, on the elements at risk considered (exposure) in function of the response of the element under effect of the hazard(s) (vulnerability). The output of the assessment consists in a detailed quantification of expected impact on the elements at risk considered (e.g. for people, the n. of deaths, injured and homeless; for buildings and infrastructure the damage levels ranging from D0-no damage to D5-total collapse), which allows in turn a reliable quantification of direct and indirect economic impacts (e.g. for buildings rehabilitation and reconstruction, for business interruption, etc.).

The impact scenario can thus be assessed by the convolution (3). It represents the time (t) - space (Minimum Reference Unit - MRU) distribution of damage occurred on the different elements exposed *e* in relation to the hazard(s) considered: $D_e\ [(MRU)]_t$. The reliability of the impact scenario analysis is strongly influenced by the ability to provide accurate information in relation to the three key variables H, E, V and manage the related uncertainties thresholds. However, it is always possible to perform impact analyses with different levels of detail and reliability according to the data available.

Hazard characterization needs to be modelled through the support of experts in the specific field of investigation (e.g. seismology, hydrogeology, climate sciences, etc.), deriving probabilities of occurrence of different event's magnitude, time and spatial extension. The choice of the reference event object of the simulation is defined according to end-users' needs, ranging from a series of simulations of diverse types of events with attached probabilities of occurrence, to single events (or chains of events) deterministically chosen for specific reasons (e.g. analyse the "worst-case" or the "most probable" scenario).

Exposure and inventory data include all the collection of relevant information in relation to the elements at risk considered in the analysis, ranging from the geometric typological, morphological and construction features of built environment (buildings, open spaces, transport and networks, critical infrastructure, etc.), census data (e.g. population distribution, socio-economic data, etc.), catalogued and geo-referenced according to the MRU to be analysed. It can benefit of the significant innovation in the field of satellite surveys and big data analytics, thus allowing simplifying the collection of a minimum datasets of information at global scale, which is used to customize and calibrate the vulnerability and impact models.

Vulnerability analysis represents the crucial step to build a reliable and flexible all-hazards impact model. The proposed approach is based on a two-fold level of analysis with different resolutions. At National level, (Italy), census data and satellite information are detailed with a MRU constituted by the Region and/or the municipality. A continuous activity on field data collection (including post-event surveys in areas affected by seismic and hydrogeological events) allows to refine the general vulnerability functions in relation to the various hazards investigated and specific characteristics of the elements at risk in the study area (e.g. recurring building and construction typologies, land use, population occupancy, etc.). Such refinement allows providing more precise information on the expected impacts of the reference event(s), with a MRU based on a territorial mesh on the territory up to a 250x250 size. The customization of the models on different geographical areas is generally subject to a field survey aimed at establishing the due correlations among the vulnerability functions available in relation to the Italian and Campania Region models, with the specific features of the elements at risk in the study area [100] [99].

The seven bricks are synthetically described in the following. They represent the components of a theoretical model able to include all the variables of interest to be considered within risk/impact assessments targeted at mitigation/adaptation options priorities identification.

SPACE. The analysis of impacts induced on the territory by single and multiple hazards require the choice of a geographical Minimum Reference Unit (MRU), which coincides with the minimum spatial unit of analysis of input and output elements of the model (it can be e.g. the "Region" or "Municipality" for national scale assessment, districts, census wards, or street blocks or a grid draped on the territory, for more fine-tuned analyses).

TIME. In dynamic analyses (such as seismic swarms, volcanic reactivation, climate-related hazards, cascading effects, NaTech but also in the socioeconomic transformation of areas (land uses – e.g. by urban growth), the time reference frame is essential to define the variation of models' parameters (e.g. exposure variation in case of evacuation, or vulnerability variation in case of preparedness measures in place). In the proposed model, the time scale adopted is of discrete type. It is constituted by the single instants t_0, t_1, ..., t_n which characterize relevant timestamps along the time history (e.g. sequence of hazards in a cascading effects chain, forecast and alert information, decision makers' orders, etc.) able to vary the model(s) input.

HAZARD. In case of single hazards, relevant parameters characterizing the location and magnitude determine the key variables of analysis. Risk assessment requires different hazard magnitudes and locations to be considered and included in the relation (2), while impact scenario analyses can be performed considering the parameters of a single event, according to end user decision (e.g. most probable; most damaging; etc.). In case of time dependent hazards, cascading effects and NaTech, the hazard is constituted by a single timeline of events chosen on the base of ad hoc criteria (i.e. probability of occurrence, impact on specific elements at risk, stakeholder interests, etc.). The chains of events and their probabilities of occurrence can be assessed on the bases of analysis of past events combined with expert judgements and/or elicitation techniques. In the model, the *Hazard elementary brick* is defined by the spatial distribution of magnitude M of all hazards (H0, H1,..., Hk,..., Hn) in the chain on examination for each MRU adopted to discretize the territory: Hk [M(MRU)].

EXPOSURE. On the territory investigated, for each MRU, the analysis of exposure should be carried out by grouping, at start time t_0, the elements of each exposure category *e* (people, buildings, critical infrastructure, transport and service networks, local economy, etc.) in relation to their vulnerability under effect of each hazard Hk, thus defining a number of 'vulnerability classes' ($VC_j^{e|Hk}$): $[VC_j^{e|Hk}(MRU)]_{t0}$.

VULNERABILITY. Vulnerability classes for the elements at risk considered can be assessed through typical 'vulnerability curves' (VC) (**Figure 23**). They express the probability that a given vulnerability class exceeds a certain level of damage D_i (**Table 3**), given a level of hazard magnitude. For each element exposed *e* under effect of each single hazard Hk, the vulnerability functions must be defined: $V\ [P(D \geq D_i | E^e \cap H_k)]$.

Vulnerability curves can be obtained through three different approaches, in function of the information available: *Empirical methods* (evaluating the curves through the statistical analysis of the analyses of the damage caused by past events on samples of elements exposed); *Mechanical methods* (evaluating the curves through statistical processing of the results obtained by analytical approaches conducted on a random sample of models representing the elements exposed in examination - subject to a representative set of events -hazards-); *Hybrid methods* (evaluating the curves combining analytical approaches and observations of damage caused by events occurring).

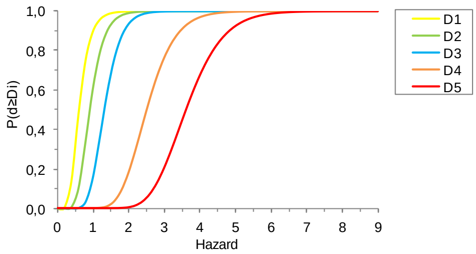


Figure 23: Typical shapes of vulnerability curves referred to a given vulnerability class and to a specific hazard.

Table 3: Damage scale for the generic element exposed.

DAMAGE LEVEL	DESCRIPTION OF PHYSICAL DAMAGE ON ELEMENT EXPOSED or ALTERATION OF FUNCTIONALITY FOR GRIDS	REACTIVATION TIME
D0	No damage on element exposed	0 days
D1	Slight damage	⇩
D2	Moderate damage	
D3	Heavy damage	
D4	Partial crisis	
D5	Total crisis	Many days

DYNAMIC VULNERABILITY (OPTIONAL – NEEDED IN CASE OF CASCADING EFFECTS AND NATECH ANALYSES). Dynamic phenomena (such as seismic swarms, volcanic reactivation, climate-related hazards, cascading effects and NaTech) may cause a progressive increase of the vulnerability of the element exposed, depending on the evolution of the damaging process. The theoretical approach for the implementation of the dynamic vulnerability model is based on background researches developed by LUPT-PLINIVS within the EU-FP6 EXPLORIS project [101] and subsequently adopted in the model of EU-FP7 CRISMA project. The approach updates the exposure and vulnerability through a routine that estimates the increase of vulnerability due to the previous events. It assigns a virtual vulnerability class, proportionally to the damage level, that will address the choice of the damage probability curve to be used when the following event occurs.

DAMAGE. “Damage” elementary brick constitutes the output of the model. It provides the distribution of damage on different elements exposed according to the hazard(s) considered. A possible measure of damage for different element exposed is indicated in **Table 3**. The impact scenario can thus be assessed by the convolution (3). It represents the time (t) - space (MRU) distribution of damage occurred on the different elements exposed *e* in relation to the hazard(s) considered: $D_e\ [(MRU)]_t$. Damage is calculated by equation (1), for each element exposed (people, buildings, infrastructures, economy, etc.) with reference to:

- geographical distribution of the damage level for each element exposed (i.e., number of deaths, number of building collapsed, hour outage of power line, reduction of Gross Domestic Product (GDP) in the Minimum Reference Unit (MRU);
- time distribution of the damage level for each element exposed in all time steps of analysis.

The impact is calculated as a single damage if the element exposed is affected by one hazard, while it is calculated by cumulative damage if the element exposed is affected by two or more hazards.

HUMAN BEHAVIOUR INFLUENCE (OPTIONAL). The space-time distribution of damage D(s,T) must take into account the human behaviour as a factor able to strongly influence the final impact scenario as variable influencing hazard, exposure and vulnerability as effect of behavioural due to socioeconomic and lifestyle changes. It is considered in the model as a coefficient α affecting the quantification of the corresponding parameter following specific analyses conducted in team with behavioural scientists and consolidated methods in literature [102] [103] [104] [105].

3.4 Adaptation Strategies and Decision Support

3.4.1 Adaptation Strategies

The selection of the set of adaptation options defines an Adaptation strategy for the project and mainly relates to Module 6 (appraisal of adaptation scenarios/options) of the adapted EU-GL guideline (see Section 3.1).

The selection of an adaptation strategy should be made on a sound information base that can only be provided through a Risk Assessment and Impact Scenario Analysis taking into account potential adaptation options.

This means that adaptation options need to be "connected" to impact models in the sense that an adaptation option may change either:

1. the hazard intensity by protecting the element at risk from damage induced by a hazard or the
2. vulnerability by increasing the resilience of an element at risk regarding the damage induced by a hazard or
3. exposure by changing the geographic position of an element at risk towards a location with lower hazard intensity.

To this aim, a catalogue of adaptation options has to be defined, highlighting for each of them the relevant parameters to "connect" them to the impact models, including the field of application (e.g. new development/retrofitting) parametric cost evaluations and assessment of related co-benefits, as fundamental information to make available to decision makers to support the appraisal process. An evaluation of these adaptation options is planned in order to assess their productiveness and will be addressed with the future deliverables D3.2 and D3.3.

Figure 24 illustrates a preliminary example of the proposed structure of adaptation options catalogue within CLARITY.

Constructing the connection between a specific adaptation measure and an Impact Model is task to be performed by collaboration of at least an expert for the specific adaptation model and an expert for the impact model.

An Impact model where adaptation options have been incorporated at the levels of hazard, vulnerability or exposure is enabled to create Adaptation Scenarios (**Figure 25**). These scenarios used in a Risk Assessment and Impact Scenario Analysis provide the possibility to compare the potential effects on impacts and risks as defined in Section 3.3 of different adaptation options.

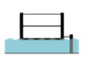
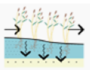
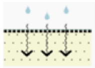
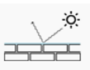
ADAPTATION OPTION		TOWARDS WHICH HAZARD	VARIATION ON CLIMATE SIGNALS	VARIATION ON VULNERABILITY	COST		CO-BENEFITS
					NEW DEVELOPMENT	RETROFITTING	
	Amphibious buildings	Pluvial Flooding	%	%	€€	N/A	Biodiversity • Multifunctional space usage •
	Constructions on piles	Pluvial Flooding	%	%	€€	N/A	Biodiversity Multifunctional space usage •
	Artificial urban wetlands	Pluvial Flooding	%	%	€	€	Biodiversity •• Air quality Social and economic importance •• Multifunctional space usage ••
		Drought	%	%			
		Heat	%	%			
	Green roofs (extensive)	Pluvial Flooding	%	%	€€	€€	Biodiversity Air quality Energy efficency Social and economic importance Multifunctional space usage
		Drought	%	%			
		Heat	%	%			
	Green roofs (intensive)	Pluvial Flooding	%	%	€€€	€€€	Biodiversity •• Air quality Energy efficency • Social and economic importance •• Multifunctional space usage ••
		Drought	%	%			
		Heat	%	%			
	Gutter	Pluvial Flooding	%	%	€	€	Social and economic importance
	Helophyte filters	Pluvial Flooding	%	%	€€	€€	Biodiversity •• Air quality Energy efficency Social and economic importance • Multifunctional space usage ••
		Drought	%	%			
		Heat	%	%			
	Porous pavements	Pluvial Flooding	%	%	€	€	Biodiversity Multifunctional space usage
		Drought	%	%			
		Heat	%	%			
	Reduced paved surfaces	Pluvial Flooding	%	%	€	€	Biodiversity • Air quality Energy efficency Social and economic importance • Multifunctional space usage •
		Drought	%	%			
		Heat	%	%			
	Water squares	Pluvial Flooding	%	%	€€€	€€€	Biodiversity Social and economic importance • Multifunctional space usage ••
	Adding green in streetscape	Pluvial Flooding	%	%	€	€	Biodiversity Urban agriculture Air quality Energy efficency Social and economic importance Multifunctional space usage
		Drought	%	%			
		Heat	%	%			
	Green facades	Pluvial Flooding	%	%	€€	€€	Biodiversity •• Urban agriculture Air quality Energy efficency Social and economic importance • Multifunctional space usage •
		Drought	%	%			
		Heat	%	%			
	Cool (reflective) roofs	Drought	%	%	€	€	Multifunctional space usage
	Cool paving and building materials	Heat	%	%	€€	€€	Energy efficency Multifunctional space usage
	Green ventilation grids	Drought	%	%	€€	N/A	Biodiversity Air quality Energy efficency Social and economic importance Multifunctional space usage •

Figure 24: Proposed structure for the CLARITY catalogue of adaptation options[27,28].

[27] www.climateapp.nl
[28] www.urbangreenbluegrids.com

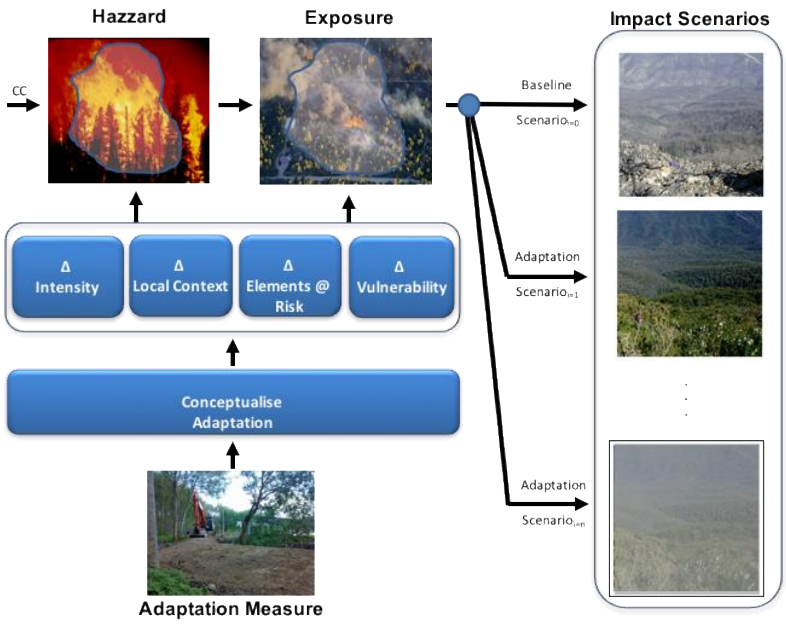


Figure 25: Conceptualisation of Adaptation options

3.4.2 Decision Support

Even with a number of optional adaptation scenarios at hand, the decision maker is confronted with complex sets of information such that the comparison of adaptation options to be included in the adaptation strategy proves to be very difficult.

One way to considerably reduce complexity while preserving the key properties of an adaptation scenario is to capture and aggregate decision relevant information into so called (key) performance indicators. This approach has a long history in various fields such as economics and business controlling as well as environmental performance assessment and is de-facto standard in measuring the performance of emergency services e.g. [106]. While performance indicator sets pertaining to adaptation option performance allow us to compare the individual indicator values, decision makers still face multiple, often-conflicting decision objectives involving more than one criterion. As a result, the selection of a specific adaptation option in the context of a strategy with the “best” performance is very difficult. Established methods of Multi-Criteria Decision Analysis (MCDA) [107] offer solutions to the problem.

Indicators and Decision Support

The overall idea is based on results of the CRISMA project [108]: (a) Let the Decision Maker (DM) produce and use scenarios in support of the decision; (b) provide aggregated but representative information about scenarios (indicators); (c) support the DM in defining an explicit decision strategy (criteria, priorities, Andness and Orness, see Section 3); and (d) assist in comparing and ranking impact scenarios according to the decision strategy.

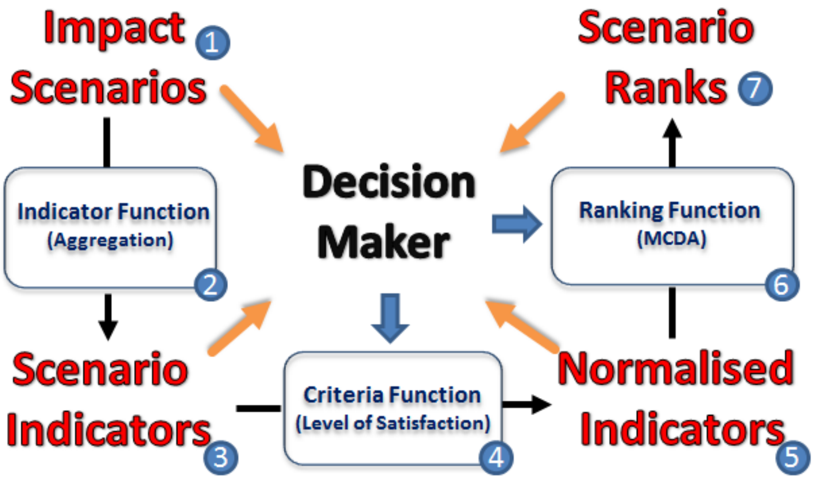


Figure 26: Indicators as drivers of Decision Support Concept Overview

The overall concept consists of seven elements - four data and three functional - to support the DM (**Figure 26**): (1) an impact scenario consisting of information required to take a decision, e.g. representing the possible consequences of a flood for people living in the flooded area; (2) an indicator function to map an impact scenario to indicators; (3) a set of representative scenario indicators consisting of aggregated scenario information, e.g. climate hazard induced damage level and cost; (4) a criteria function mapping each element of the indicator set to a level of satisfaction; (5) a level of satisfaction in a normalised scale (0-1 or 0%-100%); (6) a ranking function mapping normalized indicator sets to scalar values; and (7) corresponding scalar values (ranks/score) comprising a highly aggregated representation of a scenario that can be used to compare the performance of adaptation options in the context of a specific baseline scenario.

The DM can use the four data elements as a basis for the decision and define individual decision strategy mapping indicators to criteria with the help of criteria functions. From the CRISMA project there is a set of tools available to support the DM in assigning priorities to indicators as well as defining the level of "Andness" and "Orness" of the ranking function [109] through the parameterization of a MCDA method [107]. More concretely the DM is supported in:

- Using indicators derived from impact scenario data (usually aggregated) to quickly assess and compare impact/adaptation scenarios
- Defining a decision strategy by:
    - Mapping performance indicators to decision criteria (defining the level of satisfaction for each indicator)
    - Defining priorities by assigning weights to indicators
    - Defining the level of Andness and Orness to be considered when computing the rank of an impact scenario
- Dealing with a multi-criteria decision problem by obtaining a ranking of scenarios with respect to the defined decision strategy.

3.5 Economic and Societal Impact

In relation to the objectives of CLARITY, the Economic and Societal Impact evaluation will appraise the Economic Impacts on the generic element exposed to hazards, as well as evaluate the different adaptation measures and the costs/benefits of alternative adaptation strategies, over time (i.e. after a given period of time including the project forecast period [1]).

The Economic Impacts are generally described in terms of Direct and Indirect costs connected to a specific impact scenario.

Benefit arising from an adaptation measure can be calculated considering comprising both economic impact on the baseline scenario and the economic impact after implementing an adaptation measure or a set of adaptation measures.

The Direct Costs are direct consequences of the damage on the generic element exposed to hazards over time. The Indirect Costs are flows of costs that occur over time and are effects of the damage (e.g. specific area variation in gross income in the impact scenario).

In the CLARITY context, the Economical and Societal Impact evaluation step is located within the “AAO” module since it is part of a standard CBA example (see **Figure 27**) and because it allows to select efficient and ‘optimal’ adaptation options i.e. those maximising net benefits.

The applicable Economic evaluation methodology is a monetary i.e. financial evaluation method. In CLARITY, this is a method to estimate the costs and benefits of applicable adaptation measures over a time span. The adopted economic methodology will allow to determine investment and operating costs of the options, establish unit values for benefits and value non-market impacts.
So, the economic impact evaluation in CLARITY will answer questions such as:

- What is the total cost of damage in a baseline scenario (i.e. project baseline [1])?
- What would be the difference in the total cost of the damage (i.e. Benefits from avoided costs) in a baseline scenario if an adaptation measure had been used?
- What is the cost of an adaptation measure?
- What is the Co-Benefits Value generated by an adaptation measure?

In relation to the last question, the Co-Benefits generated by an adaptation measure (e.g. such as Air Quality enhancement, Energy Savings, Social and Economic Importance, etc, proposed and reported in the http://www.urbangreenbluegrids.com site) could be estimated only in case for each of such Co-Benefit would be available data and/or models which allow an estimation of the material benefits.

Furthermore, the Cost-benefit analysis is an evaluation method to determine the feasibility of a project/plan/investment by quantifying its costs and benefits to help to make a decision. Cost-effectiveness could be calculated by using a ratio by dividing costs of an investment (e.g. adaptation option cost) by units of effectiveness. For an adaptation measure, the number of lives saved would be an obvious unit of effectiveness.

Cost-efficiency is the act of saving money by performing an activity in a better way. The cost efficiency of an adaptation measure is largely based on the avoidance or reduction of the damage costs.

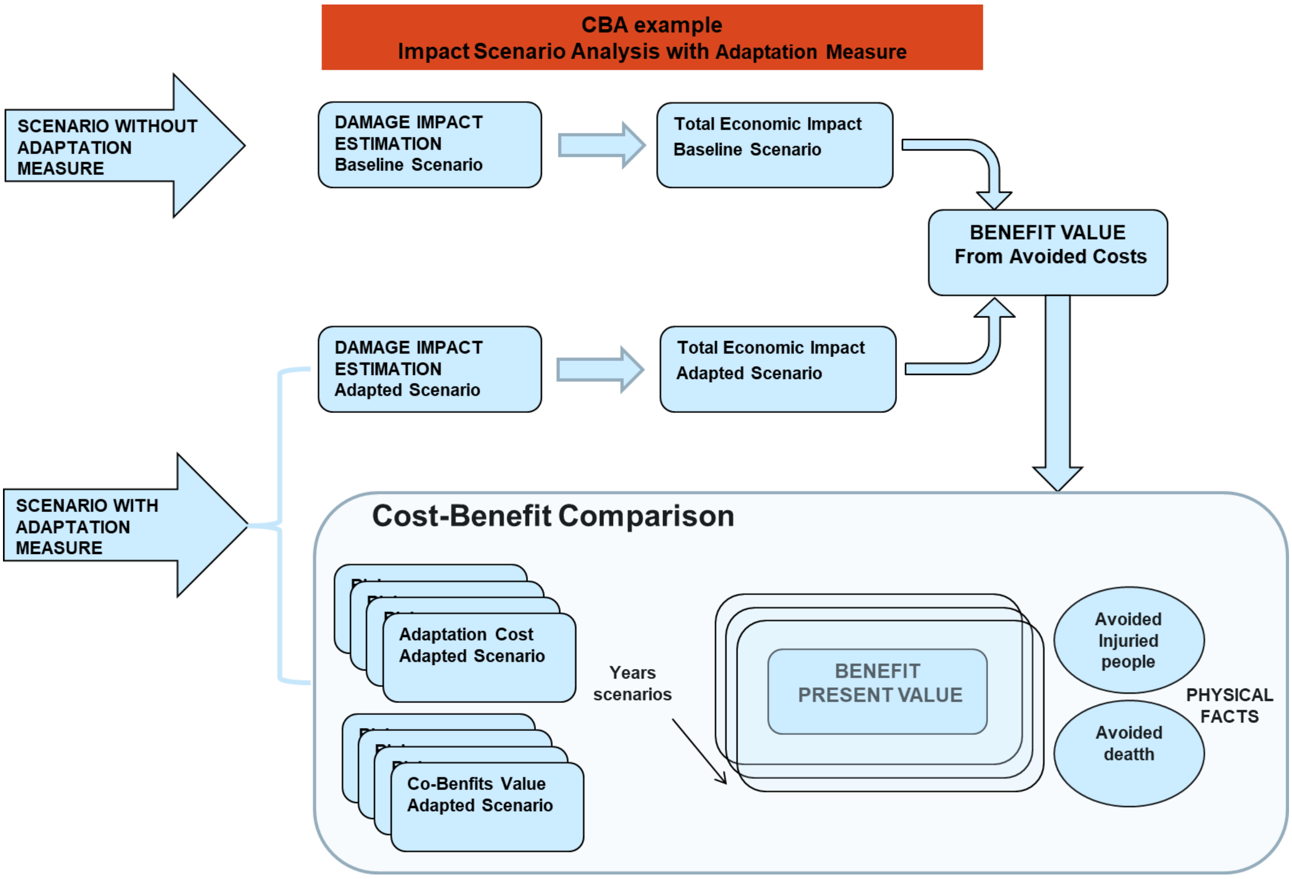


Figure 27: Cost-Benefit Analysis example

The Economic Evaluation

Conceptually, over time, the economic evaluation will take the Damage as input (i.e. the distribution of damage on different elements exposed according to the hazard(s) considered) and will calculate the related costs according to the expected output.

The Damage cost will include both costs of direct physical damages as well as indirect and secondary impacts arising from the hazards.

In addition to the calculation of the cost of the damage, the economic evaluation will include the evaluation of present and future costs linked to Adaptation Measure investments as well as Co-Benefits generated by such adaptation measures where the available data can allow such estimation. The economic evaluation will produce a set of economic result indicators and the results of the economic evaluation could be used, together with other indicators produced by other models, to support decision-making.

The evaluation will cover both quantitative and semi-quantitative evaluation, i.e. monetary and non-monetary evaluation of the impacts and adaptation measures.

The input values required to produce the economic evaluation (i.e. Dataset) should be the best monetary or non-monetary value estimates of costs and benefits (e.g. data from previous similar cases, expert judgement, results from other models, e.g. EU-FP7 CRISMA project, and simulations, from mathematical models / cost functions or formulas).

It should be taken into consideration that costs and benefits are highly dependent on the decision-making context (i.e. demonstration cases) and the adaptation measures to be evaluated.

From an economic point of view, the evaluation could include specific activities that are directly related to the evolution of the hazard, and it can produce indirect effects on economic activities.

With regard to the indirect economic effects produced by the hazard, the following activities could be considered depending on the economic data availability: decrease in local valued added due to psychological effects; effects on economic activities (interruption, slowing-down, etc.) which can produce a change in Gross Local Product (GLP) or in local value-added.

The economic evaluation aims to estimate, in probabilistic terms, the direct costs related to the above-mentioned activities and the indirect costs related to the effects of the hazard on economic growth (**Figure 28Figure 28:** Economic Impact Evaluation - details example).

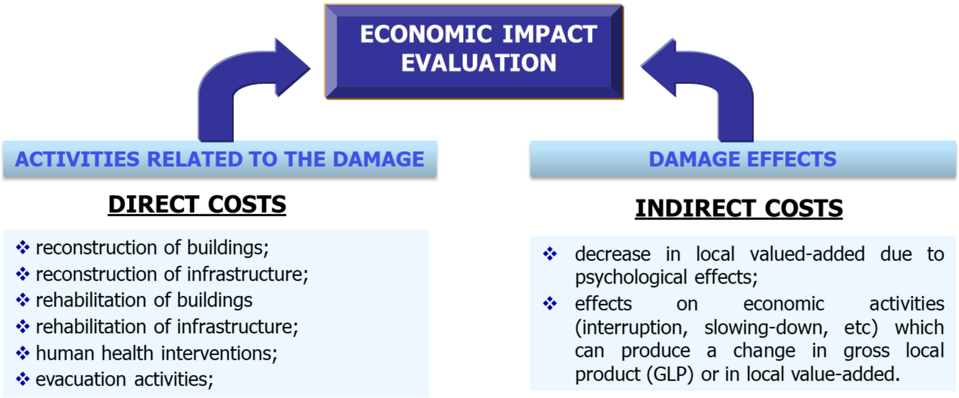


Figure 28: Economic Impact Evaluation - details example

The economic evaluation will be based on a Cost Breakdown structure that is a hierarchical structure which includes all cost items relevant to the applicable demo case and divides larger cost items into smaller and more concrete cost parameters which are easier to give a monetary value.

The cost and benefit breakdown structure implemented in CLARITY will be a way to recognise all relevant cost and benefit categories, depending on the availability of input values.

- Damage costs will consist of impacts on element exposed, i.e. people, infrastructure, nature, agriculture, and other assets.
- Investment costs will be all costs incurred prior to implementation of adaptation measures / set of measures. Investment cost describes the total amount of money necessary to put a measure into operation.
- Operating costs are all costs incurred after implementation of an investment and are related to the operation of an adaptation measure. Operating costs include both fixed costs and variable costs.
- Benefits will be largely the avoidance or reduction of negative consequences of damages generated by different adaptation measures and the Co-Benefits generated by the adaptation measure.

The breakdown structure could also differentiate between Tangible and Intangible costs.

Tangible cost refers to damages to goods, and services that can have market values and they can be either direct or indirect tangible cost.

Intangible costs are typically those for which no market exists and there is no systematic or agreed method available to measure them. Comprising both direct and indirect intangible cost.

The economic evaluation will be based on a logical scheme that allows evaluation of impacts by the combination of three different factors: time, space and stakeholders (i.e. point of view) (**Figure 29**).

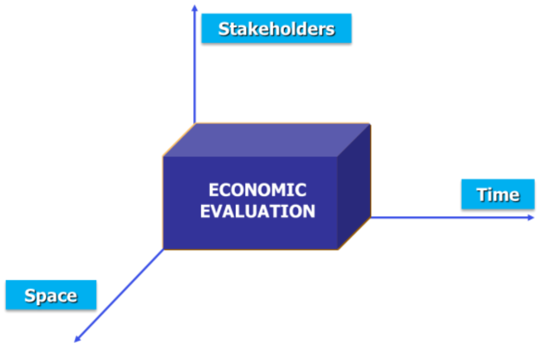


Figure 29: Factors involved influencing economic evaluation

The "Time" factor is linked to the temporal phases of the hazard; it is significant because the direct and indirect economic impacts may vary according to the selected temporal phase.

The "Space" factor is significant because the above-mentioned activities and effects may have a different connotation according to the area or zone affected by the hazard.

The factor "Stakeholders" connects the economic impact according to the stakeholders "community" affected. For example, it could be possible to identify higher costs for Public Administration (e.g. Campania Region) but not for private people, or costs for a specific community that are, at the same time, benefits for another one.

The current economic evaluation includes the economic evaluation of intangibles (human casualties, etc.). Nevertheless, a share of the damage to the local cultural heritage (building, historical places, monuments, etc.) is linked to the economic impact on tourism, which is included in the estimation of indirect costs. On the other hand, the inputs are represented by the elements on which the algorithms used for the evaluation of the above-mentioned economic impacts are based.

Main Cost Categories

The main cost categories will be represented by the evaluation of the direct costs related to activities and of the indirect costs related to the effects on economic growth, considering at a specific combination of the factors time, space and point of view.

In particular, with regard to the direct costs, the evaluation could be focused on determining the cost categories, such as the following examples:

1. Evacuation direct costs: related to the activities provided for the evacuation of the population from the affected area, according to the specific needs included in the individual municipal plans.
2. Reconstruction costs: related to the activities provided for removing the physical damage to capital assets including buildings, infrastructure and industrial plants through "in place" or "delocalized" reconstruction.
3. Rehabilitation costs: related to the activities provided for removing the physical damage to capital assets, including buildings, infrastructure and industrial plants by the rehabilitation of damaged.
4. Delocalization costs: related to the economic incentives provided for encouraging the consensual delocalization of part of population and of the economic functions not compatible with hazard risk proneness. The percentage of resident population and of the number of economic actors which are delocalized is linked to the percentage of the volume of residential buildings and of industrial plants which will be subject to delocalized reconstruction interventions.
5. Human health intervention costs: related to the health care management as the implementation of advanced medical structures, the strengthening of the existing local health structures, the

identification of poor people (elderly and disabled), the psychological and social assistance, chemical analysis, etc.

6. Decrease in local value added due to psychological effects: estimated through the comparison of the value of the production in two different moments in order to explore the psychological effects caused by hazards effect on resident population and, consequently, on human labour.
7. Change in Gross Local Product or local valued-added: referred to the reduction of the flows of goods and services, which can be bought and sold in markets. It can include, for example, lower output from damaged or destroyed assets and infrastructure and loss of income due to damage to marketing infrastructure.

Methodology & Assumptions

Modelling & Simulation (M&S) has been widely recognized as the best and most suitable methodology for investigation and problem solving in real-world complex systems in order to choose correctly, understand why, explore possibilities, diagnose problems, find optimal solutions and eventually transfer R&D results to real systems. In order to implement a Modelling & Simulation (M&S) based approach for studying economic impacts which has to be flexible and parametric for creating and investigating different scenarios and efficient in terms of time required for simulation run execution and to provide a decision-making tool for strategic choices and decisions about territorial planning or strategies for local economic growth , the conceptual model will be translated into a flexible, time-efficient and parametric simulation model. The simulation model could be considered as a decision-making tool, being capable of analysing different scenarios by using an approach based on multiple performance measures and user-defined set of input parameters. An example of the logical flow at the base for the conceptual model is shown in **Figure 30**.

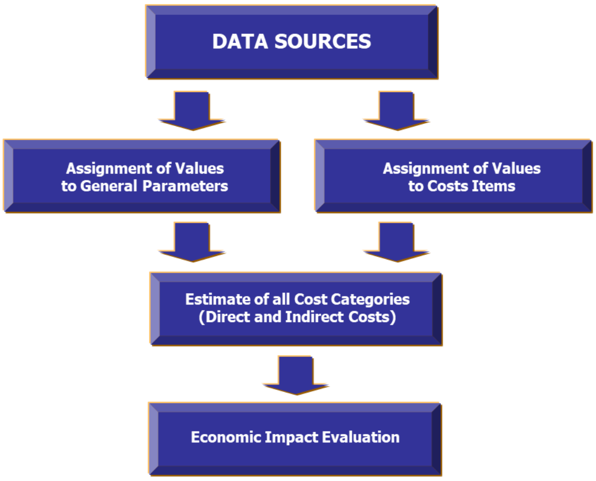


Figure 30: Economic Evaluation - Conceptual Model

About the indirect costs connected to the decrease in local value added due to psychological effects, the estimation will be implemented by reference to the productivity index, to the percentage of resident population which is employed and to the percentage of resident population that could suffer psychological problems because of hazard effects.

The indirect costs connected to the change in local valued added will be estimated taking into account its composition by productive sector (agriculture, industry, services) and the losses due to interrupted or reduced economic activities because of the damages caused by the hazard effects.

The main reference documents which constitute the background of this section are the following: [110] [111] [112] [113].

4 Knowledge Database

Background information (datasets, models, projects) that is relevant for the development of CSIS and the implementation of the demonstration cases is collected and stored in the CLARITY catalogue[29] to promote knowledge-sharing among the involved partners.

Section 4.1 provides an overview of existing background projects relevant for CLARITY; Section 4.2 describes models and tools that are necessary for the realization of the demonstration cases; Section 4.3 summarizes the involved datasets.

4.1 Background Projects

The CLARITY methodological approach and functionality is partly built on concepts developed within several national and international projects. Furthermore, datasets and other relevant background information provided by various projects will be integrated into the CLARITY Climate Services.

4.1.1 Core Projects

Some of the results and methodological approaches provided by the FP7 projects ENVIROFI, SUDPLAN, CRISMA and by the Copernicus projects Urban SIS and SWICCA will be included in the CLARITY CSIS:

The **SUDPLAN**[30] project (***S****ustainable* ***U****rban* ***D****evelopment* ***Plan****ner for Climate Change Adaptation*, FP7-247708, 2010-2012) aimed at establishing tailored planning tools that integrate relevant climate change information, i.e. climate and environmental modelling results, to facilitate decision support for long-term urban planning. Based on local data provided by the end-users, climate and environmental variables are obtained by downscaling of regional climate simulations.

The **CRISMA**[31] project (*Modelling* ***cris****is* ***ma****nagement for improved action and preparedness*, FP7-284552, 2012-2015) offers a framework for developing crisis management applications which are based on simulations of hazards and impact scenarios with the aim of providing mitigation/adaptation strategies and decision support. It is strongly end-user driven and allows decision makers to carefully compare simulation results and to consider alternative adaptation strategies in order to make better action plans.

The two **C3S** proof-of-concept projects Urban SIS and SWICCA provide urban climate and hydrology data that will be involved in the Demonstration Cases, acting as a starting point for user stories:

The **Urban SIS**[32] project (***Urban*** ***S****ectoral* ***I****nformation* ***S****ystem*) aims at delivering city specific climate and impact indicators for major European cities with special focus on infrastructure and health sectors. This information can be used directly by consultants, urban planners, engineers or scientists dealing with the following hazards: intense rainfall, heat waves and air pollution. The **SWICCA** project[33] (***S****ervice for* ***W****ater* ***I****ndicators in* ***C****limate* ***C****hange* ***A****daptation*) provides water-related climate indicators relevant for climate impact assessments and aims to bridge the gap between data providers and policy makers. Within the CLARITY project, part of the climate information produced within Urban SIS and SWICCA will be integrated and further developed and will particularly play a role in the implementation of Demonstration Case 2.

The projects mentioned above set the base for the development of user-oriented Climate Services and web-based decision-support tools that are a core part of the CLARITY CSIS.

[29] http://cat.clarity-h2020.eu
[30] www.sudplan.eu
[31] www.crismaproject.eu
[32] http://urbansis.climate.copernicus.eu/
[33] http://swicca.climate.copernicus.eu/

The **reclip:century**[34] project (Regional Climate Scenarios for Austria, ACRP/Klien, 2007-2010) provided COSMO CLM forcing data for the time range 1971-2100 as hourly data with 10x10km resolution based on SRES A1B scenario, based on ERA40 and HADCM3 input data, for further simulations for national (4x4km) and urban levels (1x1km) to be used for Linz COSMO CLM urban simulations.

The **EURO-CORDEX**[35] project, which is a branch of the international CORDEX initiative, produces regional climate change projections for the European domain, under the consideration of different representative concentration pathways (RCP 2.6, 4.5, 8.5). Within the CLARITY project, the model data produced by EURO-CORDEX will be used for the analysis of long-term climate projections on a European level or on the local level (e.g. for the implementation of DC1 and DC3) via further downscaling.

Within the framework of the Austrian national projects **SISSI-I+II**[36] (BMWFW, 2010-2011), **FOCUS-I**[37] (ACRP/KLIEN, 2011-2013) and **KELVIN** (FFG Cities of Future, 2014-2015) [114], high-resolution urban climate scenarios have been provided and the efficiency of possible adaptation strategies with respect to urban planning has been tested for selected cities in Austria.

The **UHI**[38] project (INTERREG CE, 2011-2014) provides database and application tools on mitigation and risk prevention regarding urban heat islands for eight metropolitan areas in Central Europe.

RESCCUE[39] project **(**RESilience to cope with Climate Change in Urban arEas) is a multisectorial approach focusing on water. The probabilities of strong climate anomalies and/or weather extreme events are estimated using the CFS ensemble of 25 members. In addition, simulations from the downscaled decadal models will be analysed and an ensemble of its projections will be performed in order to measure the probability of climatic anomalies.

EUPORIAS[40] project (European Provision Of Regional Impacts Assessments on Seasonal and Decadal Timescales) is a four-year collaborative project that brings together a wide set of expertise from academia, the private sector and the national met services. This project aims to develop a few fully working prototypes of climate services addressing the need of specific users, particularly for the time horizon between a month and a year ahead with the aim of extending it towards the more challenging decadal scale.

SPECS[41] project (Seasonal-to-decadal climate Prediction for the improvement of European Climate Services) undertakes research and dissemination activities to deliver a new generation of European climate forecast systems, with improved forecast quality and efficient regionalisation tools to produce reliable, local climate information over land at seasonal-to-decadal time scales, and provide an enhanced communication protocol and services to satisfy the climate information needs of a wide range of public and private stakeholders. The improved understanding and seamless predictions will offer better estimates of the future frequency of high-impact, extreme climatic events and of the prediction uncertainty.

The database of available background projects and results that are relevant for the CLARITY CSIS is not final and is being continuously updated by partners through the CLARITY catalogue.

[34] https://www.klimafonds.gv.at/assets/Uploads/Projektberichte/KFF-2009/20120427RECLIP-CENTURYWolfgang-Loibl.pdf
[35] www.euro-cordex.net
[36] http://www.zamg.ac.at/cms/de/klima/klimaforschung/stadtklima/sissi
[37] https://www.klimafonds.gv.at/assets/Uploads/Projektberichte/ACRP-2009/03032015FOCUSZuvela-AloiseEBACRP2B060373.pdf
[38] www.eu-uhi.eu
[39] http://www.resccue.eu/resccue-project
[40] http://www.euporias.eu/
[41] http://www.specs-project.eu/

4.1.2 Other Relevant Projects

In addition to the core projects listed in section 4.1.1 there are currently several active Europe-wide projects which deal with developing climate risk and adaptation strategies based on the demands of users. It is in CLARITY's interest to keep up to date with the developments of these projects and seek to develop possible synergies to not only achieve our goals, but also to further develop the impact and risk assessment analyses concerning climate change. Where available, deliverables from the projects which are relevant to this deliverable have been used as sources of information. Although not an exhaustive list, the main projects of interest include:

BRIGAID[42] (Bridging the Gap for Innovations in Disaster Resilience) – aims to bridge the gap between innovators and end-users in resilience to floods, droughts and extreme weather by offering state-of-the-art scientific knowledge and methods. Their mission is to provide integral support for innovations for climate adaptation. The project began in 2016 and is scheduled to run for four years. Their deliverable 5.2 "A Testing and Implementation Framework (TIF) for Climate Adaptation Innovations describes their methodology and how they quantify the hazard assessment **Es ist eine ungültige Quelle angegeben.**. This is similar to what CLARITY plans to do, and so can be used as a guide. One difference to CLARITY is that BRIGAID focuses their analysis on administrative units, which is the right approach if this is intended for the administrative stakeholders preparing climate adaptation strategies (states, regions or cities). However, in CLARITY we have stakeholders from different sectors and they are interested in their infrastructure and not (only) decision making on the level of administrative units. BRIGAID has already produced hazard maps for river floods, heat waves, wildfires, wind storms, and heavy precipitation and can be used to compare with the results from CLARITY. BRIGAID has used multiple climate model runs to calculate the different climate indicators to assess the hazards, and this is also the plan within CLARITY. From the ensemble of results, a mean is used to characterise the hazard. BRIGAID appears to have used only one climate indicator to assess each hazard, while CLARITY plans to use multiple indicators. The reason for this, is that it is not always possible to completely capture the effects of a hazard with only one index – e.g. although daytime heat may be well represented by an indicator such as the number of heat waves which only considers the maximum temperature, low night-time temperatures can moderate the effect of the heat wave and this can be represented by a tropical nights indicator.

CLARA[43] (Climate forecast enabled knowledge services) – aims to develop a set of climate services building upon the newly developed Copernicus Climate Change Services near term forecasts and sectorial information systems (SIS). It will set up a forum in which service purveyors, public agencies and authorities, and other users of climate services can contribute to the design and implementation of the project. Its focus is on hydrological applications, such as floods and irrigation, and also urban air quality and climate. These services may be of interest for CLARITY. The project began in June 2017 and will run for three years.

Climateurope[44] (Linking science and society) – aims to coordinate and support Europe's knowledge base to enable better management of climate-related risks and opportunities. It seeks, among other things, to enhance the communication between the generators of climate data and knowledge with the stakeholders who require such information. The project began in December 2015 and will run for five years. A Climateurope Network Platform is available for registered users and provides wikis, facilitates the exchange of documents, links and other useful content among its members.

COACCH[45] (Co-Designing the Assessment of Climate Change Costs) – aims to produce an improved downscaled assessment of the risks and costs of climate change in Europe that can be directly accessed by end users such as research, businesses, investment, and the policy-making community. Similar to the aims of CLARITY, an interactive tool is planned to provide a user-friendly, open access, interactive, multilevel

[42] https://brigaid.eu/
[43] http://www.clara-project.eu/
[44] https://www.climateurope.eu/
[45] https://www.coacch.eu/ [124]

web interface allowing interested users to access the data and results. As the 42-month project has only begun in December 2017, the level of detail offered in these results is unknown at this stage.

C3S[46] (Copernicus Climate Change Service) – The C3S provides information about the past, present and future climate to support adaptation and mitigation policies of the European Union. Free and open access to climate data and tools is offered through the Climate Data Store (CDS), which was launched in June 2018. The available datasets comprise "observations, historical climate data records, estimates of Essential Climate Variables (ECVs) derived from Earth observations, global and regional climate reanalyses of past observations, seasonal forecasts and climate projections. Access to data is open, free and unrestricted." In addition to the provided datasets, the CDS includes a toolbox, which enables users to build their own workflow and to analyse data that is available in the CDS. So far, it is not possible to combine non-climatic third party data (e.g. eurostats) into the workflow. While the CDS provides the means to access and analyse climate data, CLARITY focuses on the impact of climate change in urban areas and for traffic infrastructure, which involves the e.g. the overlay of non-climatic data with hazard maps to perform the exposure analysis. According to the FAQ page of the CDS website, it is planned to enable access to trusted third party data from a workflow in the future. Since new data products are still being developed and added, we will keep monitoring the progress of the CDS development.

DRMKC[47] (Disaster Risk Management Knowledge Centre) – aims to provide a networked approach to the science-policy interface in disaster risk management (DRM) across the Commission, EU Member States and the DRM community within and beyond the EU. It seeks to improve science-based advice through networks and partnerships, improve the use and uptake of research and operational knowledge, and advance technologies and capacities in disaster risk and crisis management. A Risk Data Hub in the form of a GIS web-platform was established in 2017 to improve the access and sharing of curated European-wide risk data, tools and methodologies for fostering DRM related actions. The Risk Data Hub gathers loss and damage data from past events. Its intention is to also provide a risk analysis for various hazards. Up to now (Dec 2018) the risk analysis comprises the exposure analysis and is provided for the following hazards: river flood, earthquake, landslide and subsidence. They also intend to integrate results from other projects, e.g. from ResCult into the Risk Data Hub. Contact was established with the developers of the Risk Data Hub to discuss potential interaction / cooperation between CLARITY and the Risk Data Hub. It is planned that datasets generated within CLARITY will be uploaded to this platform not only to help the climate change community, but also to further the disseminate the CLARITY CSIS.

ERA4CS[48] (European Research Area for Climate Services) – aims to boost the development of efficient Climate Services in Europe, by supporting research for developing better tools, methods and standards on how to produce, transfer, communicate and use reliable climate information to cope with current and future climate variability. The five-year project began in January 2016. This may be useful for CLARITY during the development of the CSIS online tool.

PLACARD[49] (PLAtform for Climate Adaptation and Risk reDuction) – aims to establish a comprehensive coordination and knowledge exchange platform for Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR). The platform will serve to encourage multi-stakeholder dialogue to address the gaps and fragmentation challenges in current CCA and DRR research, policy-making and practice, and to support the development of an evidence-base for research and innovation policies. The project began in June 2015 and is scheduled to run until June 2020. A first prototype designed to illustrate the main functionality of the proposed "Connectivity Hub" has been made available online, whereas the full version is scheduled to be launched in mid-2019. This will be of interest to CLARITY, as one its aims is to connect users with experts when they wish to have more detailed information after the screening study.

[46] https://climate.copernicus.eu/climate-data-store
[47] https://drmkc.jrc.ec.europa.eu/
[48] http://www.jpi-climate.eu/ERA4CS
[49] https://www.placard-network.eu/

PUCS[50] (Pan-European Urban Climate Services) – aims to use the best available urban climate data and convert it into information that is relevant for public and private end-users operating in cities. The goal is to improve decision-making in regard to sector policies and urban planning, and to help end-users address the consequences of climate change at the local scale. The project started in June 2017 and is scheduled to run until November 2019. As in CLARITY, PUCS uses case studies within several European cities to provide a detailed service evaluation and socio-economic impact analysis to quantify the benefits of using urban climate information. The available deliverables from the project (D5.1 Urban primary data need analysis and D5.2 Urban climate data for demonstration cases) describe the use of the climate data, urban climate model, and methods used to downscale the climate data to the urban scale. Their urban boundary layer climate model "UrbClim" is a sophisticated high-resolution model designed to model the urban climate and has similar characteristics to MUKLIMO_3 which will be used within CLARITY (see Section 4.2). The focus of UrbClim is in modelling the heat hazards, specifically the heat island effect. In order to investigate the urban flooding hazard, extreme rainfall maps and climate scenarios are generated through statistical downscaling of the publicly available global and regional climate model outputs. Such downscaling methods will be of interest for CLARITY as the coarse spatial resolution of the EURO-CORDEX climate model data will need to be increased for it to be useful for use within the urban landscape.

STORM[51] (Safeguarding Cultural Heritage through Technical and Organisational Resources Management) – aims to provide critical decision making tools to all European Cultural Heritage stakeholders charged to face climate change and natural hazards. Focus is on the three areas of prevention, intervention and policies, and planning and processes. Five pilot sites are used to implement their method in their calculations of the risk posed by the relevant climate hazards. Such risk models may be of interest for the risk analyses to be produced within CLARITY. The 3-year project began in June 2016.

Relevant projects which have already been completed, or are almost completed include:

ESPREssO[52] (Enhancing Synergies for disaster PRevention in the EurOpean Union) – is a Coordination and Support Action (CSA) aimed at contributing to new research and governance approaches to DRR and CCA. The project has taken advantage of a broad stakeholders engagement process focused around three key challenges, identified as overarching issues to facilitate discussion and interaction within dedicated Stakeholder Forums and Think Tanks: i) integrating DRR and CCA to foster resilience, ii) bridging the gap between science and legal/policy issues at local and national levels, and iii) improving national regulation to prepare for trans-boundary crises. The main output of ESPREssO consists in the "Vision Paper on future research strategies following Sendai Framework for DRR" and the "Guidelines for Enhancing Risk Management Capabilities". The project started in May 2016 and ended in October 2018. Being a CSA, ESPREssO did not produce any specific datasets, models or tools, so the main input for CLARITY is related to the "Vision" outlined, to be taken into account in the design of CLARITY services, especially for what concerns the needed research and innovation improvements in the field of i) climate-related hazard characterization, ii) risk and impact assessments, iii) data management and iv) DRR/CCA measures implementation (see deliverable 5.5[53]). The development of CLARITY methodology, services and tools, both concerning CSIS and Expert Services, perfectly match the key considerations of the "Vision Paper", thus representing an operational response to the gaps and needs in the field of DRR and CCA identified by ESPREssO.

EU-Circle[54] – aims to develop a framework to support Europe's infrastructure resilience to climate pressures. The project is developing a modelling environment where multiple scientific disciplines can work together to understand infrastructure interdependencies. The design principles will allow potential users to

[50] https://climate-fit.city/
[51] http://www.storm-project.eu/
[52] http://www.espressoproject.eu/
[53] http://www.espressoproject.eu/images/deliverables/ESPREssO_D5.5.pdf
[54] http://www.eu-circle.eu/

introduce fully tailored solutions and infrastructure data, by defining and implementing customised impact assessment models, and use climate / weather data on demand. The 3-year project ran from June 2015 to 2018. A portal has been developed to facilitate the contacts and the business activities related to the buying and selling of models, data, services and assessment related to the project outcomes and CI resilience in general. This could be used as a guide for the development of the portal planned within CLARITY.

RESIN[55] (Climate Resilient Cities and Infrastructures) – aims to investigate climate resilience in European cities by developing practical tools to help cities design and implement local climate adaptation strategies, working towards a formal standardisation of adaptation strategies. RESIN began in May 2015 and will end in November 2018. From their deliverable 5.1/2.2 Standardization in urban climate adaptation, the three main results of RESIN were (i) the development of the e-Guide, a decision support tool to support decision makers in following a standardised path towards the choice of appropriate and effective adaptation measures, (ii) the development of a standardized methodology (IVAVIA) for conducting a risk-based process for assessing impacts and vulnerabilities of urban areas and their infrastructures related to consequences of climate change, and (iii) a catalogue of urban adaptation options encompassing both technical, ecological and behavioural/institutional elements giving information on costs, benefits and effectiveness for various climatic and urban conditions. These are all topics which are also addressed in CLARITY and can be used as a guide to produce a more advanced product.

It should be pointed out that the CLARITY CSIS will not just be an information system for the collection, organization, storage and communication of arbitrary climate-change related information, as is the case for several of the above mentioned projects (e.g. RESIN, EU-Circle). Instead, the CLARITY CSIS represents a platform that unites, under a common user interface, Climate Services that support climate change risk/impact assessments targeted at mitigation/adaptation options priorities identification following the EU-GL-based CLARITY modelling methodology. This is the main difference and most important innovation in comparison to the existing Climate Change Adaptation Platforms that provide conceptual and practical guidance but not the technical means to ensure compliance to underlying theoretical framework.

Table 4 shows a summary of the key features of each EU-Project described previously and what elements are similar to those of CLARITY and can subsequently be used as a guide. Many of these projects provide or will provide access to data on some aspects of the EU-GL steps which CLARITY follows (e.g. hazard characterisation at DRMKC), and so will be a useful link for CLARITY. As much of the information has been collected from what was available on the project websites, empty entries within the table simply mean that this item was not explicitly mentioned as being a focus of the project.

[55] http://www.resin-cities.eu/home/

Table 4: Summary of the EU-Projects described within the text comparing the elements important to CLARITY. Note that empty cells only mean that information regarding that element was not explicitly available.

Project Comparison							
		Climate analysis corresponding to steps of the EU-GL methodology					
Project	**What tool is being developed?**	**Hazards**	**Element Exposure**	**Vulnerability**	**Risks/Impact**	**Adaptation strategies & Appraisal**	Comments
CLARITY	Portal offering Screening and Expert Study Climate Analyses for any location in Europe.	Heat, cold, floods, wind storms, droughts, fire, landslides	y	y	y	y	Multiple climate models, multiple indices for each hazard, and emissions scenarios RCP2.6, 4.5, 8.5
BRIGAID	Testing and Implementation Framework: Self Assessment Tool to identify societal, technical, environmental and sectoral issues	Heat, floods, heavy precipitation, wind storms, droughts, fires	y	y	y	y	Only one index per hazard. Emissions scenarios RCP4.5, 8.5 considered
CLARA	Climate services developed through co-generation and a toolkit for assessing economic value	Hydrological (floods, water management), heat and air pollution			y	y	Builds upon Copernicus Climate Change Services
Climateurope	Develop a framework for Earth-system modelling and climate service activities	y					Earth-System and European climate modelling
COACCH	Climate Change Impact & Policy Simulator and Database				y	y	Economic costs of climate change at different scales for difference socio-economic and climate scenarios
DRMKC	Risk Data Hub data portal	All	y		y		Data Platform continually growing as new datasets for hazards, risks are added
ERA4CS	Support research for developing better tools, methods and standards on how to produce, transfer, communicate climate information	y	y	y	y	y	Enhance user adoption of and satisfaction with Climate Services
PLACARD	Connectivity Hub to improve collaboration, communication and coordination				y	y	Uses the SPINE database which has been developed in cooperation with the ESPREssO project
PUCS	An urban climate data platform to make climate data available	Heat, floods			y	y	Will provide access to the already developed urban climate model UrbClim and an interactive web-based map tool.
STORM	Critical decision making tools	Heat, floods	y	y	y	y	Focused on European Cultural Heritage stakeholders
RESIN	Methodologies and tools developed by the partners tailored to the city's needs	Heat, floods		y	y	y	Create a unifying framework that allows comparing strategies, results and identification of best practices.
ESPREssO	Stakeholder forum promoting mechanisms and interactions with key players	Trans-boundary crises			y	y	SPINE database developed in cooperation with the PLACARD project
EU-Circle	Critical Infrastructure Resilience Platform, Exploitation Platform	Heat, Floods, fires			y		
Project is running							
Project finished							

4.2 CLARITY Models & Tools

The CLARITY methodological approach for Expert Climate Services relies on employment of several climate and environmental modelling tools that provide high quality data necessary for impact assessment. These models will be employed in offline mode and their results will be integrated into the CLARITY CSIS.

MUKLIMO_3

MUKLIMO_3 is a dynamical model, developed by the Deutscher Wetterdienst[56] (DWD), suitable for urban climate applications (see [115], [116]). It provides hourly data of air temperature, wind speed, relative humidity and heat fluxes at a spatial scale of 20 – 200 m and at a vertical resolution of 10 – 100 m. Based on a dynamical-statistical downscaling technique, called the "cuboid method" (see, for example, [117] and [118]), it is possible to derive 30-year climate indices (mean annual number of summer days, heat days, warm nights, tropical nights). This method combines long-term climate projections (e.g. from EURO-CORDEX simulations) with high-resolution model output. The model requires high-resolution input data, i.e. meteorological data, land use, topography, building properties and vegetation information.
In the CLARITY project, the model will be used for the implementation of Demonstration Cases 1 and 3, in particular for exploring and analysing urban heat island patterns and for identifying hot spots, i.e. microclimatic sensitive areas. Furthermore, it will be used to evaluate the efficiency of possible adaptation measures (e.g. increased vegetation, decreased soil sealing etc.) in accordance with user stories. The results from previous Austrian national projects may serve as a baseline here (see Section 4.1).

COSMO CLM

COSMO CLM will be applied for Demonstration Case 3 to provide climate data for impact assessment and climate adaptation tests. COSMO CLM or CCLM model is based on a numerical, non-hydrostatic model for operational weather prediction which has been extended to run in climate mode simulating atmospheric dynamics for a time range of up to centuries. The model domain covered initially the Greater Alpine Region (GAR) where a one-way double nesting approach has been used. Hindcast runs are forced by ERA40/ERAinterim data from the ECMWF covering the years from 1960 to 2015 are used to validate the model performance. In The climate scenario run, forced by HadCM3 GCM simulations (Hadley Centre Coupled Model, version 3), is using the IPCC SRES-scenario A1B carried out for IPCC AR4.

The domain for the first nesting step was Europe with a spatial resolution of 0.44°. The second domain for GAR was embedded with defined with a resolution of 0.09°. For Austria simulations were further conducted with a 4x4 km resolution, for greater urban areas in Austria simulations at a 1x1 km grid.

The Linz simulation is conducted applying a special version of Cosmo-CLM (cclm_4.8_clm19_c6) which includes selected urban extensions such as TERRA URB. Two additional fields need to be added to the standard model input: the urban fraction (URBAN) and annual-averaged anthropogenic heat flux (AHF). Hourly results for atmospheric conditions (temperature, humidity wind speed, precipitation) for certain vertical levels, further soil parameters and surface data are stored as input data for hazard - and finally impact mapping and impact research, or as boundary conditions for further downscaling simulations.

ENVI_MET V4

ENVI_MET V4 is a holistic three-dimensional non-hydrostatic model for the simulation of surface-plant-air interactions used to simulate urban environments and to assess microclimate effects of greening and desealing measures. It contains an atmospheric model (wind field turbulence, temperature, radiative fluxes, humidity), a soil model (surface and soil temperature, soil water content, vegetation water supply),

[56] www.dwd.de

a vegetation model (3D plant geometry, foliage temperature, exchange with environment: evaporation) and a building model (3D building geometry, materials, building physics, building energy performance, green wall and roof systems). It is designed for microscale with a typical horizontal resolution from 0.5 to 5 metres and a typical time frame of 24 to 48 hours with a time step of 1 to 5 seconds. This resolution allows analysing small-scale interactions between individual buildings, surfaces and plants.

Within CLARITY, the model will be used for the implementation of Demonstration Case 3, in particular on the micro scale (district level, settlement areas) and hence, for analysing the microclimatic situation of certain urban areas. It will further be used to model possible adaptation strategies against heat wave hazards, such as green infrastructure measures.

MIKE

The MIKE products are developed by the Danish Hydraulic institute (DHI) for modelling water environments. Mike 11 is a fully dynamic, one-dimensional model for modelling river flow. By describing the appearance of the river with cross sections, hydraulic structures and boundaries, the program calculates the discharge, flow velocities and water levels along the river. The model requires information about river bathymetry, high-resolution topography, hydraulic structures and boundary conditions. Mike 21 is a fully dynamic, two-dimensional model that calculates water level and flow conditions. The model is mainly developed for coastal areas but is commonly used for extreme rainfall modelling in urban areas. The program requires high resolution topography data, land use, information about infiltration and rainfall data.
In the CLARITY project, the model will be used for the implementation of DC2 for Jönköping, Sweden (CABJON) and/or in User Stories US-DC2-P1. The results will be used to assess the risk of current and planned infrastructure and to evaluate possible adaptation measures.

HYPE

HYPE is a continuous process-based hydrological model developed at SMHI, which simulates components of the catchment water cycle at a daily or hourly time step. The model is a semi-distributed conceptual model, in which a river basin may be subdivided into multiple sub-basins, which can further be subdivided into homogeneous hydrological response units (HRUs) based on combined soil type and land use classes. Normally, model outputs are generated at the sub-basin outlet. The model has conceptual routines for most of the major land surface and subsurface processes (e.g. including snow/ice accumulation and melting, evapotranspiration, surface and macro-pore flow, soil moisture, discharge generation, groundwater fluctuation, aquifer recharge/discharge, irrigation, abstractions and routing through rivers, lakes and reservoirs). The model requires input data that describe the land surface features of the catchment, such as topographic, soil and land use maps, as well as daily or hourly surface meteorological data (precipitation and temperature). Optional local information on irrigation and river/reservoir regulation may be used as well.
In the CLARITY project, the model will be employed in DC2 to explore the risk of flooding in the Stockholm and Jönköping urban areas associated with intense precipitation and possible lake level changes. The model can further be employed to assess the impact of measures such as planning of wetlands around Jönköping on the reduction of flood risk. In addition to new tailored data that will be produced in this project, data produced in a previous project, UrbanSIS, by employing the same model can be used.

4.3 CLARITY Datasets

A large variety of datasets will be used within the project, in particular for the implementation of the CLARITY CSIS and the four demonstration cases. These include already existing datasets originating from climate and earth monitoring systems or from numerical model simulations with the purpose of providing a scientific baseline or for serving as input for further model applications and tools. Some other datasets will be produced within the project. A short summary of main datasets necessary for risk and impact analysis or as input for modelling tools was provided within D7.8 Data Management Plan [119]. Further information and mapping of different input and output datasets for the modelling process is provided in D2.1 "Demonstration and Validation Methodology" [120]. This section provides short overview of data types necessary to support methodological approach in the CLARITY CSIS and data sources considered in implementation.

Part of the relevant datasets that will be mainly used for hazard characterisation on a high level can be obtained from European data sources, often free of charge. They provide a solid baseline with respect to hazard identification, climate change analysis and risk assessment.

Available hazard maps

The **ESPON**[57] database provides a large number of already existing maps covering different hazards (extreme temperatures, floods, storms, droughts, amongst others. The European Commission's **Joint Research Centre**[58] (JRC) offers information and maps dealing with additional hazards (e.g. wild fires). High-resolution maps of landslide susceptibility and other soil threats are provided by the **European Soil Data Centre**[59] (ESDAC), as part of the JRC. These datasets might be directly integrated in CLARITY CSIS with the aim of supporting hazard characterisation at a prefeasibility level. Despite the large number of various hazard maps, datasets are generally not consistent and often only available at low resolution.

Hazard analysis and characterization through available climate data

Another way of performing hazard characterisation and climate analysis is based on available observational and modelling data. These datasets (e.g. temperature, precipitation, wind etc.) can be further used to derive climate indices and climate change signals needed for the evaluation of hazards. This allows for consistent and flexible climate and hazard analysis at a high resolution.

The **European Climate Assessment & Dataset**[60] (ECA&D) project, which was founded by the European Climate Support Network in 1998, offers a database of quality-controlled daily meteorological data from measuring stations across Europe and derived indices of climate extremes with the objective of monitoring and analysing climate change. Additionally, a high-resolution gridded dataset (E-OBS) that is based on the ECA&D observational data is available. The **SWICCA** project (see Section 4.1) offers water-related climate impact data. Different climate (impact) indicators at different spatial resolutions are openly available for visualisation or can be downloaded and used for further analysis. These hydrological datasets are of particular importance for the implementation of the Swedish Demonstration case. The aforementioned **EURO-CORDEX** project (see Section 4.1) produces regional climate change projections for the European domain at a spatial resolution of 0.11° (~12.5 km), under the consideration of different representative concentration pathways (RCP 2.6, 4.5, 8.5). Within the CLARITY project, the model data produced by EURO-CORDEX will be used for the analysis of long-term climate projections on a European level and for hazard characterisation based on further evaluation of climate change indices and signals. On an expert level, in particular within the framework of the demonstration cases, EURO-CORDEX data will be used to further downscale climate information to the local/urban scale.

High-resolution datasets

High-resolution datasets will mainly serve as input for further model application within the framework of the four demonstration cases. Some datasets are openly available through European land monitoring

[57] https://www.espon.eu/
[58] https://ec.europa.eu/jrc/en
[59] https://esdac.jrc.ec.europa.eu/
[60] http://www.ecad.eu/

services or agencies, while others originate from local authorities and are highly end-user driven. The Copernicus Land Monitoring Service[61] offers the following high-resolution datasets (**Table 6**): **Urban Atlas** (2012) high-resolution land cover data is provided for 695 cities across EU and EFTA (European Free Trade Association) countries. The current version distinguishes 27 land use classes. Furthermore, a **tree cover density** raster layer (20 m) and a **European settlement map** (10 - 100 m) are available. The European Environment Agency[62] provides a **Digital Elevation Model** (DEM) at 30 m horizontal resolution and a **soil sealing layer** at 20 m horizontal resolution. These datasets are openly available and serve as input data for further climate calculations (e.g. MUKLIMO_3) and enable climate analysis on an expert level. The fact that they are available at a European level makes results comparable across the different Demonstration Cases.

Table 5: Key datasets from Copernicus Land Monitoring Services.

Dataset	*Description*	*Type*
Urban Atlas	*The Urban Atlas service offers a high-resolution land use map of urban areas. It is providing pan-European comparable land use and land cover data for Functional Urban Areas (FUA). The product is adapted to European needs and contains information that can be derived mainly from Earth Observation (EO) data backed by other reference data, such as Commercial Off-The-Shelf (COTS) or Open Street Map (OSM) navigation data and topographic maps.*	→ *697 FUAs* → *Most EU28 cities over 50,000 inhabitants* → *17 urban classes with MMU 0.25 ha; minor nomenclature changes* → *10 Rural Classes with MMU 1ha* → *Street Tree Layer (STL) within Urban Areas for selected FUAs*
CORINE Land Cover (CLC)	*It consists of an inventory of land cover in 44 classes (grouped in hierarchical 5 macro-classes). CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The time series are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha.*	1. *Artificial Surfaces* 2. *Agricultural areas* 3. *Forest and seminatural areas* 4. *Wetlands* 5. *Water bodies*
High Resolution Layers (HRL)	*HRLs provide information on specific land cover characteristics and are complementary to land cover / land use mapping such as in the CLC datasets. The HRLs are produced from 20 m resolution satellite imagery through a combination of automatic processing and interactive rule-based classification. Five themes have been identified so far, corresponding with the main themes from CLC, i.e. the level of sealed soil (imperviousness), tree cover density and forest type, (semi-) natural grasslands, wetlands and permanent water bodies.*	1. *Imperviousness* 2. *Forests: Tree Cover Density (TCD) and Forest Type (FTY)* 3. *Grassland* 4. *Wetlands* 5. *Permanent Water Bodies*
European Settlement Map	*It is a spatial raster dataset that is mapping human settlements in Europe based on SPOT5 and SPOT6 satellite imagery. It is published with two associated data layers. It has been produced with GHSL technology by the European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Global Security and Crisis Management Unit.*	*It represents the percentage of built-up area coverage per spatial unit. The GHSL method uses machine learning techniques in order to understand systematic relations between morphological and textural (pantex) features, extracted from the multispectral and panchromatic (if available) bands, describing the human settlement. The thematic content of this product is somewhat similar to the imperviousness HRL.*
EU-DEM (Digital Elevation Model over Europe)	*A digital surface model (DSM) of EEA member and cooperating countries representing the first surface as illuminated by the sensors. It is a hybrid product based on SRTM and ASTER GDEM data fused by a weighted averaging approach.*	*The statistical validation of EU-DEM v1.0 documents a relatively unbiased (-0.56 meters) overall vertical accuracy of 2.9 meters RMSE, which is fully within the contractual specification of 7m RMSE (European Commission 2009).*

[61] http://land.copernicus.eu/
[62] https://www.eea.europa.eu/

EU-Hydro	*A dataset for all EEA39 countries providing photo-interpreted river network, consistent of surface interpretation of water bodies (lakes and wide rivers), and a drainage model (also called Drainage Network), derived from EU-DEM, with catchments and drainage lines and nodes.*	*River network*

Demonstration-case specific datasets

Other datasets relevant for climate analysis on an expert level are entirely demonstration-case specific, which means that they are available for particular regional/local areas only or that they have been directly provided by end-users in connection with the user stories. A profound discussion on DC-specific datasets and their collection methodology is found in D2.1 and therefore, just a short summary will be provided here.

Demonstration Case 1:

Considering the different types of models and applications used within DC1, including an urban model (addressing heat wave hazards), surface flood models (addressing extreme precipitation events) as well as different vulnerability models, a variety of local datasets will be needed as input data, offered by local data providers. These include:

- Historical meteorological data – ISPRA
- LIDAR dataset: DEM, DSM, DTM (2009/2012) – Naples metropolitan City
- Vegetation and land use data – Naples municipality
- Building typologies classification: historic centre (2016) – Naples municipality
- Building typologies classification and open spaces (1990-2017) – PLINIVS
- Satellite data (e.g. albedo, impervious parts of the canopy layer) – Ministry of Environment
- Census data of population, business and industry (2011) – ISTAT
- Urban Masterplan and 2nd level public and private initiatives (2015) – Naples municipality

Demonstration Case 2:

- 1 km resolution dataset, covering the city of Stockholm, including (provenance: C3S UrbanSIS):
    - meteorological data, produced by the HARMONIE model
    - air quality data, produced by the MATCH model
    - hydrological data, produced by the HYPE model
    - derived indicators (climate, health, environment, infrastructure)
    - for more information see: http://urbansis.climate.copernicus.eu/urban-sis-climate-indicators/http://urbansis.climate.copernicus.eu/urban-sis-climate-indicators/
- Water related pan European indicators, resolution 0,5 degrees and catchment based (provenance: C3S SWICCA)
    - water quantity data (including river flow, flow recurrence, snow)
    - water quality data (Phosphorous, Nitrogen and temperature)
    - meteorological data (air temperature, freezing degree days, precipitation intensity, dry spells, cloud cover and relative humidity)
    - socioeconomic data (including land use and population)
    - for more information see: http://swicca.climate.copernicus.eu/start/climate-indicators/

Demonstration Case 3:

As DC3 is dealing with heat hazards on urban scale and related climate change adaptation strategies, various datasets are needed for the application of the involved models. In particular, the following input data are required:

- 1m Digital Elevation Model (DEM) for the City of Linz (2009)
- 5m DEM for Upper Austria (2009)
- 1m Normalized Differential Surface Model (NDSM) for the City of Linz (2009)
- Land cover data (CORINE & Urban Atlas 2006, 2012)
- LIDAR data for the City of Linz (2009)
- LIDAR point cloud data, providing altimeter information for the City of Linz (2011) and derived 3D-Building model (LOD 2) and footprint model for the city of Linz (2011)
- Building footprint model for the City of Linz (2017)
- Vegetation layer based on areal photo classification and storey information at building level
- Zoning Plan for Upper Austria (2017)
- Map of planning permissions for new buildings (last 5 years - with size indication) for the City of Linz (pdf, transferred to tif and georeferenced)) – (2017)
- OSM roads, building footprints, for the Linz Greater Region (2017)

Demonstration Case 4:

The following datasets, used within DC4 that deals with the improvement of the resilience of transport infrastructure, are provided by the Spanish Geographic Institute. They cover all Spain territory and will be used for hazard characterization and for the identification of vulnerable elements.

- LiDAR point cloud data providing altimeter information
- Digital Elevation Model (5m)
- Land cover data
- Spanish transport network layers, including all types of roads and railways
- Meteorological data

5 Science Support for CLARITY Climate Services

This section provides an overview about methodological and technical aspects required for the implementation of ICT and Expert Climate Services, as well as the scientific concept. It is an initial attempt to link User Stories with Test Cases and describe the expected workflow. At this point, it should be mentioned that not all of this information is yet available but remains subject to further discussion. Nevertheless, a first picture of what the workflow is expected to look like, can be provided.

5.1 ICT Climate Services

Among others, the ICT Climate Services (ICT-CS) aim to provide CLARITY users with a pre-feasibility analysis tool which does not require end-users to provide detailed information on exposure and vulnerability at local level, mainly relying on datasets publicly available at EU and/or national level.

Indeed, the output of this set of climate services has a higher level of uncertainty and a limited reliability compared to the CLARITY expert services (see Section 5.2). Nevertheless, it allows to perform a preliminary analysis of specific issues to be tackled in the context of adaptation measures’ planning and design.

The ICT-CS concept model aims to assess the damage induced by climate changes (heat waves, floods, landslides, heavy rains) at large scale, considering, as minimum unit of measure, regions or nations, in function of the available data.

The approach is founded on the consolidate definitions of risk, as convolution of hazard, exposure and vulnerability (see CLARITY glossary and Section 3.3).

The quantitative and qualitative evaluation of 'hazard' (extreme temperatures, droughts, etc.), 'exposure' in terms of vulnerability factors (DEM, infrastructures location, urban density, population, tree cover density, etc.) and 'vulnerability' can be carried out on the base of information deduced by free data base available for European territory.

In particular, the vulnerability can be assessed as 'climate change damage functions', as obtained by Roson and Sartori (2016) [121], which are developed six specific equations, referring to: sea level rise, agricultural productivity, heat effects on labour productivity, human health, tourism flows, and households’ energy demand. All parameters of the damage functions are estimated for each of the 140 countries and regions in the Global Trade Analysis Project 9 data set.

The databases containing information to define the Hazards (see Section 4.3) are, for example: ESPON[63] database; Joint Research Centre[64]; European Soil Data Centre[65]; European Climate Assessment & Dataset[66].

Table 6 provides an overview of most relevant hazard types in the CLARITY project, examples of indices that can be used to quantify the hazards and available data sources. The list of hazard types is not limited and can be extended in the future dependent on the user requirements. Some of the listed indices follow the definitions recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI)[67] who defined a core set of 27 climate change indices and by ECA&D[68] that provides an additional set of 46 indices of extremes, specifically designed for Europe. Some other indices are taken from relevant literature, cited in Section 2.1. Further research and discussion within the framework of CLARITY may lead to the requirement of additional indices and/or to a modification of those that already exist. The list of data sources is also not limited and will be updated in case of new data sources (e.g. from Copernicus Data

[63] https://www.espon.eu/
[64] https://ec.europa.eu/jrc/en
[65] https://esdac.jrc.ec.europa.eu
[66] http://www.ecad.eu
[67] http://etccdi.pacificclimate.org/list_27_indices.shtml
[68] https://www.ecad.eu//indicesextremes/indicesdictionary.php#8

Store) become available. Especially, if better quality and higher resolution data on regional scale are accessible.

The database containing information useful to define the Exposure are, for example: EuroStat[69]; OpenStreetMap[70]; Copernicus[71]; Global Earthquake Model[72].

The database containing information to define the Vulnerability are: The World Bank[73]; MunichRe[74]; GTAP[75].

In function of assigned climate change hazard scenario (i.e. a given increase in temperature), for each region or nation (with available data), the outputs of the model can be:

- a risk index, in the range [0-1];
- or the percentage incidence on GDP.

These parameters can be assessed also in the hypothesis of implementation of mitigation strategies (adaptation measures), with the aim to have comparative assessments.

CSIS should support strategic pre-feasibility risk screening for elements at risk, help them to better understand the problem at hand, decide if they need additional studies and formulate the requests for additional expert studies if needed. The user should be able to perform risk analysis on a high level and use the results for decision-making.

The following user stories outline the expected science support needed for a successful implementation of the ICT Climate Services at a pre-feasibility level, addressing different steps of the adapted EU-GL methodology:

- US-CSIS-121 pre-feasibility study – risk analysis
    - tool that allows users with no in-depth modelling knowledge to perform the (ultra)high-level strategic pre-feasibility risk screening;
- US-CSIS-122 pre-feasibility study – impact scenario analysis
    - tool that allows users with no in-depth modelling knowledge to perform the (ultra)high-level strategic pre-feasibility impact scenario analysis;
- US-CSIS-123 pre-feasibility study – adaptation options
    - a tool that will allow users with no in-depth modelling knowledge to perform the (ultra)high-level strategic pre-feasibility identification and appraisal of the adaptation options

The user stories are resolved by corresponding test cases. **Table 9** summarizes the expected workflow for ICT Climate Services in Annex II (ICT Climate Services).

[69] http://ec.europa.eu/eurostat
[70] www.openstreetmap.org
[71] http://www.copernicus.eu/
[72] https://www.globalquakemodel.org/
[73] https://data.worldbank.org
[74] http://natcatservice.munichre.com/
[75] https://www.gtap.agecon.purdue.edu/

Table 6: Hazards and their respective indices

Hazard	Index	Provided by	Data sources
Temperature Extremes/Heat waves/Cold waves	***HWMI(d):*** *Heat Wave Magnitude Index (daily)* ***SU:*** *Number of summer days* ($T_{max} \geq 25°C$) ***TR:*** *Number of tropical nights* ($T_{min} \geq 20°C$) ***CDD***: *Number of consecutive SU*	ZAMG, SMHI, AEMET	ECA&D[76], EURO-CORDEX[77], SWICCA[78]
Extreme precipitation	***R10mm:*** *Heavy precipitation days (precipitation ≥ 10mm)* ***R20mm:*** *Very heavy precipitation days (precipitation ≥ 10mm)* ***R95p:*** *Very wet days (days with precipitation sum > 95th percentile of daily amounts)*	ZAMG, SMHI, AEMET	EURO-CORDEX SWICCA[79]
Floods	*to be discussed*	SMHI, other data suppliers	SWICCA
Droughts	***SPI:*** *Standardized Precipitation Index* ***CDD:*** *Consecutive Dry Days*	ZAMG, SMHI, AEMET	EURO-CORDEX
Storms/Extreme wind speed	*to be discussed* *e.g. 98th percentile of daily maximum wind speed*	ZAMG, SMHI, AEMET, other data suppliers	EURO-CORDEX
Forest Fires	***FWI:*** *Fire Weather Index* ***SSR:*** *Seasonal Severity Rating*	ZAMG, AEMET, other data suppliers	EURO-CORDEX European Forest Fire Information System (EFFIS)[80]
Landslides	***Susceptibility*** *levels at continental scale*	PLINIVS, other data suppliers	European Soil Data Centre (ESDAC)[81]
Earthquakes	*to be discussed*	PLINIVS, other data suppliers	European-Mediterranean

[76] https://www.ecad.eu//indicesextremes/indicesdictionary.php#8
[77] http://www.euro-cordex.net/
[78] http://swicca.eu/
[79] http://swicca.eu/
[80] http://effis.jrc.ec.europa.eu/
[81] https://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus-v2

			Seismological Centre (EMSC)[82] Observatories & Research Facilities for European Seismology (ORFEUS)[83] USGS Earthquake Hazards Program[84]
Volcanic Eruption	***VEI:*** *Volcanic Explosivity Index*	PLINIVS, other data suppliers	NOAA Significant Volcanic Eruption Database[85]

5.2 Expert Climate Services

Whereas the ICT Climate Services aim to provide easy-to-use (pre-feasibility analysis) tools, Expert Climate Services should support the end-user with project-specific and detailed studies (full study), including micro- and urban climate modelling and high-resolution climate risk and adaptation scenarios. The end-user should get information about the required steps that are to be taken for requesting a full study and about the information that is required by the experts.

5.2.1 Demonstration Case 1

DC1 User Stories (see D1.1 [122] and D2.1 [120]) outline the objectives and key requirements from local end-users in terms of innovative climate services aimed at integrating adaptation measures within infrastructure projects in the context of the Metropolitan City of Naples, with a specific focus on the Municipality of Naples, as main urban centre and capital city of the metropolitan area.

Two main broad areas of interest are identified:

- Climate adaptive planning (US-DC1-100), targeting ongoing large urban redevelopment projects such as those related to the Bagnoli-Coroglio and East Napoli areas.
- Climate adaptive design guidelines and building regulations (US-DC1-200), targeting the ongoing legislation update related to the local building code and the technical norms of the local urban plan, to foster the integration of adaptation measures in the private initiatives related to buildings and open spaces retrofitting.

The first area highlights the need of the local administration of evaluating the requirements needed for urban regeneration, new construction and building retrofitting in highly densely populated areas, by integrating the inevitable constraints (due to traditional building techniques, landscape preservation requirements, effective cost of retrofitting) with a new approach based on climate modelling, directing to the use of sustainable materials and technologies aimed at climate adaptation. The approach, applied to potential transformation and real urban plans will help investigating the performances of different typologies of land use and alternative technological options. This will allow, in compliance with the standard building regulations, to test different planning/design alternatives to help the project manager to choose solutions which maximize the climate adaptation benefits.

[82] https://www.emsc-csem.org/#2
[83] https://www.orfeus-eu.org/data/strong/
[84] https://earthquake.usgs.gov/
[85] https://www.ngdc.noaa.gov/

The second area highlights the need of integrating new climate regulations within local building codes to streamline “ordinary” retrofitting interventions, mainly from private initiative and widespread on the territory. Being the Metropolitan City of Naples a multi-risk prone area, subject to the potential impact of seismic, hydrogeological and volcanic events, such regulation and design guidelines cannot be developed without taking into account the regulatory constraints already existing in relation to the geophysical hazards in the area. This condition, while defining a complex modelling and operational framework that needs to take into account multiple vulnerability conditions and risks, outline the potential of building new regulation aimed at integrating Climate Change Adaptation and Disaster Risk Reduction, an issue that show a high replication potential not only in the 91 municipalities of the Metropolitan Area, but also in the entire Italian context, extensively subject to multi-risk conditions related to both geophysical and climate hazards.

The Sub Stories defined within DC1 clearly outline the modelling workflow and thus the expected science support needed to ensure a successful implementation.

- US-DC1-110 - Climate adaptive planning / Hazard
  - visualize heat wave, landslide and pluvial flood hazard maps in relation to climate change projections for the area of the Metropolitan City of Naples to identify the most exposed areas in terms of buildings and population density, considering the expected hazard exposure variation due to climate change.
- US-DC1-120 - Climate adaptive planning / Impact
  - quantify the impact of heat waves, landslides and pluvial floods (based on climate projections) in relation to the following elements at risk: population, residential buildings, strategic buildings, critical transport infrastructures, local economy for the area of the Metropolitan City of Naples to understand the effect of extreme climate events in the area in relation the expected impact variation due to climate change.
- US-DC1-130 - Climate adaptive planning / Comparison
  - apply the results of CLARITY simulations and climate services to both existing conditions and design scenarios, with different levels of details – in relation to the area object of the analysis (e.g. Metropolitan City vs. city neighbourhood), to the available datasets and to the scope of the analysis (e.g. preliminary planning vs. final planning) – to use the CLARITY system in different operational contexts, depending on the role of the Municipality of Napoli (e.g. direct design/planning activity, consultation, evaluation of projects presented by private entities or other public authorities)
- US-DC1-140- Climate adaptive planning / Adaptation
  - acquire detailed information on climate adaptation potential of alternative planning scenarios in specific areas (e.g. brownfield and redevelopment areas in East Napoli and Bagnoli-Coroglio), by applying the model to different proposed options – which may include variations in the volumetric distribution of new buildings, the hydraulic and sewerage system, the urban surfaces and vegetation – to prioritize the design scenarios and identify the benefits of climate adaptive solutions, and measure the cost-effectiveness of investments in relation to both short- and long-term benefits (current conditions and variation due to climate change).
- US-DC1-150 - Climate adaptive planning / Display results 1
  - visualize the results of CLARITY simulations and climate services as Georeferenced maps, to use them as official planning documents for the redevelopment projects to be directly implemented by the Municipality of Naples.
- US-DC1-160 - Climate adaptive planning / Display results 2

- visualize the results of CLARITY simulations and climate services as synthetic document (e.g. pdf with text and images), to use the maps as consultation documents for the redevelopment projects to be implemented jointly with Regional or State level authorities.

- US-DC1-210 - Climate adaptive design guidelines and building regulations / Multi-risk integration
  - acquire a set of design guidelines to integrate climate adaptive solutions within current building regulations (now in an update process to be adapted to the national standardized model), addressing at the same time the relevant set of existing constraints – such as 1) landscape protection, a third of the total area of Naples/city; 2) volcanic risk from Vesuvius and Campi Flegrei, east and west of Naples; 3) landslide floods and hydrogeological issues; 4) earthquakes – to address ongoing structural retrofitting interventions, both in public policies (e.g. reinforcing of school buildings, 136M€ available to the metropolitan area of Naples from the 2015-2017 national financial programs) and private investments (75%-85% "Sismabonus" tax contribution available for private citizens for seismic improvements), to include climate adaptation within a multi-hazard resilience perspective and evaluate the opportunity of climate financial incentives (e.g. reflective or green facade materials following a seismic/landslide structural improvement).
- US-DC1-220 - Climate adaptive design guidelines and building regulations / Benchmarking
  - acquire a set of benchmarks and assessment tools for alternative DRR and CCA techniques to evaluate projects presented by private entities for new buildings and retrofitting actions (for permit release, incentives quantification, etc.).

In terms of “Level of Details” of simulations and climate services output requested for the implementation, the expectation of end-users emphasize the need of acquiring “Detailed Level (fully tailored)” information, thus implying specific needs in terms of science support.

The first Test Case developed for DC1 “Enabling comparison of alternative adaptation scenarios” is useful to outline the expected input from science support.

This test case enable to set up the simulation of alternative adaptation scenarios through the expert workflow, including the "no adaptation" option(s) (in turn referred to different climate projections and RCP scenarios). The "adaptation" scenarios to be simulated are discussed by users and experts in a preparatory stage, and made available through the Scenario Management Building Block (BB) (see D4.1 “Technology Support”). Additional adaptation scenarios simulation can be requested if not available, thus entailing a new (offline) modelling workflow based on user request. Dynamic visualization of simulation results is an essential feature, enabled by the Map Component BB. MCDA analyses should be available to run online, based on different weighting criteria and performing the needed calculations by using the simulation results. A final report includes all the relevant output of the test case (including map/table simulation scenarios and MCDA results).

The following table (**Table 7**) summarizes the modelling workflow and the science support needed for DC1.

Table 7: Science support in relation to DC1 modelling needs.

Model	Provided by	Run	Level 2 US	EU-GL Scope:
Heat wave hazard	ZAMG	offline	US-DC1-110	RA / IA Decision Support
Surface flood hazard	SMHI? Third party?	offline		
Landslide hazard	ZAMG (precipitation data) PLINIVS (geological data)	offline		
Seismic hazard	PLINIVS	offline		
Volcanic hazard	PLINIVS	offline		
Heat wave vulnerability	PLINIVS	offline	US-DC1-120 US-DC1-150 US-DC1-160	RA / IA IAO AAO Integration Decision Support Action Plan
Surface flood vulnerability	PLINIVS	offline		
Landslide vulnerability	PLINIVS	offline		
Seismic vulnerability	PLINIVS	offline		
Volcanic vulnerability	PLINIVS	offline		
Integrated vulnerability	PLINIVS	offline		
Heat wave impact	PLINIVS (phyiscal impact) EUREKA (economic impact)	offline		
Surface flood impact	PLINIVS (phyiscal impact)	offline		
Landslide impact	EUREKA (economic impact)	offline		
Seismic impact	PLINIVS (phyiscal impact)	offline		
Volcanic impact	EUREKA (economic impact)	offline		
Integrated impact	PLINIVS (phyiscal impact)	offline		
Adaptation options benchmarking	PLINIVS	n/a	US-DC1-130 US-DC1-140 US-DC1-210 US-DC1-220	RA / IA IAO AAO Integration Decision Support Action Plan
MCDA	PLINIVS CISMET EUREKA	online		

Table 10 in Annex II (Expert Climate Services – Demonstration Case 1) provides a more enhanced version of the expected workflow for DC1.

5.2.2 Demonstration Case 2

The Swedish user stories compiled in DC2 (see D1.1 [122] and D2.1 [120] for more details) reflect the communication between SMHI and WSP as data providers and the two local end-users: the municipalities of Stockholm (STOCKCITY) and Jönköping (CABJON). The demonstration is thus focused on these two counties and targets the assessment of the risks associated to heat and flooding and its relation to urban development and climate change. The most relevant source of data for these user stories are the two C3S projects SWICCA (on water management) and Urban SIS (on urban climate, hydrology and air quality).

DC2 is structured into 2 parent user stories that are disaggregated into 6 more specific user stories. The test cases described in **Table 11** assume that some of these stories share the same workflow. The parent story US-DC2-100 on water hazards is related to the assessment of the risk to urban areas associated to high precipitation, high flow in rivers and sea/lake level changes, and to adaptation measures (such as wetlands). US-DC2-210 is looking at urban vegetation as a climate adaptation tool. Finally, stories US-DC2-220 and US-DC2-230, which are related to delivering climate indicators (in particular in connection to health and the environment) and build upon SWICCA and Urban SIS, have been already included in **Table 7** as a pre-feasibility service.

Table 11 summarizes the expected workflow for DC2 in Annex II (Expert Climate Services – Demonstration Case 2).

5.2.3 Demonstration Case 3

The Linz Demonstration Case addresses heat hazards at the urban scale (including the urban heat island effect) and aims to examine climate-change adaptation strategies to support climate-resilient urban planning and decision-making with respect to temperature increase.

The main objectives of DC3 are manifested through the following (parent) user stories:

- US-DC3-100 Heat island adaptation measures-Linz-02
- US-DC3-200 Ventilation pattern adaptation measures-Linz-03

US-DC3-100 reflects the general needs of spatial planners to get information on measures that could reduce heat exposure in order to support decision-making during future heat waves and to make people suffering less from heat exposure. The user story comprises the following sub-stories:

- US-DC3-110 Microclimate/Indicators: show the general microclimatic patterns in the city based on indicators/maps in order to facilitate climate sensitive city planning
- US-DC3-120 Microclimate/existing settlement area: assess effects of changes in the building heights and density on the microclimate in existing settlement areas in order to consider the microclimatic effects of the changes in urban regeneration or densification measures
- US-DC3-130 Microclimate/greening measures in existing settlement areas: user wants to get information about the effects of unsealing and greening measures on the microclimate in existing settlement areas so that optimal greening measures can be planned/set
- US-DC3-140 Microclimate/recommendations for urban development areas: user wants to get recommendations on how to plan climate resilient new settlement areas so that guidelines can be provided and instructions can be given to developers to build high-qualitative settlement areas

In US-DC3-200, the user wants to get information on the general ventilation pattern in Linz based on the current urban fabric and the expected changes over time so that the masterplan can be adapted and air quality can be increased. The user story comprises the following sub-story:

- US-DC3-210 Ventilation/changes in settlement density and building heights: user wants to know about the effects of changes in the building heights and density on ventilation patterns in the city of Linz

To successfully resolve these user stories, a set of test cases has been defined. The following describes the work flow after a user has selected the “order expert study” option. This description applies to the following test cases:

- TC DC3 01 Preparing climate maps for heat hazard analysis on city scale.
- TC DC3 02 Evaluating the impact of greening measures on the heat load of urban areas.
- TC DC3 03 Evaluating the impact of building characteristics on ventilation within urban areas.

In the following, as an example, the workflow is described for the application of the urban climate model MUKLIMO_3.

The study region, the horizontal resolution, and the future time period of interest is defined by the user. The input data necessary to run the model (in this case MUKLIMO_3) is prepared on a domain at the required resolution by the expert. For these cases the input data required are:

1. EU-DEM
2. Urban Atlas Landcover 2012
3. ECA&D
4. EURO-CORDEX ensemble climate simulations

Data element 1 provides the necessary elevation data for the domain. Data element 2 provides rudimentary land cover details which will be supplemented by land use data uploaded by the user. This is essential to provide a valid representation of the urban area fabric. Data element 3 provides information on the current climate, which is necessary to establish a baseline for the model. The meteorological parameters required are temperature, relative humidity, and wind speed and direction. Data element 4 provides the climate scenarios for the analysis. All input data are converted to ASCII-text form which can be read by MUKLIMO_3.

When the user requests test case involving changes to green areas (case b) or building characteristics (case c), additional input needs to be supplied by the user so that the expert knows what changes need to be made. For example, changes to the green areas may involve the introduction of new green areas, or the modification of existing green areas, such as in the height or leaf/stem properties. Changes to the building characteristics may involve changes in building density, height, wall or roof albedo, etc.

MUKLIMO_3 is run by experts, which, depending on the size of the domain and spatial resolution required, may take up to several days. The output from MUKLIMO_3 is then combined with the EURO-CORDEX dataset using an additional processing package (cuboid) to provide the final climate scenario for the urban area. In addition to the model run required by the user, a reference run will be performed whereby the original urban landscape without any modifications is simulated. This will permit a comparison of the hazard impact to be made in order to evaluate the success of planned adaptation measures.

The output data from the model is in the format of ASCII- and NETCDF-data. The production of the desired output for the user may require a further couple of days. This output will then be uploaded to the server and the user will be subsequently contacted.

Table 12 summarizes the expected workflow for DC3 in Annex II (Expert Climate Services – Demonstration Case 3).

5.2.4 Demonstration Case 4

For the Spanish demonstration case two user stories have been defined as level one. These user stories seek to transform climate services into road management in response to design, planning, construction and maintenance. In turn, these user stories are divided into seven user stories of level two to describe the different services offered. The test cases have been developed to measure and achieve the success of the different user stories of level two defined. In total, nine test cases have been defined (**Figure 31**). It is necessary to clarify that the same test cases can be used to measure the success of two user stories (**Figure 32**).

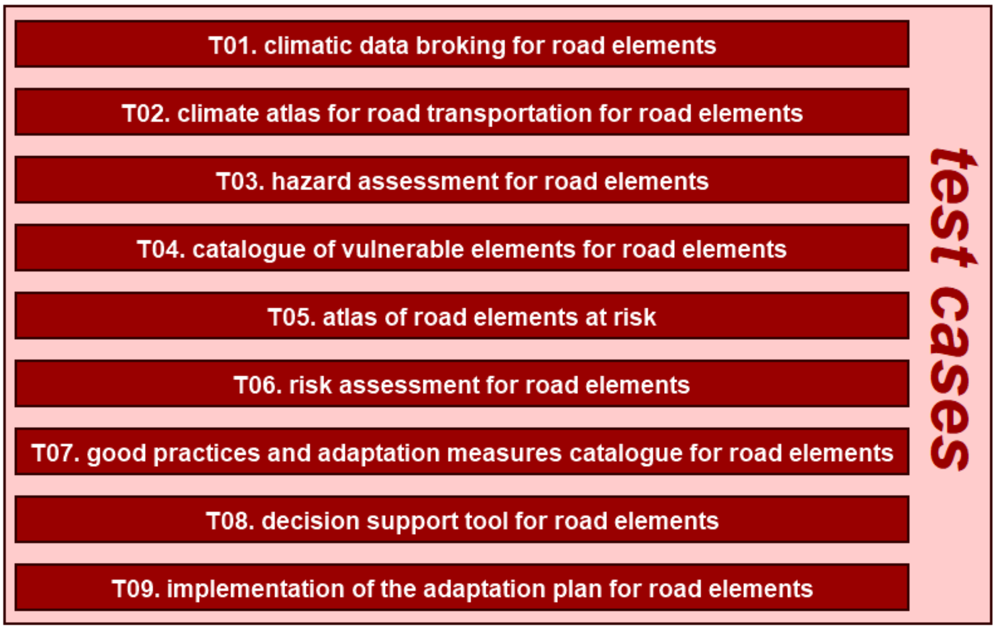


Figure 31: Test cases defined

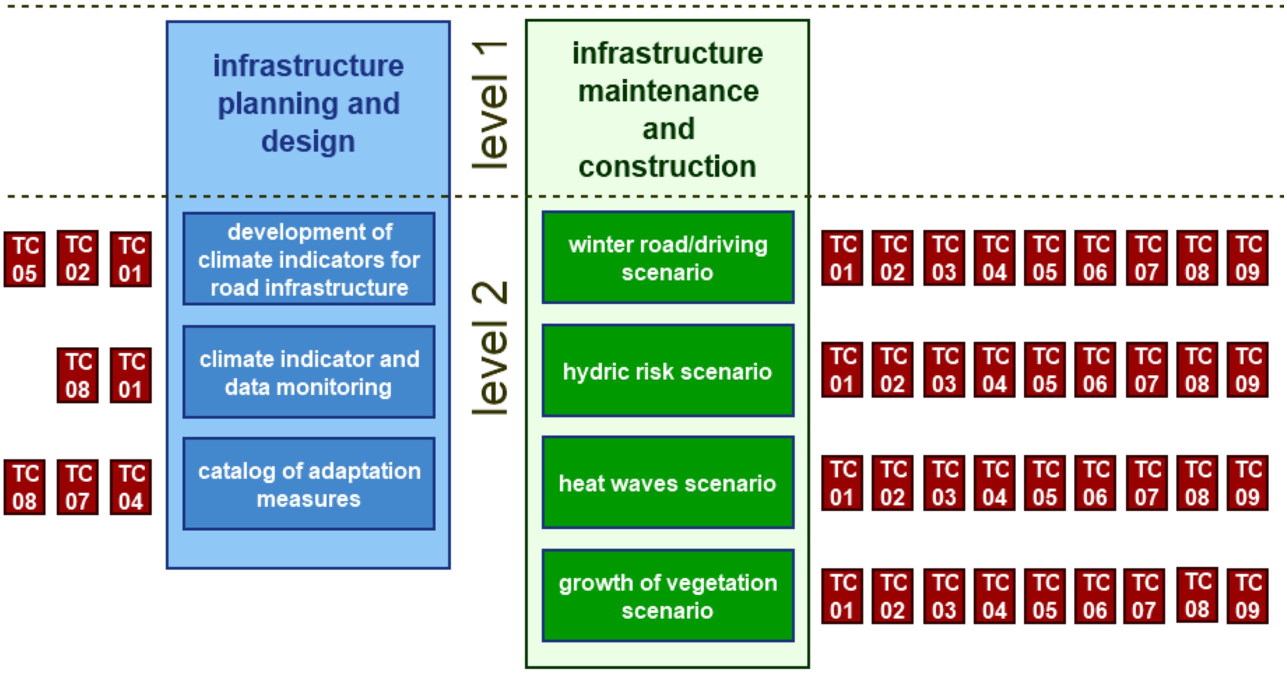


Figure 32: Relation of user stories with the test cases

The following test cases have been defined:

TC DC4 010 Climate Broker for road element

- TC Objective: Obtain all the necessary data to perform a Hazard assessment
- Context: For application in the design, construction, maintenance and operation phases, on roads and/or railways. The process of selecting scenarios from a model is tedious and complex due to several facts: (1) Each model has different spatial and temporal resolutions, (2) the formats in

which the original data is stored are not standard and (3) collection methods for the data need to be adapted in each case.

- Workflow summary: (1) Identify the climate model needed for the hazard assessment, (2) define spatial and temporal horizons, (3) identify the needed variables from the model, (4) obtain the data from the source, (5) process the data as required, (6) produce the output data in the appropriate format.

TC DC4 020 Climate variables and indexes Atlas for road elements

- TC Objective: The objective of this TC is to provide the foreseen evolution of climate variables and climate indexes related to road design and management. The user should be able to define new indexes based on the already available information. It includes information for both, the feasibility study and detailed studies.
- Workflow Summary: The CSIS should be able to provide / upload / store / compute / maps at a regional o local scale to allow to evaluate the foreseen changes in the variables and indexes related to road design and management.

TC DC4 030 Hazard assessment for road elements

- TC Objective: Identify hazard conditions based on climatic variables and their occurrence
- Context: For application in the design, construction, maintenance and operation phases, on roads and/or railways
- Workflow Summary: (1) Identify/define which phenomena have produced damage to the physical and/or human environment, (2) analyse which variables determine this phenomenon, (3) define the temporal and spatial horizon, (4) quantify the occurrence of such climatic events and their intensity, (5) relate hazard parameters and climatic variability, (6) model the danger according to climatic variables for the different horizons. (7) Obtain maps that characterize the intensity and occurrence of the hazard studied (8) Incorporation of future climate scenarios into threat estimation and (9) consideration of uncertainty statistics.

TC DC4 040 Catalogue of road elements at risk

- TC Objective: The aim is to create a catalogue of road elements. Elements must be defined with sufficient attributes to define their climate risk.
- Context: CSIS must be able to create, incorporate or modify catalogues of roadway elements that may be damaged by climate
- Workflow Summary: (1) selection of the type of elements, (2) definition of the technical characteristics of each element, (3) vulnerability functions of each element and (4) quantification of the acquisition cost for each element.

TC DC4 050 Atlas of road elements at risk

- TC Objective: The objective is to obtain the geographic location of the possible elements affected by climatic risks
- Context: The CSIS should be able to provide / upload / store the vulnerable element to generate geographical information at a national or local scale
- Workflow Summary: (1) selection of catalogue of vulnerable elements to be used, (2) selection of geographical context, (3) selection of the register of elements to work with, and (4) updating of element typology.

TC DC4 060 Risk assessment for road elements

- TC Objective: To analyse the probability of damage associated with climatic hazards in economic terms and loss of human life through the results obtained in the study of hazard, exposure and vulnerability.
- Context: The CSIS should be able to provide / upload / store / compute / maps at a regional o local scale to allow to evaluate the climate risks related to road design and management.

- Workflow Summary: (1) establish numerical modelling procedures for input variables, (2) probabilistic integration of hazard, exposure and vulnerability, (3) analysis of impact scenarios. (4) valuation of the associated losses in economic and human terms

TC DC4 070 Good practices and adaptation measures catalogue for road

- TC Objective: The objective is to collect and propose practices and measures that minimize the impact of climate change on road elements
- Context: The CSIS should be able to provide / upload / store a catalogue with measures and good practices that minimize the impact of climate change on road elements
- Workflow Summary: (1) revision of adaptation measures and good management practices, (2) selection of means and practices to be incorporated in the catalogue, (3) defining the characteristics and properties of the selected measures and practices.

TC DC4 080 Decision support tool for road element

- TC Objective: The aim is to create a tool that helps decision making. This tool should suggest the best measures or practices (economic, social and environmental) to reduce the impact of climate change.
- Context: The CSIS should incorporate a decision tool for the management of road elements at risk
- Workflow Summary: (1) recollection of adaptation measures and good practices included in the catalogue carried out (2) Analysis of the benefit and cost (environmental, social and economic) of each measure, (3) monitoring and follow up of this of elements at risk, and (4) multicriteria analysis for the selection of measures and practices in decision support.

TC DC4 090 Implementation of the adaptation plan for road elements

- TC Objective: The objective is to monitor and control the measures and actions proposed in the adaptation plan.
- Context: The CSIS shows a preliminary report with the results obtained in the project and allows the inclusion of new information for the generation of the final report.
- Workflow Summary: (1) development of an action plan for adaptation, (2) identification of the roles and responsibilities of the stakeholders involved, (3) evaluation of methods of financing, (4) monitoring and follow-up of the measures.

Table 13 summarizes the expected workflow for DC4 in Annex II (Expert Climate Services – Demonstration Case 4).

6 Conclusions

The main objective of the task T3.1 “Scientific Background” and the corresponding deliverable D3.1 “Science Support Plan and Concept” was to provide the scientific background and methodological concept to support the development of the CLARITY CSIS and to design the workflow including models and algorithms for implementation of the CLARITY Demonstration Cases. The CLARITY methodological concept follows the recommended EU-GL methodology, while its application for the Demonstration Cases is driven by end-user requirements.

The literature research on Climate Change impacts in Europe, global and EU Guidelines and Actions for Climate Services, including review of existing studies about Climate Change and climate resilient planning for urban and transportation infrastructure has been performed and summarized in this report as **Scientific Background**.

The step-wise **EU-GL methodological approach** was analysed and revised to comply with the latest IPCC-AR5 approach. The adaptation of the methodological approach was particularly important in order to define a common and transparent method regarding Hazard Characterisation, Risk Assessment and Impact Analysis. The background knowledge behind each methodological module was collected and analysed to provide adequate workflow for implementation. This included methodology ranging from generation and analysis of climate and environmental data, employment of high-resolution climate models to analyse climate change on local scale, hazard characterisation, risk assessment and impact analysis, identification and appraisal of adaptation measures and finally decision support and analysis of socio-economic impact.

The required **Knowledge Database** for Science Support was analysed and the necessary information about input datasets, modelling tools and background results from previous projects were collected. The information about data requirements and the data collection process for future implementation of Demonstration Cases was done as part of the activities in WP2 “Demonstration and Validation” and the results can be found in D2.1 “Demonstration and validation methodology” and in the “Data Management Plan” (D7.8, [119]). Other information was collected both within the D3.1 “Science Support Plan and Concept” and the online CLARITY catalogue.

The **Science Support for CLARITY CSIS** was envisaged as the application of the methodological concept and description of workflow behind CLARITY ICT and Expert Climate Services. The CLARITY CSIS requirements and co-creation process is part of the activities in WP1 “CO-Creation”. Therefore, this report gives overview of specific Demonstration Cases user stories and test cases, which were collected and analysed in the co-creation process, and proposes the methodology how they will be addressed in the CLARITY CSIS.

The implementation of modelling workflow in CLARITY CSIS for ICT and Expert Services is work in progress. It follows the development of Demonstration Cases user stories and test cases in WP1 “CO-Creation”, as well as the design of the CLARITY architecture in WP4 “Technology Support” and will be updated in the follow-up period.

The methodology, as envisaged in CLARITY, has been thoroughly described and a first attempt has been made to adjust the scientific concept to end-user requirements, in terms of their user stories. The main outcome of this deliverable will be used to integrate all the collected information into the CLARITY CSIS, based on a sound knowledge database and scientific background to support further progress of the implementation of the modelling workflow for ICT and Expert Climate Services.

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Annex I – EU-GL Methodology

The EU-GL [1] were published with the aim to help project managers to account for current climate variability and future climate change within their projects in order to make investments climate resilient. The guidelines also list other relevant EU policies or guidelines that are relevant to assets and infrastructure, like e.g. the "Guidance on integrating climate change and biodiversity into environmental impact assessment", published in March 2013 [68]. The EU-GL [1] provide a toolkit to incorporate climate resilience into a normal project cycle. The Climate Resilience Toolkit comprises 7 modules (taken from [1], Table 1):

1. Sensitivity analysis,
2. Evaluation of exposure,
3. Vulnerability analysis,
4. Risk assessment,
5. Identification of adaptation options,
6. Appraisal of adaptation options,
7. Integration of adaptation action plan into the project.

Compared to the SWD 134 Guidelines on developing adaptation strategies [58], the EU-GL [1]provide more detail on Step 2 'Assessing Risks and Vulnerabilities to Climate Change' from SWD 134 [58] (**Table 8**).

Table 8: Comparison of the 6 steps to build an adaptation strategy as proposed by the SWD 134 Guidelines on developing adaptation strategies [58], the 7 modules from the Climate Resilience Toolkit, as presented in the EU-GL non-paper guidelines for project managers [1] and the 7 modules adapted for the CLARITY project.

SWD (2013) 134 final: Guidelines on developing adaptation strategies	Guidelines for Project Managers, 2013: Climate Resilience Toolkit
1. Prepare ground	
2. Risk and vulnerability	1. Identify Climate Sensitivity 2. Evaluate Exposure 3. Assess Vulnerability 4. Assess Risks
3. Identify adaptation options	5. Identify adaptation options
4. Assess and select options	6. Appraise options
5. Implement 6. Monitor and evaluate	7. Implement

1. Sensitivity analysis

The EU-GL [1] suggests a number of climate variables and related secondary effects / hazards that should be considered during each project. However, for the CLARITY project, the list was reviewed and adapted. According to the EU-GL [1], for every project type (e.g. road bridge, water treatment plant, etc.) it should be assessed how relevant the identified climate related hazards are for the following key themes:

- On-site assets and processes,
- Inputs (water, energy, others)
- Outputs (products, markets, customer demand)

– Transport links,

using a basic three-step evaluation scheme:

– High sensitivity

– Medium sensitivity

– No sensitivity

Climate-related hazards that have a significant (high sensitivity) or slight (medium sensitivity) impact on one or more of the four key themes, are considered essential factors, “against which potential locations for the project should be subsequently systematically mapped using GIS to determine level of exposure and finally vulnerability” [1].

2. Evaluate exposure to climate hazards

2.a. Assess exposure to baseline / observed climate for those climate variables and related hazards identified to have high or medium sensitivity. Information regarding exposure to climate-related risks might be found at state / regional institutes or organisations, at the Climate-ADAPT homepage or on other portals, which are listed in the [1] Annex III (Annex III: Geographic exposure mapping portals with European coverage).

2.b. Assess exposure to future climate

When assessing exposure to future climate, uncertainty in climate model projections as well as uncertainty due to emission scenarios should be acknowledged and reported by providing a summary of model outputs.

3. Assess vulnerability

The vulnerability to baseline/ observed climate and to future climate should be considered. The latter differs from the former by using the future exposure data instead of the current exposure data.

Vulnerability (V) is calculated as follows:

V = S x E,

With S being the degree of sensitivity the asset has and E being the exposure to baseline/ current or future climate conditions. The result can be displayed in a vulnerability matrix (**Figure 33**)

	Exposure			
		No	**Medium**	**High**
Sensitivity	**No**			
	Medium	Humidity		
	High			Flood

Vulnerability level	
	No
	Medium
	High

Figure 33: Vulnerability classification matrix as presented in the EU-GL [1], Table 9

The vulnerability analysis might reveal that more attention is needed regarding specific risks. A detailed vulnerability analysis should then be carried out (repeat step 1-3), which e.g. involves a more detailed breakdown of the project into smaller elements and potentially on-site inspections of specific locations to assess the exposure to climate hazards.

4. Assess Risks

According to the EU-GL [1] a risk assessment is a structured method, which includes "assessing the likelihoods and severities of the impacts associated with the hazards identified in Module 2, and assessing the significance of the risk to the success of the project". A high-level risk assessment, which often involves a Risk Identification Workshop, can be carried out at an early stage, while more detailed risk assessments, typically involving numerical modelling, are usually performed at a later stage.

As mentioned in the EU-GL [1] "Risk is defined as the combination of the probability of an event occurring and the consequence associated with that event." To support project managers identifying risks, probability and consequence scores are suggested ([1] Tables 10 and 11).

The detailed risk assessment is divided into 4 steps. (1) It involves an analysis of specialists to quantitatively evaluate risks while taking into account climate change. (2) Aspects and characteristics of the most relevant climate hazards need to be defined. According to the EU-GL [1] the following aspects should be included: "magnitude and direction of change, statistical basis, averaging period and joint probability events". (3) The ability of the project to cope with existing climate variability and with future climate hazards should be assessed. This typically involves the use of numerical models (e.g. climate impact models). The assessment should involve a number of climate models and a range of greenhouse gas emissions. (4) The results should then be used to update the risk register and risk matrix.

5. Identify adaptation options

Identifying adaptation options typically involves a workshop to identify appropriate options for the identified risks and smaller meetings with technical experts to gain a more detailed understanding of the pros and cons for each option. Technical expects and external stakeholders should attend the workshop. To be well prepared for the workshop, project managers should make themselves familiar with respective guideline documents, best practice adaptation examples, engineering standards etc.

The EU-GL [1] provide several documents that should help to identify, record and evaluate possible adaptation options ([1], e.g. Annex VIII, Annex IX, Annex X). They furthermore mention a variety of aspects that should be considered during that process, e.g. how to deal with uncertainty ([1, p. 44]).

After identifying all possible adaptation options, a shortlist of adaptation options for the specific project should be selected. Preferred options should be "environmentally, socially, technically and legally feasible, robust and should not have negative impacts on other areas or groups."

6. Appraise adaptation options

This module comprises a cost-benefit-analysis (CBA) in the context of climate change. The steps outlined in the EU-GL [1] are listed below to provide an overview:

- Determine the project boundary: This step involves the definition of climate-related impacts and stakeholders that should be included. "The impacts are defined in qualitative terms over the project forecast period" [1] and should be evaluated under at least one future climate change scenario.
- Define the forecast period and discount rate: "The project forecast period […] should reflect the economic life of the investment project as a whole." [1]
- Establish project baseline(s): The project baseline represents the situation without implementing climate change adaptation options.
- Identify costs and benefits of the various options.
- Value costs and benefits of adaptation options: Determine investment and operating costs of the options. "Establish unit values for benefits" and value non-market impacts.

- Assess hedging effectiveness and certainty of impact of options
- Assess distributional impacts
- Determine the decision rule for option selection

7. Integrate adaptation action plan into the project development cycle

Based on the previous steps, make decisions about modifications to technical project design and management options and develop an implementation plan for the selected adaptation measures. The implementation should clarify responsibilities and identify actions that need cooperation and thus specific communication channels. Step 7 furthermore comprises a more detailed plan on how to finance the measures as well as a plan for monitoring and response efforts. The latter is important to assess the implemented measures and to identify whether adjustments are needed.

Annex II – Workflows for ICT and Expert Climate Services

ICT Climate Services

Table 9: Workflow for ICT Climate Services

Service Name	*ICT CS for "Characterize Hazard" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Characterize Hazard" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	This is a Meta-TC for all generic TCs related to the first step "Characterize Hazard" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards, and determining which one might affect the response of project options to climate variables in relation to each of four key themes (elements at risk).	1. Select location 2. Select elements at risk 3. Select hazards and indices 4. Prepare hazard maps (offline) 5. Prepare maps with elements at risk (offline) 6. Upload hazard maps or provide link 7. Upload data for elements at risk 8. Visualize hazards and elements at risk 9. Analyse Hazards Prepare Report	**EU-GL**: RA – HC **User Stories:** US-CSIS-100 US-DC1-110 US-DC2-220 US-DC2-230 **Test Cases:** TC-CSIS-1000
Description of the scientific support planned for this			
ZAMG, SMHI, PLINIVS (Experts) CSIS BBs			
Service Name	*ICT CS for "Evaluate Exposure" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Evaluate Exposure" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	This is a Meta-TC for all generic TCs related to the second step "Evaluate Exposure" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards, and determining which one might affect the response of project options to climate variables in relation to each of four key themes (elements at risk).		**EU-GL**: RA – E **User Stories:** US-CSIS-100 **Test Cases:** TC-CSIS-2000
Description of the scientific support planned for this			
PLINIVS (Experts) CSIS BBs			
Service Name	*ICT CS for "Vulnerability Analysis" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use	This is a Meta-TC for all generic TCs related to the third step		**EU-GL**: RA – V

several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Vulnerability Analysis" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	"Vulnerability Analysis" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards, and determining which one might affect the response of project options to climate variables in relation to each of four key themes (elements at risk).		**User Stories:** US-CSIS-100 **Test Cases:** TC-CSIS-3000
Description of the scientific support planned for this			
PLINIVS (Experts) CSIS BBs			
Service Name	*ICT CS for "Assess Risks and Impact" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Risk and Impact Assessment" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	This is a Meta-TC for all generic TCs related to the fourth step "Risk and Impact Assessment" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards and determining which one might affect the response of project options to climate variables in relation to each of four key themes (elements at risk).		**EU-GL**: RA / IA **User Stories:** US-CSIS-100 US-CSIS-122 **Test Cases:** TC-CSIS-4000
Description of the scientific support planned for this			
AIT, PLINIVS (Experts) CSIS BBs			
Service Name	*ICT CS for "Identify Adaptation Options" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Identify Adaptation Options" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	This is a Meta-TC for all generic TCs related to the fifth step "Identify Adaptation Options" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards, and determining which one might affect the response of project options to		**EU-GL**: IAO **User Stories:** US-CSIS-100 US-CSIS-123 **Test Cases:** TC-CSIS-5000

	climate variables in relation to each of four key themes (elements at risk).		
Description of the scientific support planned for this			
PLINIVS (Experts) CSIS BBs			
Service Name	*ICT CS for "Appraise Adaptation Options" Step*		
Objective	**Context**	**Workflow summary**	**References**
End Users and Climate Service Providers can use several generic ICT CS ("tools") integrated into an overall CLARITY CSIS for collaboratively performing the "Appraise Adaptation Options" Step of a Climate Change Adaption Study that follows the structured and methodological approach of the CLARITY EU-GL Methodology.	This is a Meta-TC for all generic TCs related to the fifth step "Appraise Adaptation Options" step of the CLARITY EU-GL Methodology to build an adaptation strategy. It covers mainly generic TCs to identify hazard conditions in the project area, in relation to a range of climate variables and climate-related hazards, and determining which one might affect the response of project options to climate variables in relation to each of four key themes (elements at risk).		**EU-GL**: AAO **User Stories:** US-CSIS-100 US-CSIS-123 **Test Cases:** TC-CSIS-6000
Description of the scientific support planned for this			
PLINIVS, EUREKA (Experts) CSIS BBs			

Expert Climate Services

Demonstration Case 1 – Italy

Table 10: Expected workflow for DC1

<table>
<tr><th>Service Name</th><th colspan="3">Climate adaptive planning / Hazard (Multi-Hazard Analysis)</th></tr>
<tr><td>Objective</td><td>Context</td><td>Workflow summary</td><td>References</td></tr>
<tr><td>Visualize heat wave, landslide and pluvial flood hazard maps in relation to climate change projections for the area of the Metropolitan City of Naples</td><td>Identify the most exposed areas in terms of buildings and population density, considering the expected hazard exposure variation due to climate change.</td><td>1. Select location, hazards and elements at risk
2. Prepare hazard maps (offline)
2a Heat wave hazard
2b Surface flood hazard
2c Landslide hazard
2d Seismic hazard
2e Volcanic hazard
3. Upload hazard maps and elements at risk
4. Visualize hazards and elements at risk
5. Analyse Hazards
6. Prepare Report</td><td>EU-GL:
RA / IA
Decision Support

User Stories:
US-DC1-110</td></tr>
<tr><td colspan="4">Description of the scientific support planned for this</td></tr>
<tr><td colspan="4">ZAMG, PLINIVS (Experts)
CSIS BB</td></tr>
<tr><td>Service Name</td><td colspan="3">Climate adaptive planning / Impact and Visualization of results</td></tr>
<tr><td>Objective</td><td>Context</td><td>Workflow summary</td><td>References</td></tr>
<tr><td>(1) Quantify the impact of heat waves, landslides and pluvial floods (based on climate projections) in relation to the following elements at risk: population, residential buildings, strategic buildings, critical transport infrastructures, local economy for the area of the Metropolitan City of Naples.
(2) Visualize the results as georeferenced maps and as synthetic document.</td><td>Understand the effect of extreme climate events in the area in relation the expected impact variation due to climate change. Prepare results as official planning documents for the redevelopment projects to be directly implemented by the Municipality of Naples, and as consultation documents for the redevelopment projects to be implemented jointly with Regional or State level authorities.</td><td>1.Select location/project
2.Vulnerability analysis (offline)
2a Heat wave vulnerability
2b Surface flood vulnerability
2c Landslide vulnerability
2d Seismic vulnerability
2e Volcanic vulnerability
2f Integrated vulnerability
3.Impact analysis (offline)
3a Heat wave impact
3b Surface flood impact
3c Landslide impact
3d Seismic impact
3e Volcanic impact
3f Integrated impact
4. Visualize results
5. Prepare Report</td><td>EU-GL:
RA / IA
Decision Support

User Stories:
US-DC1-120
US-DC1-150
US-DC1-160</td></tr>
<tr><td colspan="4">Description of the scientific support planned for this</td></tr>
<tr><td colspan="4">PLINIVS (physical impact), EUREKA (economic impact)
CSIS BB</td></tr>
<tr><td>Service Name</td><td colspan="3">Climate adaptive planning / Comparison and Adaptation
Climate adaptive design guidelines and building regulations / Multi-risk</td></tr>
</table>

	integration and Benchmarking		
Objective	**Context**	**Workflow summary**	**References**
(1) Apply the results of CLARITY simulations and climate services to both existing conditions and design scenarios (2) acquire detailed information on climate adaptation potential of alternative planning scenarios in specific areas (3) identify the benefits of climate adaptive solutions, and measure the cost-effectiveness of investments in relation to both short- and long-term benefits (4) acquire a set of design guidelines to integrate climate adaptive solutions within current building regulations (5) acquire a set of benchmarks and assessment tools for alternative DRR and CCA techniques to evaluate projects presented by private entities for new buildings and retrofitting actions	Apply the results of CLARITY simulations and climate services to both existing conditions and design scenarios, with different levels of details in relation to the area or object of the analysis in different operational contexts and stakeholders involved.	1. Adaptation options benchmarking (n/a) 2. MCDA	**EU-GL**: RA / IA IAO AAO Decision Support Action Plan **User Stories:** US-DC1-130 US-DC1-140 US-DC1-210 US-DC1-220
Description of the scientific support planned for this			
PLINIVS, CISMET, EUREKA (Experts) CSIS BB			

Demonstration Case 2 – Sweden

Table 11: Expected workflow for DC2

Service Name	*Water hazards and supply*		
Objective	**Context**	**Workflow summary**	**References**
Investigate precipitation, high flow in rivers, sea/lake level changes and combined events and how they affect the city. Consider flood/drought risk reduction by green areas and wetlands.	Swedish use cases have problems understanding how combined effects of flooding, precipitation and sea/lake level rise could affect the city in the future.	User selects location, hazards and elements at risk 2. Expert gets in contact with the user requiring more information 3. User uploads local input data for the model 4. Expert applies models for the risk assessment (offline) 4a Surface flood 4b Intense precipitation 4c Lake and sea levels 4d Hydraulic conditions 5. Expert uploads hazard maps and elements at risk 6. Visualize hazards and elements at risk 7. Analyse Hazards 8. Prepare Report	**EU-GL**: RA / IA **User Stories:** US-DC2-100
Description of the scientific support planned for this			
SMHI, WSP (Experts) CSIS BB			
Service Name	*Urban vegetation in Stockholm as a climate adaptation tool*		
Objective	**Context**	**Workflow summary**	**References**
Maximize the role of Urban Green Infrastructure (UGI) as a climate change adaptation measure.	The Green Area Factor (GAF) is used in Stockholm as a planning tool. However GAF has limitations (e.g., does not include air quality effects). Also, the applicability of GAF can be extended if high resolution climate data in the future is known.	1. User selects location, hazards and elements at risk 2. Expert gets in contact with the user requiring more information 3. User uploads local input data for the model 4. Expert applies models for the risk assessment (offline) 4a Surface flood 4b Intense precipitation 4c Lake and sea levels 4d Hydraulic conditions 5. Expert uploads hazard maps and elements at risk 6. Visualize hazards and elements at risk 7. Analyse Hazards 8. Prepare Report	**EU-GL**: **User Stories:** US-DC2-210
Description of the scientific support planned for this			
SMHI, STOCKITY (Experts) CSIS BB			

Demonstration Case 3 – Austria (first draft workflow)

Table 12: Expected workflow for DC3

<table>
<tr><td>Service Name</td><td colspan="3">Preparing climate maps for heat hazard analysis on city scale</td></tr>
<tr><td>Objective</td><td>Context</td><td>Workflow summary</td><td>References</td></tr>
<tr><td>Provide high resolution climate maps for heat load at city scale;</td><td>Preparation of input data for risk assessment required by several DC. It enables user to order a heat load map from expert for detailed study.</td><td>1. User inserts location, requirements
2. User orders expert study
3. User is asked to provide (upload) input data (land use….) for climate modelling
4. Expert gets input data and compiles / harmonizes the data sets
5. Expert conducts regional and urban climate model simulations for heat load for current and future climate conditions (offline)
6. Expert uploads data to the server
7. The data are visualized
8. User is informed</td><td>EU-GL:
HC
RA/IA

User Stories:
US-DC3-100
US-DC3-110
US-DC3-140

Test Cases:
TC DC3 01</td></tr>
<tr><td colspan="4">Description of the scientific support planned for this</td></tr>
<tr><td colspan="4">AIT, ZAMG (Expert)
CSIS BB</td></tr>
<tr><td>Service Name</td><td colspan="3">Evaluating the impact of greening measures on the heat load of urban areas</td></tr>
<tr><td>Objective</td><td>Context</td><td>Workflow summary</td><td>References</td></tr>
<tr><td>Evaluate the impact of greening measures on urban heat load for the City of Linz. Visualize the implementation map showing the impact of greening measures on urban areas</td><td>Preparation of input data for risk assessment required by several DC. It enables a heat load map to be generated showing the impact of greening measures resulting from an expert for detailed study.</td><td>1. User specifies location and requirements, e.g. what changes are to be made to the green areas
2. User orders expert study
3. User is asked to upload input for the modelling (e.g. before and after maps of the planned green areas)
4. Expert gets input data and compiles, harmonizes data sets
5. Expert conducts urban climate model (local and microscale) simulations with green infrastructure (offline)
6. Expert uploads data to the server
7. The data are visualized
8. User is informed</td><td>EU-GL:
HC
RA/IA
IAO
AAO

User Stories:
US-DC3-100
US-DC3-130

Test Cases:
TC DC3 02</td></tr>
<tr><td colspan="4">Description of the scientific support planned for this</td></tr>
<tr><td colspan="4">ZAMG, AIT (Experts)
CSIS BB</td></tr>
<tr><td>Service Name</td><td colspan="3">Evaluating the impact of building characteristics on ventilation within</td></tr>
</table>

	urban areas		
Objective	**Context**	**Workflow summary**	**References**
Providing wind maps showing the impact of building characteristics within urban areas	Preparation of input data for risk assessment required by several DC. This test case enables a wind field map to be generated showing the impact of building characteristics (height, density) generated from an expert for detailed study.	1. User specifies location and requirements, e.g. what aspects of the buildings are to be investigated (height, density) 2. User orders expert study 3. User is asked to upload input for the modelling (e.g. before and after maps of the planned building changes) 4. Expert gets input data and order 5. Expert conducts urban model (local and microscale) simulations for wind field evaluation (offline) 6. Expert uploads data to the server 7. The data are visualized 8. User is informed	**EU-GL**: HC RA/IA IAO AAO **User Stories:** US-DC3-200 US-DC3-210 **Test Cases:** TC DC3 03
Description of the scientific support planned for this			
ZAMG, AIT (Experts) CSIS BB			

Demonstration Case 4 – Spain

Table 13: Expected workflow for DC4

Service Name	*Climate Broker for road element*		
Objective	**Context**	**Workflow summary**	**References**
Obtain all the necessary data to perform a Hazard assessment For application in the design, construction, maintenance and operation phases, on roads and/or railways.	The process of selecting scenarios from a model is tedious and complex due to several facts: (1) Each model have different spatial and temporal resolutions, (2) the formats in which the original data is stored are not standard and (3) collection methods for the data need to be adapted in each case	1. Identify the climate model needed for the hazard assessment (offline) 2. Define spatial and temporal horizons (offline) 3. Identify the needed variables from the model (offline) 4. Obtain the data from the source (offline) 5. Process the data as required (offline) 6. Produce the output data in the appropriate format (offline) 7. Upload results to CSIS data archive	**EU-GL**: HC RA / IA **Test Cases:** TC DC4 010
Description of the scientific support planned for this			
METEOGRID, AEMET (Experts) CSIS BB			
Service Name	*Climate variables and indexes Atlas for road elements*		
Objective	**Context**	**Workflow summary**	**References**
Provide the foreseen evolution of climate variables and climate indexes related to road design and management.	The user should be able to define new indexes based on the already available information. It includes information for both, the feasibility study and detailed studies. The CSIS should be able to provide / upload / store / compute / maps at a regional o local scale to allow to evaluate the foreseen changes in the variables and indexes related to road design and management.	1. Select location, hazard, element at risk 2. Visualize existing hazard maps and elements of risk from CSIS archive 3. Prepare new data (hazard maps, indices) (offline) 4. Upload of new data (hazard maps, indices) 5. Store new data (hazard maps, indices) 6. Visualize new hazard maps and elements of risk	**EU-GL**: HC RA / IA **Test Cases:** TC DC4 020
Description of the scientific support planned for this			
METEOGRID (Expert) CSIS BB			
Service Name	*Hazard assessment for road elements*		
Objective	**Context**	**Workflow summary**	**References**
Identify hazard conditions	For application in the	1. Identify/define which	**EU-GL**:

based on climatic variables and their occurrence	design, construction, maintenance and operation phases, on roads and/or railways	phenomena have produced damage to the physical and/or human environment (offline) 2. Analyse which variables determine this phenomenon (offline) 3. Define the temporal and spatial horizon (offline) 4. Quantify the occurrence of such climatic events and their intensity 5. Relate hazard parameters and climatic variability (offline) 6. Model the danger according to climatic variables for the different horizons (offline) 7. Obtain maps that characterize the intensity and occurrence of the hazard studied (offline) 8. Incorporation of future climate scenarios into threat estimation and Consideration of uncertainty statistics.	HC RA / IA **Test Cases:** TC DC4 030
Description of the scientific support planned for this			
ACCIONA, CEDEX, METEOGRID, AEMET (Experts) CSIS BB			
Service Name	*Catalogue of road elements at risk*		
Objective	**Context**	**Workflow summary**	**References**
The aim is to create a catalogue of road elements. Elements must be defined with sufficient attributes to define their climate risk.	CSIS must be able to create, incorporate or modify catalogues of roadway elements that may be damaged by climate	1. Selection of the type of elements 2. Definition of the technical characteristics of each element 3. Vulnerability functions of each element (offline) 4. Quantification of the acquisition cost for each element	**EU-GL**: E/V RA/IA **Test Cases:** TC DC4 040
Description of the scientific support planned for this			
METEOGRID, CEDEX, ACCIONA (Experts) CSIS BB			
Service Name	*Atlas of road elements at risk*		
Objective	**Context**	**Workflow summary**	**References**
The objective is to obtain the geographic location of the possible elements affected by climatic risks	The CSIS should be able to provide / upload / store the vulnerable element to generate geographical information at a national or local scale	1. Selection of catalogue of vulnerable elements to be used 2. Selection of geographical context 3. Selection of the register of elements to work with 4. Updating of element typology	**EU-GL**: RA / IA **Test Cases:** TC DC4 050
Description of the scientific support planned for this			

CSIS BB			
Service Name	*Risk assessment for road elements*		
Objective	**Context**	**Workflow summary**	**References**
To analyse the probability of damage associated with climatic hazards in economic terms and loss of human life through the results obtained in the study of hazard, exposure and vulnerability.	The CSIS should be able to provide / upload / store / compute / maps at a regional o local scale to allow to evaluate the climate risks related to road design and management.	1. Establish numerical modelling procedures for input variables (offline) 2. Probabilistic integration of hazard, exposure and vulnerability 3. Analysis of impact scenarios 4. Evaluation of the associated losses in economic and human terms	**EU-GL**: RA / IA **Test Cases:** TC DC4 060
Description of the scientific support planned for this			
AEMET, METEOGRID (Experts) CSIS BB			
Service Name	*Good practices and adaptation measures catalogue for road*		
Objective	**Context**	**Workflow summary**	**References**
The objective is to collect and propose practices and measures that minimize the impact of climate change on road elements	The CSIS should be able to provide / upload / store a catalogue with measures and good practices that minimize the impact of climate change on road elements	1. Revision of adaptation measures and good management practices 2. Selection of means and practices to be incorporated in the catalogue 3. Defining the characteristics and properties of the selected measures and practices	**EU-GL**: IAO **Test Cases:** TC DC4 070
Description of the scientific support planned for this			
METEOGRID, ACCIONA, CEDEX (Experts) CSIS BB			
Service Name	*Decision support tool for road element*		
Objective	**Context**	**Workflow summary**	**References**
The aim is to create a tool that helps decision making. This tool should suggest the best measures or practices (economic, social and environmental) to reduce the impact of climate change.	The CSIS should incorporate a decision tool for the management of road elements at risk	1. Recollection of adaptation measures and good practices included in the catalogue carried out 2. Analysis of the benefit and cost (environmental, social and economic) of each measure 3. Monitoring and follow up of this of elements at risk 4. Multicriteria analysis for the selection of measures and practices in decision support	**EU-GL**: Decision Support **Test Cases:** TC DC4 080
Description of the scientific support planned for this			
METEOGRID, ACCIONA, CEDEX (Experts) CSIS BB			
Service Name	*Implementation of the adaptation plan for road elements*		
Objective	**Context**	**Workflow summary**	**References**

The objective is to monitor and control the measures and actions proposed in the adaptation plan.	The CSIS shows a preliminary report with the results obtained in the project and allows the inclusion of new information for the generation of the final report.	1. Development of an action plan for adaptation 2. Identification of the roles and responsibilities of the stakeholders involved 3. Evaluation of methods of financing 4. Monitoring and follow-up of the measures	**EU-GL**: AAO Integration Decision Support Action Plan **Test Cases:** TC DC4 090
Description of the scientific support planned for this			
METEOGRID, ACCIONA, CEDEX (Experts) CSIS BB			