D3.2 Science support report v1

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-create an integrated Climate Services Information System (CSIS) to integrate resilience into urban infrastructure and look into the way to adjust the CSIS to transport 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. Three demonstration cases showcase CLARITY climate services in different climatic, regional, infrastructure and hazard contexts in Italy, Sweden, and Austria; focusing on the planning and implementation of urban infrastructure development projects. A fourth demonstration case in Spain illustrates how the expected effects of CC hazards and risk can be assessed in the case of road transport infrastructure and the flexibility of the CSIS system to adapt to other sectors.

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 February 11th, 2019 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
DS	Decision Support
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
GUI	Graphical User Interface
H	Human
HC	Hazard Characterisation
HRL	High Resolution Layers
HRU	Hydrological Response Unit
HTML5	Hypertext Markup Language, version 5
HTTP	Hypertext Transfer Protocol
HW	Heat Waves
HWMI	Heat Wave Magnitude Index
IA	Impact Assessment
IAAP	Integration of Adaptation Action Plan
IAO	Identification of Adaptation Options
ICC	Indicators, Criteria and Cost
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
LRI	Large Research Infrastructure
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
SME	Small and Medium Enterprise
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 D3.2 "Science support report" of the CLARITY project (H2020, Contract number 730355). It presents a report on the work performed and results obtained in WP3 since the project start. It also provides an updated plan for the WP3 work to be done until the project end.

The CLARITY project follows the seven steps[1] of the EU-GL methodology described in detail in the D3.1. Consequently, the work and results presented here will follow this workflow. The association of the original Tasks 3.2, 3.3, 3.4, and 3.5 of this work package with the EU-GL workflow is presented in the Introduction (Chapter 1).

As CLARITY will produce data and climate, risk and impact assessments at two different levels of detail data levels, this deliverable separates the work in these areas into two chapters. Chapter 2 shows the work and results for the pan-European level following the EU-GL structure. Climate indices which characterise the hazards have been calculated for a majority of the global climate model/regional climate model combinations. Hazard maps for several hazards have been produced. At the moment, however, focus has been on the heat and flooding hazards. Methods to downscale the coarse pan-European data to urban scales have been developed, one implementing an algorithm which downscales the data by incorporating pan-European datasets representing the physical characteristics of the urban environment, and a second incorporating additional locally available datasets.

Chapter 3 focuses on the four demonstration cases, which, owing to their different aims, are structured independent from each other. Their levels of progress are different.

It is to be realised that as much of this work is ongoing, some results presented may represent preliminary results and can be subject to change when the following deliverable D3.3 Science Support Report v2 is produced in a year's time.

[1] Hazard Characterisation, Evaluation of Exposure, Vulnerability Analysis, Risk & Impact Assessment, Identification of Adaptation Options, Appraisal of Adaptation Options, Integration of Adaptation Action Plan.

1 Introduction

This deliverable presents a report on the work performed in WP3 since the project start. It also provides an updated plan for the WP3 work to be done until the project end. 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 presents work which has been performed for the ICT (Screening) Services. Section 3 presents work which has been performed for Expert Services on the four Demonstration Cases (DCs). Finally, Section 4 presents the conclusions.

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 previous 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.

As the CLARITY project has adopted the EU-GL methodology (i. Hazard Characterisation, ii. Evaluation of Exposure, iii. Vulnerability Analysis, iv. Risk & Impact Assessment, v. Identification of Adaptation Options, vi. Appraisal of Adaptation Options, vii. Integration of Adaptation Action Plan), which was presented in detail in deliverable “D3.1 Science Support Plan and Concept” and is summarised at the start of Chapter 2, the work and results will primarily follow this workflow. How this workflow is associated with the original tasks are as follows:

Task 3.2 – i. Hazard Characterisation, ii. Evaluation of Exposure

Task 3.3 – iii. Vulnerability Analysis, iv. Risk & Impact Assessment

Task 3.4 – v. Identification of Adaptation Options

Task 3.5 – vi. Appraisal of Adaptation Options, vii. Integration of Adaptation Action Plan.

1.2 Screening and Expert Studies

The CLARITY CSIS will provide services at two levels of detail: 1) Screening level which aims to provide freely available data and climate evaluations for all of Europe, and 2) Expert level which will supplement the screening level study with additional, high resolution data and climate analyses based on user needs at a cost to the user. For both of these studies, a similar methodological analysis (Hazard Characterisation, Evaluation of Exposure, Vulnerability Analysis, Risk and Impact Assessment, Evaluation of Adaptation Options) will be performed with the difference being that the expert level will provide a higher data resolution, additional datasets, and thus an analyses better tailored to the urban area or infrastructure project investigated by the user. Depending on the user needs, the expert analysis can focus on certain steps of the CLARITY workflow, like hazard characterisation and adaptation option assessment. In this case, the CLARITY framework and CSIS screening study help to ensure that the remaining steps will at least be considered in a qualitative way.

This deliverable will present results of the work which has been performed on both the screening level (Chapter 2) and expert level (Chapter 3).

2 ICT (Screening) Services

The Screening Level services proposed in CLARITY aims at making data and climate analyses for all of Europe freely accessible for users who wish to perform assessments on the risk and impact of various climate hazards in their region of interest. The structure of this chapter is based on the EU-GL [1] workflow on which CLARITY is based (**Figure 1**). The methodology, including a detailed description for each of the EU-GL steps is given in the deliverable "D3.1 Science Support Plan and Concept". Work performed for the Hazard Characterisation, Evaluation of Exposure, Vulnerability Analysis, Risk and Impact Assessment, and Adaptation Options for urban infrastructure will be presented in Sections 2.1, 2.4, 2.5, 2.6, and 2.7 respectively.

In order to provide a pan-European service in on-the-fly, the spatial resolution of the data must be kept low – here around 0.11°. However, in cases where additional data is locally available (data packages), or alternatively, an algorithm exists to downscale the coarse climate data to urban scales with the assistance of urban-landscape data, climate analyses on smaller spatial scales can be achieved. This will be described in more detail in Section 2.2.

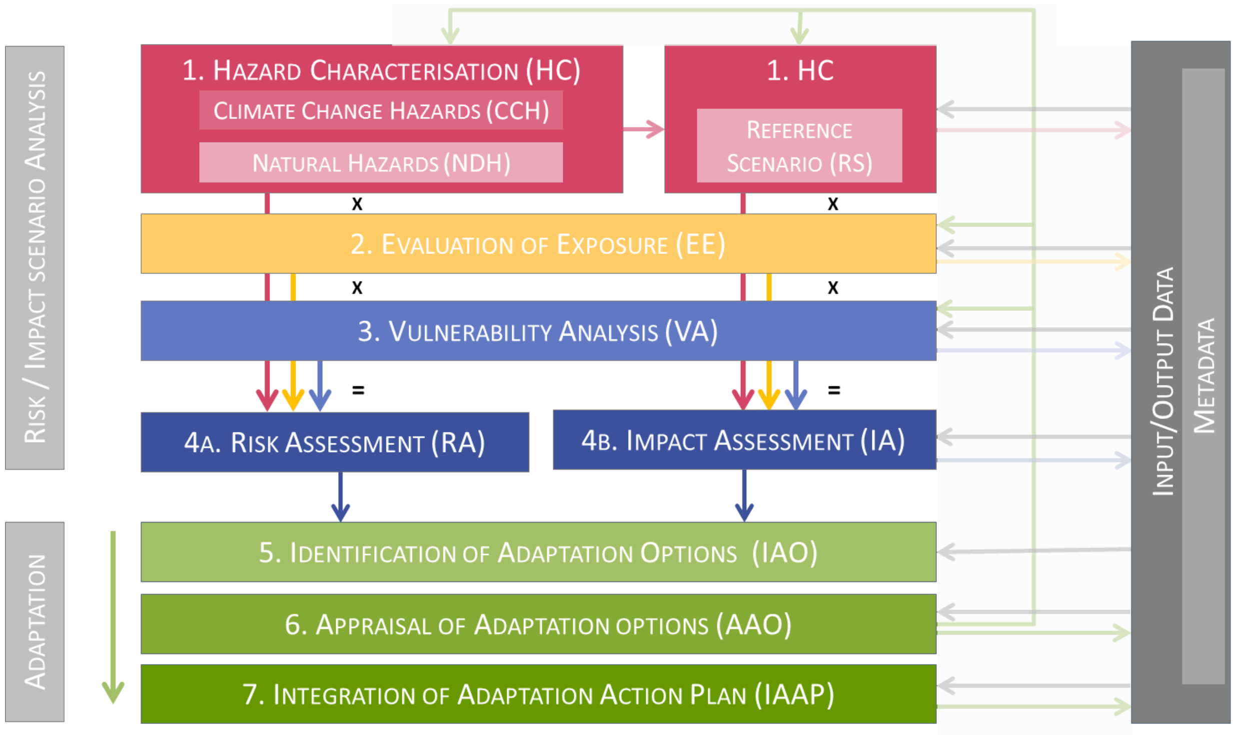


Figure 1: Schematization of the CLARITY modelling workflow in relation to the 7 steps of the EU-GLs.

2.1 Hazard Characterisation

The first step is to identify climate hazards in the project area by using a range of climate variables and indices. This is done for both the baseline/observed climate and for the predicted future climate scenarios. Climate variables and hazards related to baseline/observed climate, can be modelled by processing historical datasets. In dealing with climate change conditions, the evolution of each climate variable or hazard in the future can be determined by examining the outputs from climate prediction models.

The hazards which CLARITY will consider include: temperature related hazards such as extreme heat or cold, floods, wind storms, droughts, forest fires and landslides. Each hazard will be characterised using several climate indices, which are commonly used in the climate community or have been specifically designed for risk assessment (e.g. ECA&D[2], Urban SIS[3], ETCCDI[4]). These indices are summarised in **Table 1**, **Table 2**, and **Table 3**. Additionally, one *synthetic index* will be defined to represent each hazard by means of three hazards scales (low, medium, high). This synthetic index will be integrated in the CSIS tool in the form of a table, indicating the severity of each hazard for current and future climate periods under different greenhouse gas emissions scenarios.

The current status of the calculation of the indices is shown in **Table 4**. The columns represent each climate index from **Table 1**-**Table 3** and the rows represent the different GCM/RCM climate model simulations that are available from the EURO-CORDEX website[5]. The colours designate the progress in the calculation of the climate indices – green indicates that the indices have been calculated, yellow indicates that the indices are ready to be calculated, dependent on the availability of computational resources, and red indicates the indices which have not been calculated, either while the data has not yet been downloaded. The indices marked with no colour are already available or being processed from other data sources.

At the moment for the development of the CSIS, focus will first be on heat-related hazards and flooding.

[2] https://www.ecad.eu/indicesextremes/
[3] http://urbansis.climate.copernicus.eu/
[4] http://etccdi.pacificclimate.org/list_27_indices.shtml
[5] https://www.euro-cordex.net/

Table 1: Summary of the climate indices relating to temperature.

Climate Variable	Main Hazard	(Sub-)Hazard	Climate Index	Name	Description	Index Source	Data Sources information	Temporal coverage	Responsible	Priority
Temperature	Heat	Heat waves	***CSU***	Consecutive Summer Days	Maximum number of consecutive days per time period with daily maximum temperature above 25°C	ECA&D[1]	**E-OBS**[10] gridded dataset (ECA&D) spatial resolution: 25 km **EURO-CORDEX**[11] spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971-2000 **Future periods:** 2011-2040 2041-2070 2071-2100	ZAMG	1
			Heat Wave Duration	Hot period duration	Maximum number of consecutive days when: i) Daily T_{max} is above T_1 for at least three days, ii) the average T_{max} is above T_1 over the entire period, and iii) the daily T_{max} must be above T_2 every day of the period (the total heat wave period may be longer than three days). T1 = 97.5th percentile, T2 = 81st percentile	Urban SIS[2]				
		Extreme heat	***Hot days***	Hot days > 75th percentile	Number of days per year with a mean air temperature at 2 m above ground above the 75th percentile during summer months (Apr-Sep)	Urban SIS				
			HD	Hot days	number of days with daily maximum temperature above 30°C	ETCCDI[3]				
			SD	Summer days	number of days with daily maximum temperature above 25°C	ETCCDI				
			TN	Tropical nights	number of days with daily minimum temperature above 20°C	ETCCDI				
			Tx90p	Warm days	Percentage of days per time period where daily maximum temperature is above the 90th percentile of daily maximum temperatures of a five day window centred on each calendar day of a given 30 year	ETCCDI				
			Tx75p	max number of consecutive days when Tmax > 75th percentile (Apr-Sept)	maximum number of consecutive days where the daily maximum temperature exceeds the 75th percentile of maximum temperature during the baseline period 1971-2000 for the warm months April-September.					
	Cold	Cold waves	***CFD***	Consecutive Frost Days	Number of consecutive days per time period with daily minimum temperature below 0°C	ECA&D	**E-OBS** gridded dataset (ECA&D) spatial resolution: 25 km **EURO-CORDEX** spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971-2000 **Future periods:** 2011-2040 2041-2070 2071-2100	ZAMG	1
		Extreme Cold	***FD***	Frost days	Maximum number of days per time period with daily minimum temperature below 0°C	ETCCDI				
			ID	Ice days	number of days per time period with daily maximum temperature below 0°C	ETCCDI				
			TN10p	Cold nights	percentage of days per time period where daily minimum temperature is below the 10th percentile of daily minimum temperatures of a five day window centred on each calendar day of a given 30 year climate reference period	ETCCDI				
	Thermal Stress		***ETR***	Extreme temperature range	intra-period difference of the maximum of maximum temperature and the minimum of minimum temperature	ETCCDI	**E-OBS** gridded dataset (ECA&D) spatialresolution: 25 km **EURO-CORDEX** resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971-2000 **Future periods:** 2011-2040 2041-2070 2071-2100	ZAMG	1

Table 2: Summary of the climate indices relating to precipitation and wind speed.

Precipitation	**Floods**	Extreme precipitation	*RX1day*	highest one day precipitation amount	maximum of one day precipitation amount in a given time period	ETCCDI	**E-OBS** gridded dataset (ECA&D) resolution: 25 km **EURO-CORDEX** resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971 - 2000 **Future periods:** 2011 - 2040 2041 - 2070 2071 - 2100	ZAMG	1
			RX5day	highest five day precipitation amount	highest precipitation amount for a five day interval	ETCCDI				
			Snow Days	number of days with snow precipitation > 1cm	number of days with snow precipitation > 1cm (precipitation > 1mm & temperature < 4°C)					
			Snow95p		95^{th} percentile of accumulated snow precipitation					
		Wet periods	*CWD*	Consecutive Wet Days	number of consecutive days per time period with daily precipitation amount at least 1 mm	ECA&D				
			RR1	Wet days	number of days per time period with daily precipitation of at least 1 mm	ETCCDI				
			R20mm	Very heavy precipitation day	number of days per time period with daily precipitation equal or greater than 20 mm	ETCCDI				
			R90p	wet days wrt 90th percentile of reference period	percentage of days where precipitation is higher than the calendar 90th percentile (centred on a 5 day window) of the reference period	ETCCDI				
		River flooding	*Flood recurrence*		Flood recurrences are given as daily river flows that correspond to return periods of 2, 5, 10, 50 and 100 years. The return period values are calculated using a Gumbel distribution fitted to the yearly maximum river flows for a given 30-year period.	SWICCA[4]	**SWICCA** datasets spatial resolution: 50 km / catchment (irregular grid)		SMHI	
			River flow		River flow is the volume rate of water flow that is transported through a given cross-sectional area. It is a sysnonym to river discharge or streamflow	SWICCA				
		Pluvial flooding	*Water runoff*		Runoff is the sum of surface and subsurface runoff to streams for each grid cell	SWICCA				
Wind speed	**Storms**	Extreme wind speed	*Wind99p*		99th percentile of wind speed		**EURO-CORDEX** spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971 - 2000 **Future periods:** 2011 - 2040 2041 - 2070 2071 - 2100	ZAMG	2
			FXx	Maximum wind gust	Maximum value of daily maximum wind gust	ECA&D				
			Torro	Max. wind gust classified according to Torro scale	Derived from maximum wind gust relating it to expected damage	TORRO[5]			ZAMG	2

Table 3: Summary of the climate indices relating to droughts, forest fires and landslides.

Combined (Precipitation, temperature)	**Droughts**		*SPI*	Standardized Precipitation Index	Cumulative probability of a given rainfall event	McKee et al. (1993)[6]	**E-OBS** gridded dataset (ECA&D) spatial resolution: 25 km **EURO-CORDEX** spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	**Reference period:** 1971 - 2000 **Future periods:** 2011 - 2040 2041 - 2070 2071 - 2100	ZAMG	2
			SPEI	Standardized Precipitation Evotranspiration Index	Monthly (or weakly) difference between precipitation and potential evapotranspiration (PET)	Vicente-Serrano et al. (2010)[7]				
			CDD	Consecutive Dry Days	maximum number of consecutive days with RR < 1mm	ETCCDI				
Combined (Precipitation, temperature, wind speed, relative humidity)	**Forest Fires**		*FWI*	Fire Weather Index	The Fire Weather Index (FWI) is a numeric rating of fire intensity. It combines the Initial Spread Index and the Buildup Index	Canadian Wildland Fire Information System[8]	**EURO-CORDEX** spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85 European Forest Fire Information System (EFFIS)[12]	**Reference period:** 1971 - 2000 **Future periods:** 2011 - 2040 2041 - 2070 2071 - 2100	Meteogrid	3
			others							
Soil properties, Precipitation	**Landslides**		*ELSUS (+ precipitation data)*	Landslide Susceptibility (combined with precipitation data)	Levels of spatial probability of generic landslide occurrence at continental scale	Martina Wilde et al. (2018)[9]	**European Soil Data Centre** (ESDAC)[13] spatial resolution: 200 m **EURO-CORDEX** spatial resolution: 12.5 km scenarios: rcp26, rcp45, rcp85	tbd	Meteogrid	3

Table 4: Status of the calculated indices (ZAMG). Green = complete, yellow = in progress, red = to do.

			HEAT								COLD					FLOODS										STORMS			DROUGHTS			FOREST FIRES		LANDSLIDES
			Heat Waves		Extreme Heat						ld wav	Extreme Cold			Thrm. Stress	Extreme Precipitation			Wet periods				River Flooding		Pluv. Flood	Extreme Wind Speed								
Institute	Driving GCM	RCM	CSU	Heat Wave Duration	Hot Days	HD	SD	TN	Tx90p	Tx75p	CFD	FD	ID	Tx10p	ETR	RX1day	RX5day	Snow Days	CWD	RR1	R20mm	R90p	Flood recurrence	River Flow	Water runoff	W99p	FXa	Torro	SPI	SPEI	CDD	FWI	others	ELSUS
CLMcom	CNRM-CERFACS-CNRM-CM5	CCLM4-8-17																																
CLMcom	**ICHEC-EC-EARTH**	**CCLM4-8-17**																																
CLMcom	MOHC-HadGEM2-ES	CCLM4-8-17																					S	S	S							M	M	M
CLMcom	MPI-M-MPI-ESM-LR	CCLM4-8-17																																
																							M	M	M							E	E	E
CNRM	CNRM-CERFACS-CNRM-CM5	ALADIN53																																
																							H	H	H							T	T	T
DMI	**ICHEC-EC-EARTH**	**HIRHAM5**																																
DMI	NCC-NorESM1-M	HIRHAM5																					I	I	I							E	E	E
DMI	MOHC-HadGEM2-ES	HIRHAM5																																
																																O	O	O
IPSL-INERIS	IPSL-IPSL-CM5A-MR	WRF331F																																
																																G	G	G
KNMI	**ICHEC-EC-EARTH**	**RACMO22E**																																
KNMI	**MOHC-HadGEM2-ES**	**RACMO22E**																														R	R	R
MPI-CSC	**MPI-M-MPI-ESM-LR**	**REMO2009**																														I	I	I
SMHI	CNRM-CERFACS-CNRM-CM5	RCA4																														D	D	D
SMHI	**ICHEC-EC-EARTH**	**RCA4**																																
SMHI	IPSL-IPSL-CM5A-MR	RCA4																																
SMHI	MOHC-HadGEM2-ES	RCA4																																
SMHI	**MPI-M-MPI-ESM-LR**	**RCA4**																																

Calculated
Partially complete (errors in org data)
Ready to calculate
To do

2.1.1 Data used for the calculation of the indices

The daily E-OBS dataset at 0.22° spatial resolution is a gridded observational dataset based on daily ECA&D station data for precipitation, minimum, mean and maximum temperature and sea level pressure in Europe. E-OBS version 17.0 forms the basis for the current climate of several climate indices and is used for bias correction of temperature and precipitation data of the climate model data provided by the EURO-CORDEX initiative. From the many bias correction methods listed in D3.1 (section 3.2.5) we have chosen to apply the quantile mapping method [2] for bias correction of the EURO-CORDEX data. Pros and cons of bias correction were already discussed in D3.1.

The daily EURO-CORDEX climate model data at 0.11° spatial resolution forms the basis for the future climate projections of most of the climate indices. The climate model configurations that are available are shown in **Table 5**. All configurations have data on the emissions scenarios RCP4.5 and RCP8.5 and only a subset have the lower emission scenario RCP2.6. It is planned to calculate the indices using all of the climate model configurations shown in **Table 5** to establish an ensemble of members, so that a mean and a spread can be calculated with the latter giving an indication as to the reliability of the former quantity.

Table 5: List of EURO-CORDEX climate model configurations showing the institute, driving global climate model (GCM) and regional climate model (RCM). The last three columns show the availability of the emissions scenarios RCP2.6 (early response), RCP4.5 (effective measures), and RCP8.5 (business as usual).

Institute	**Driving GCM**	**RCM**	**RCP2.6**	**RCP4.5**	**RCP8.5**
CLMcom	CNRM-CERFACS-CNRM-CM5	CCLM4-8-17	no	yes	yes
	ICHEC-EC-EARTH	CCLM4-8-17	yes	yes	yes
	MOHC-HadGEM2-ES	CCLM4-8-17	no	yes	yes
	MPI-M-MPI-ESM-LR	CCLM4-8-17	no	yes	yes
CNRM	CNRM-CERFACS-CNRM-CM5	ALADIN53	no	yes	yes
DMI	ICHEC-EC-EARTH	HIRHAM5	yes	yes	yes
	NCC-NorESM1-M	HIRHAM5	no	yes	yes
IPSL-INERIS	IPSL-IPSL-CM5A-MR	WRF331F	no	yes	yes
KNMI	ICHEC-EC-EARTH	RACMO22E	yes	yes	yes
	MOHC-HadGEM2-ES	RACMO22E	yes	yes	yes
MPI-CSC	MPI-M-MPI-ESM-LR	REMO2009	yes	yes	yes
SMHI	CNRM-CERFACS-CNRM-CM5	RCA4	no	yes	yes
	ICHEC-EC-EARTH	RCA4	yes	yes	yes
	IPSL-IPSL-CM5A-MR	RCA4	no	yes	yes

	MOHC-HadGEM2-ES	RCA4	no	yes	yes
	MPI-M-MPI-ESM-LR	RCA4	yes	yes	yes

The relevant climate index is calculated from the daily EURO-CORDEX data and is averaged over one of the 30-year periods being investigated (1971-2000, 2011-2040, 2041-2070, 2071-2100). The use of the 1971-2000 period from the model acts as a baseline in which to compare the results of the future periods indicating the *change* of climate indices under different RCP scenarios until the end of the 21st century. As the bias-correction of the climate model data is still ongoing, preliminary results are only available for single EURO-CORDEX climate model configurations that will later be replaced by the ensemble mean of all available simulations.

The decision to select the GCM/RCM combinations shown in **Table 5** was based on similar climate analysis studies such as in the BRIGAID Project (BRIGAID D5.1 TIF[6]) and the Pan-European Urban Climate Services (PUCS; D5.2 Urban Climate Data for Demonstration Cases[7]) and what climate model data was already available at the host institutions.

2.1.2 Temperature related hazards (heat/cold)

The heat related hazards are represented by the indices CSU, heat wave duration, hot days, HD, SD, TN, Tx90p and Tx75p. The cold related hazards are represented by the indices CFD, FD, ID, and TN10p. The thermal stress is represented by the index ETR. Definitions of these indices can be found in **Table 1**. Depending on the end user's interest, some of the temperature related climate indices are defined based on the exceedance of absolute values (e.g. HD, SD, TN) while others are percentile-based (e.g. Tx90p, Tx75p). However, for the derivation of the synthetic index, which acts as a representative for each group of hazards, a percentile-based climate index is used to facilitate comparison across Europe.

Figure 2 shows a measure for heat waves in the form of the index Tx75p. This is defined as the maximum number of consecutive days where the daily maximum temperature exceeds the 75th percentile of maximum temperature during the baseline period 1971-2000 for the warm months April-September. Panel (a) shows Tx75p for the baseline period 1971-2000, and the values for the three emissions scenarios RCP2.6, 4.5, and 8.5 for the future period 2071-2100 are shown in the panels (b), (c), and (d), respectively. The most prominent feature of the future scenarios of **Figure 2** are the regions of warming expected over much of western, southern and northern Europe.

Figure 3 shows a representation of the raw index values in terms of a hazard scale (1=low, 2=medium, 3=high). The hazard scale for the baseline period (1971-2000) is defined by grouping the values of Tx75p *over space* into three terciles with the lower (upper) tercile corresponding to a low (high) hazard level. In this case, the values of these terciles are 13.5 and 15.9 days, respectively. The hazard scale for the three future periods is similarly defined *over space*, but instead of using the absolute values of Tx75p, the difference from the baseline period is used. That is, for the future periods, the hazard level refers to the *change* in the index between the baseline and future scenario. This definition of hazard level is similar to that used in the BRIGAID project (BRIGAID D5.1 TIF; quintiles are used instead of the terciles here). In order the allow a meaningful comparison of the future scenarios, the lower and upper terciles used in **Figure 3**(b-d) are those corresponding to the RCP4.5 scenario of 9.13 and 16.6 days, respectively.

It should be noted that alternative definitions for the hazard scale were examined. For example, for the future scenarios, the hazard scale was defined in terms of the amount of change from the baseline climate. In the case of Tx75p, the tercile levels for the low, medium, and high hazard levels were defined in terms of relative changes (50% and 100% increase in Tx75p, respectively) or absolute changes (20 and 40 days,

[6] https://brigaid.eu/wp-content/uploads/2016/10/BRIGAID_D5.1_TIF.pdf
[7] https://climate-fit.city/wp-content/uploads/2018/11/D5.2-Urban-Climate-Data-For-Demonstration-Cases.pdf

respectively). One disadvantage of this method is that these thresholds are dependent on the climate index being considered and need to be carefully chosen to yield meaningful[8] results each time. For example, when dealing with the precipitation index Rx5day (see Section 2.1.3) setting the tercile levels for the relative change at 10% and 20%, respectively, produced more meaningful results. For this reason, defining the hazard level in terms of spatial terciles presented first will be preferred here.

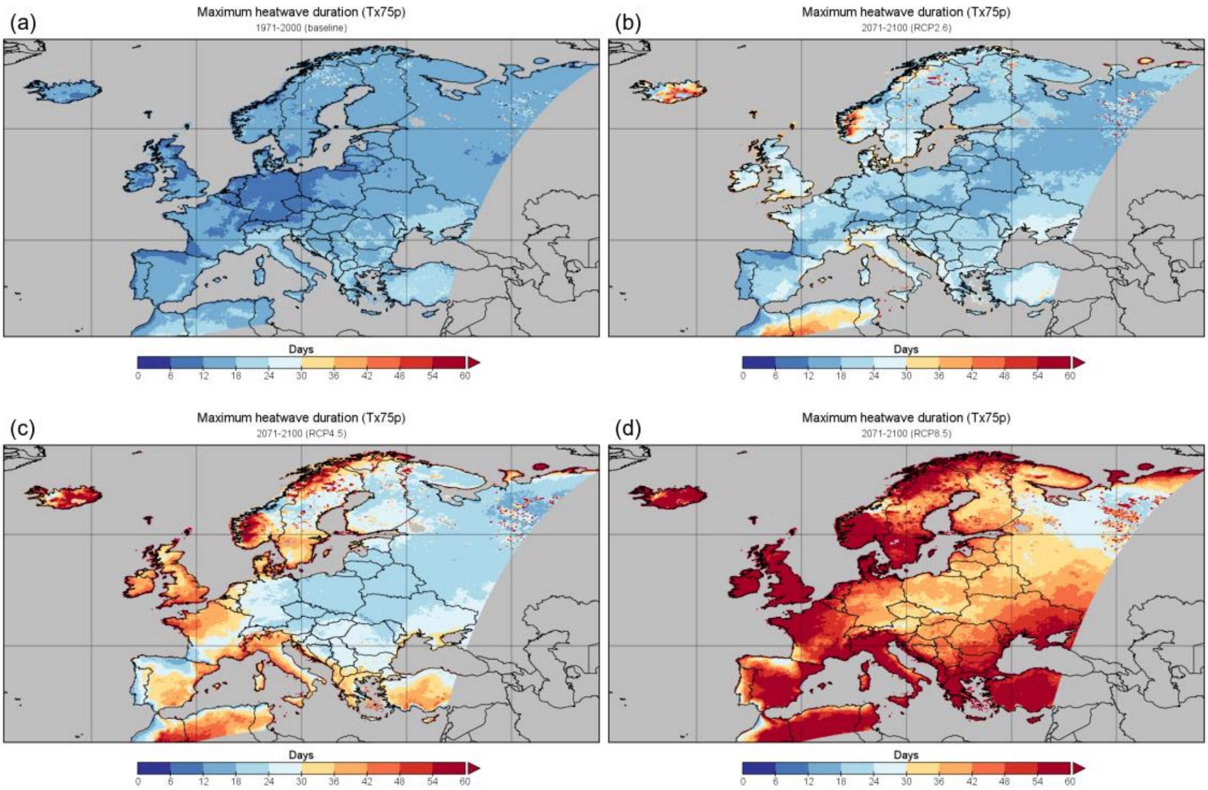


Figure 2: Heat index Tx75p for (a) the baseline period (1971-2000) and the three emissions scenarios (b) RCP2.6, (c) RCP4.5, and (d) RCP8.5 for the future period 2071-2100 for the SMHI/ICHEC-EARTH-EC/RCA4 climate model combination. The colours show the maximum heat wave duration (Tx75p) in days.

[8] Meaningful, in this case, means maps which are not everywhere classified as being of low or high hazard level for all time periods.

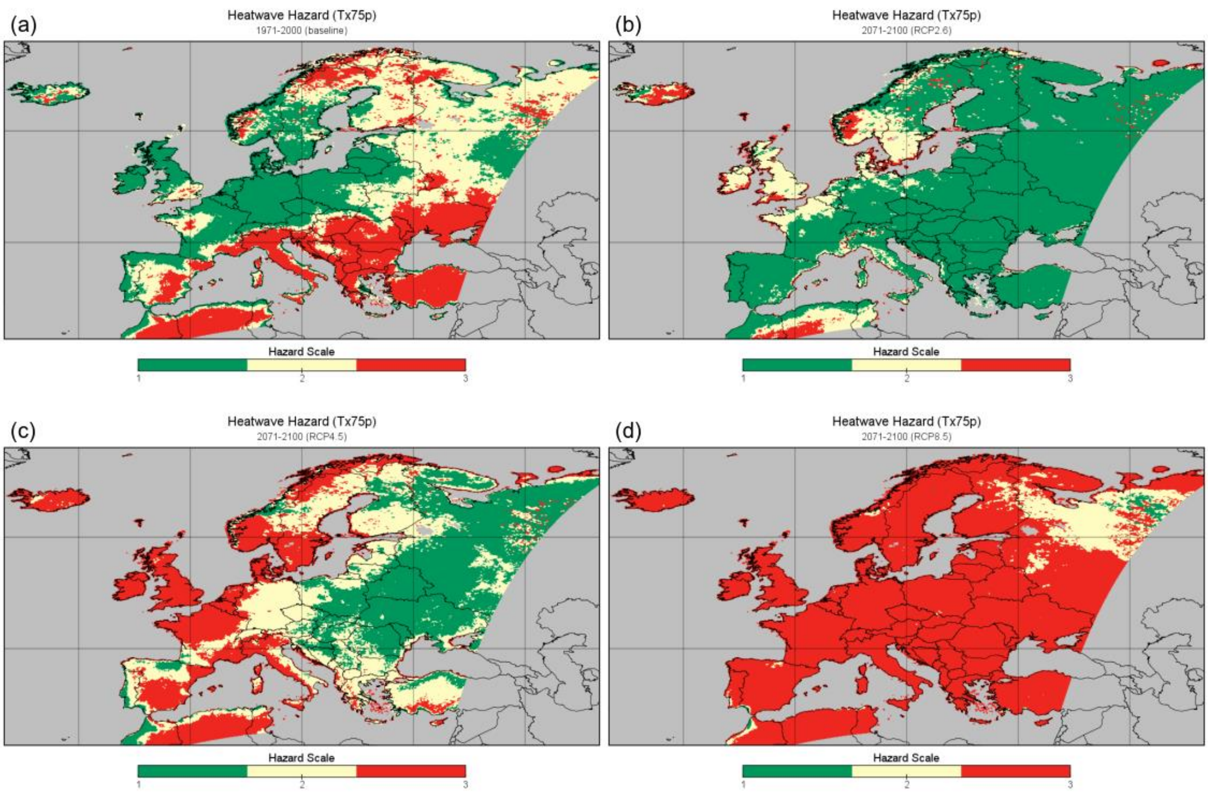


Figure 3: As in **Figure 2** but showing a representation for the hazard maps of the heat index Tx75p. The hazard levels 1=low (green), 2=medium (yellow), and 3=high (red) are defined within the text.

2.1.2.1 Heat wave hazard matrix

To assist with the calculation of the impact of heat waves (consecutive days exceeding a given maximum temperature threshold), a heat wave hazard matrix has been calculated for points in Europe corresponding with the demonstration cases (DCs; see Chapter 3). This matrix shows the likelihood of occurrence that a heat wave of duration X days whereby the maximum temperature of each day exceeds a temperature threshold of Y°C. An example of this matrix is presented in **Table 6** and **Table 7**. Both tables show data for a point representing Naples from the E-OBS dataset for the baseline period 1971-2000. The first table shows the absolute number of heat waves with duration in days (rows), where the maximum temperature for each day is above a certain threshold in degrees Celsius (columns). The second table shows a measure of the occurrence rate for a heat wave of given length and temperature that is to be expected for a given year. This has been calculated simply as the heat wave count from **Table 6** divided by 30 years. The temperature range of 24-40°C has been chosen in order for it to be applicable Europe-wide.

Table 6: A section of the heat wave hazard table showing the count of heat waves of a certain duration in days (rows) whereby the maximum temperature of each day is at least above a certain threshold in degrees Celsius (columns). Note that the durations examined extend to 50 days (not shown).

Heat wave matrix									
Period	1971-2000								
Latitude	40.9431 N								
Longitude	14.2737 E								
Data source	E-OBS								
Count									
Max. Temperature (C)	24	26	28	30	32	34	36	38	40	Total
Duration (days)										
1	71	62	79	70	62	27	7	4	0	382
2	29	49	50	37	28	16	4	0	0	213
3	23	33	38	23	16	9	1	0	0	143
4	23	25	19	17	19	5	0	0	0	108
5	16	17	13	14	8	1	0	0	0	69
6	10	14	15	13	3	2	0	0	0	57
7	12	9	10	10	3	1	0	0	0	45
8	6	9	11	7	4	0	0	0	0	37
9	2	10	5	8	2	0	0	0	0	27
10	3	5	6	4	4	1	0	0	0	23
11	4	1	2	6	3	0	0	0	0	16
12	3	6	4	2	0	0	0	0	0	15
13	5	2	5	2	1	0	0	0	0	15
14	3	0	2	4	0	0	0	0	0	9
15	4	2	2	1	1	0	0	0	0	10
16	2	2	1	2	1	0	0	0	0	8
17	3	1	0	3	1	0	0	0	0	8
18	3	3	0	2	0	0	0	0	0	8
19	1	1	2	1	1	0	0	0	0	6
20	2	1	0	0	1	0	0	0	0	4
21	2	2	3	0	0	0	0	0	0	7
22	1	2	2	0	0	0	0	0	0	5
23	0	0	0	0	0	0	0	0	0	0
24	3	2	1	0	0	0	0	0	0	6
25	2	0	0	2	0	0	0	0	0	4

Table 7: As in **Table 6** but showing the occurrence probability per year (count / 30).

Heat wave matrix									
Period	1971-2000								
Latitude	40.9431 N								
Longitude	14.2737 E								
Data source	E-OBS								
Occurence per year									
Max. Temperature (C)	24	26	28	30	32	34	36	38	40
Duration (days)									
1	2.367	2.067	2.633	2.333	2.067	0.900	0.233	0.133	0.000
2	0.967	1.633	1.667	1.233	0.933	0.533	0.133	0.000	0.000
3	0.767	1.100	1.267	0.767	0.533	0.300	0.033	0.000	0.000
4	0.767	0.833	0.633	0.567	0.633	0.167	0.000	0.000	0.000
5	0.533	0.567	0.433	0.467	0.267	0.033	0.000	0.000	0.000
6	0.333	0.467	0.500	0.433	0.100	0.067	0.000	0.000	0.000
7	0.400	0.300	0.333	0.333	0.100	0.033	0.000	0.000	0.000
8	0.200	0.300	0.367	0.233	0.133	0.000	0.000	0.000	0.000
9	0.067	0.333	0.167	0.267	0.067	0.000	0.000	0.000	0.000
10	0.100	0.167	0.200	0.133	0.133	0.033	0.000	0.000	0.000
11	0.133	0.033	0.067	0.200	0.100	0.000	0.000	0.000	0.000
12	0.100	0.200	0.133	0.067	0.000	0.000	0.000	0.000	0.000
13	0.167	0.067	0.167	0.067	0.033	0.000	0.000	0.000	0.000
14	0.100	0.000	0.067	0.133	0.000	0.000	0.000	0.000	0.000
15	0.133	0.067	0.067	0.033	0.033	0.000	0.000	0.000	0.000
16	0.067	0.067	0.033	0.067	0.033	0.000	0.000	0.000	0.000
17	0.100	0.033	0.000	0.100	0.033	0.000	0.000	0.000	0.000
18	0.100	0.100	0.000	0.067	0.000	0.000	0.000	0.000	0.000
19	0.033	0.033	0.067	0.033	0.033	0.000	0.000	0.000	0.000
20	0.067	0.033	0.000	0.000	0.033	0.000	0.000	0.000	0.000
21	0.067	0.067	0.100	0.000	0.000	0.000	0.000	0.000	0.000
22	0.033	0.067	0.067	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.100	0.067	0.033	0.000	0.000	0.000	0.000	0.000	0.000
25	0.067	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.000

2.1.3 Floods

The flood hazard will be characterised using the precipitation indices RX1day, RX5day, snow days, CWD, RR1, R20mm, and R90p (see **Table 2** for definitions).

Figure 4 shows a measure for floods in the form of the 5-day accumulated precipitation index RX5day. This is defined as the sum of the daily precipitation over five consecutive days (units mm). Panel (a) shows RX5day for the baseline period 1971-2000, and the values for the three emissions scenarios RCP2.6, 4.5, and 8.5 for the future period 2071-2100 are shown in the panels (b), (c), and (d), respectively. The most prominent features of the future scenarios of **Figure 4** are the high values of precipitation on the west-coasts of Norway and Great Britain, and the mountain regions of central and southern Europe. Changes in RX5day for the different emissions scenarios are difficult to ascertain based on the plots alone.

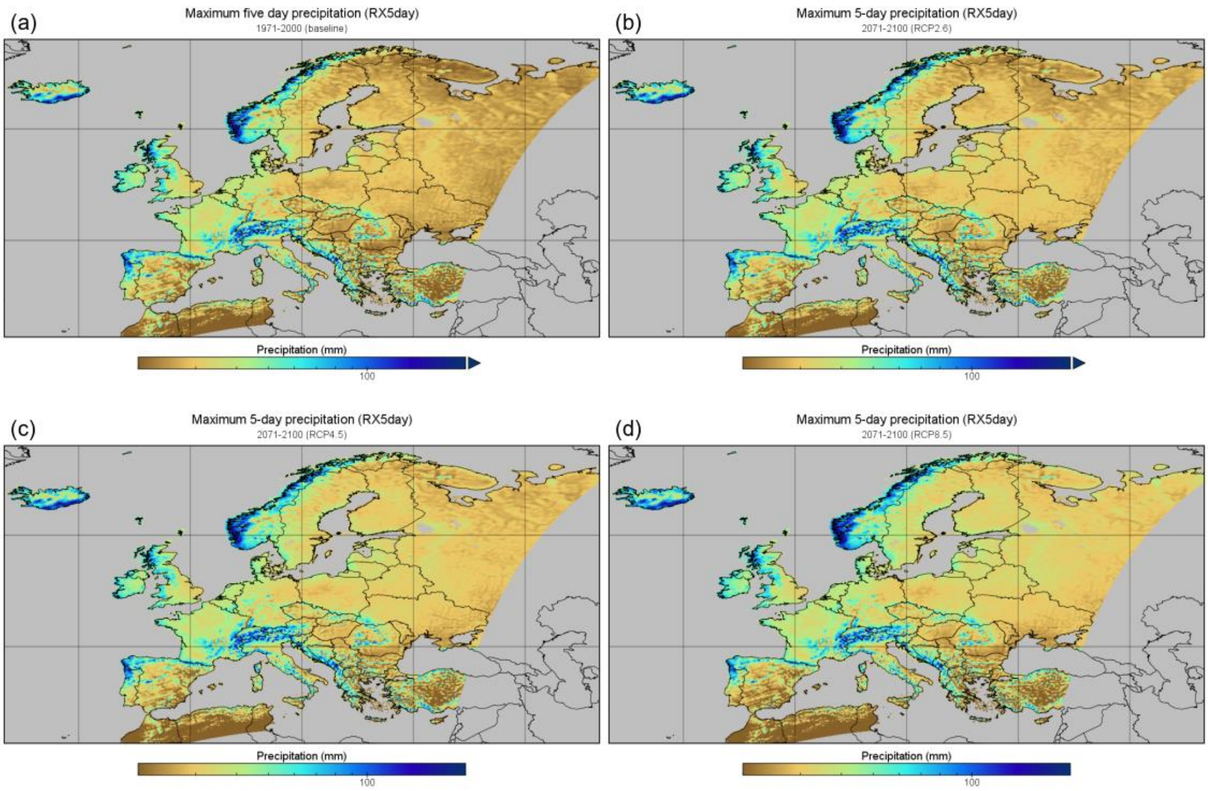


Figure 4: Precipitation index RX5day for (a) the baseline period (1971-2000) and the three emissions scenarios (b) RCP2.6, (c) RCP4.5, and (d) RCP8.5 for the future period 2071-2100 for the SMHI/ICHEC-EARTH-EC/RCA4 climate model combination. The colours show the 5-day precipitation totals (RX5day) in mm on a logarithmic scale.

Figure 5 shows the raw index values in terms of a hazard scale (1=low, 2=medium, 3=high). The hazard scale for the baseline period (1971-2000) is defined in terciles with the lower (upper) tercile corresponding to a low (high) hazard level. In this case, the values of these terciles are 26.5 and 32.6 mm, respectively. The hazard scale for the three future periods is defined as the fractional change from the baseline period (result of the future period divided by the result of the baseline period) and the spatial distribution sorted into terciles. The values of the lower and upper terciles correspond to the RCP4.5 scenario and have values of 1.05 and 1.11, respectively. According to this definition, a large portion of northern and eastern Europe can expect to experience a medium to high level of increase in the 5-day precipitation in the period 2071-2100.

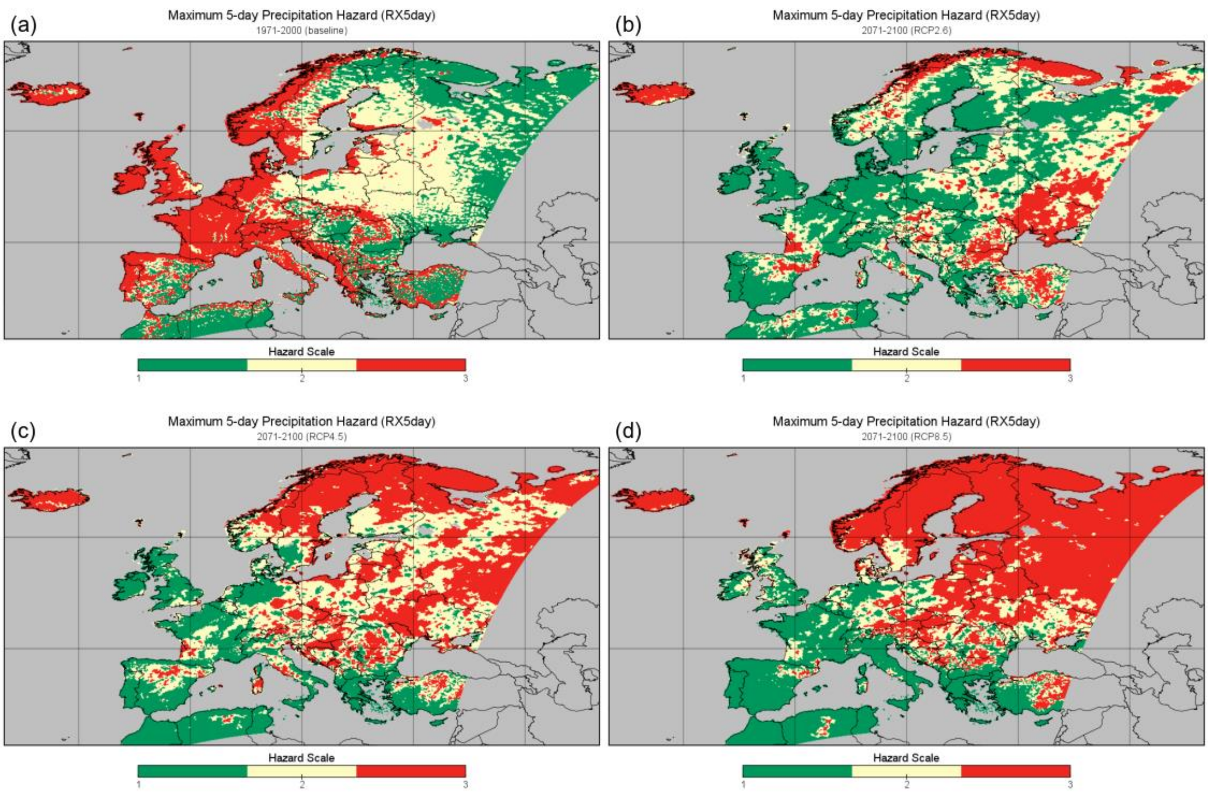


Figure 5: As in **Figure 4** but showing a representation for the hazard maps of the precipitation index RX5day. The hazard levels 1=low (green), 2=medium (yellow), and 3=high (red) are defined within the text.

2.1.3.1 River flooding

River flooding is described using daily river flows corresponding to different return periods. The river flows are estimated through simulation by employing hydrological models. Three different models of varying spatial resolution are used to enable ensemble simulation of river flows: VIC, Lisflood, and E-HYPE. The first two are grid based models with resolutions of 0.5 degree and 5 km, respectively. The third one is a sub-catchment based model with an average catchment size of 215 km^2. River discharge values are provided on a common 0.5 degree grid, which is the native grid of VIC. Lisflood and E-HYPE results are up-scaled to this resolution. Daily precipitation and temperature from a subset of the climate models described in Section 2.1.1 are used to force the hydrological models. The climate models used for this assessment are listed in **Table 8**. The return period values are calculated using a Gumbel distribution fitted to the simulated yearly maximum daily river flows for each of the 30-year periods. Return periods of 2, 5, 10, 50, and 100 years are considered. The analysis is performed within the EU FP7 project IMPACT2C (grant agreement 282746) and more information on the analysis can be found at: http://impact2c.hzg.de/imperia/md/content/csc/projekte/impact2c_d5.1_fin.pdf .

Figure 6 shows the projected ensemble mean changes in the 10-years river flow over the three future time periods in relation to the reference period. The ensemble consists of all combinations of hydrological models and climate models used for the analysis under all three RCPs. The projections show a coherent spatial pattern of changes in the extreme river flow. Extreme flows are projected to decrease in the northern and eastern parts of Europe and increase in the central, western, and southern Europe, as well as southern parts of Scandinavia for the all three time horizons.

Table 8: Subset of EURO-CORDEX climate model configurations used for climate impact analysis of river flooding.

Institute	Driving GCM	RCM	RCP2.6	RCP4.5	RCP8.5
IPSL-INERIS	IPSL-IPSL-CM5A-MR	WRF331F	no	yes	no
SMHI	ICHEC-EC-EARTH	RCA4	yes	yes	yes
	MOHC-HadGEM2-ES	RCA4	no	yes	yes
MPI-CSC	MPI-M-MPI-ESM-LR	REMO2009	yes	yes	yes
KNMI	ICHEC-EC-EARTH	RACMO22E	no	yes	yes

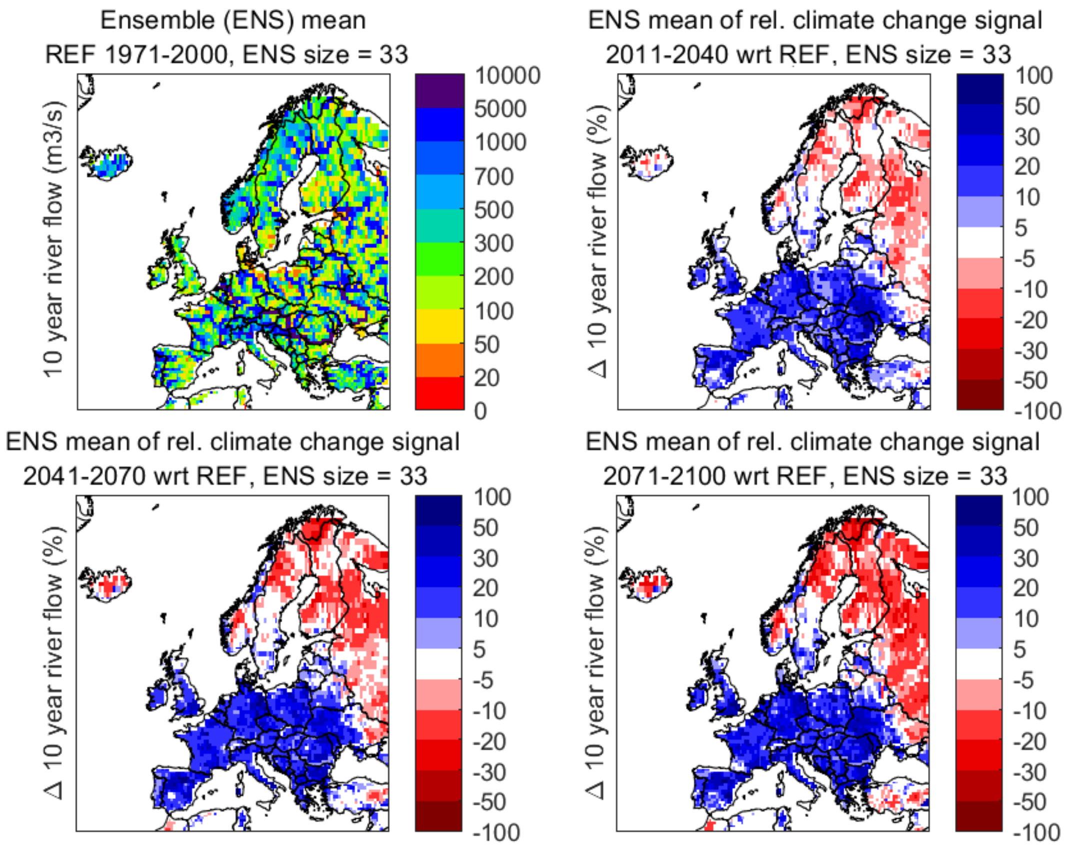


Figure 6: Projected changes in the 10-year river flow relative to the reference period for three future time periods across Europe.

2.1.4 Wind storms

Wind storms will be characterised using the indices Wind99p, FXx, Torro (see **Table 3** for definitions). Wind analysis is based only on model results, since no gridded wind climatology on European scale is available.

Figure 7 shows a measure for wind storms in the form of the 99th percentile of the daily maximum wind speed (Wind99p) index. This is defined based on the daily maximum wind speed over the 30-year period investigated. Panel (a) shows Wind99p for the baseline period 1971-2000, and the values for the three emissions scenarios RCP2.6, 4.5, and 8.5 for the future period 2071-2100 are shown in the panels (b), (c), and (d), respectively. The most prominent features are the high wind speeds on the west-coasts of Norway, Great Britain, and the mountain regions of central and southern Europe. Changes in Wind99p for the different emissions scenarios are difficult to ascertain based on the plots alone.

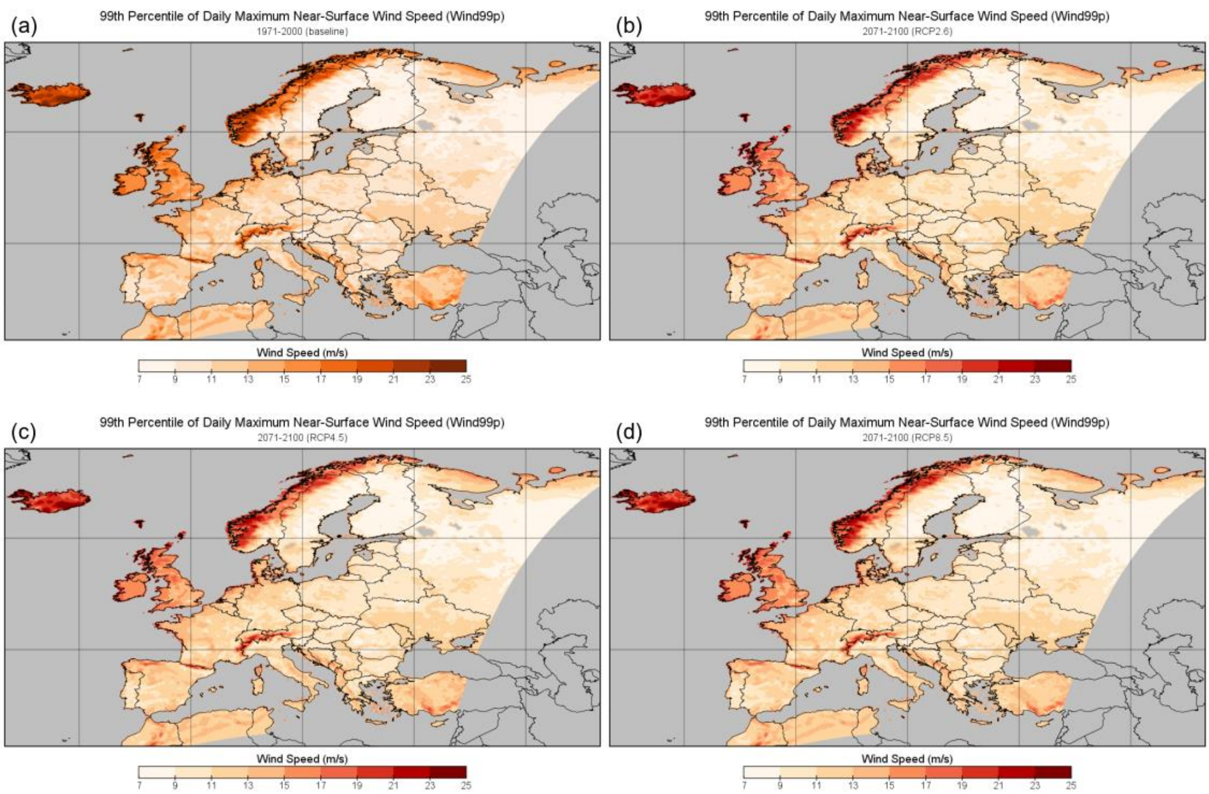


Figure 7: Wind index Wind99p for (a) the baseline period (1971-2000) and the three emissions scenarios (b) RCP2.6, (c) RCP4.5, and (d) RCP8.5 for the future period 2071-2100 for the SMHI/ICHEC-EARTH-EC/RCA4 climate model combination. The colours show the wind speed (m/s).

Figure 8 shows the raw index values in terms of a hazard scale (1=low, 2=medium, 3=high). The hazard scale for the baseline period (1971-2000) is defined in terciles with the lower (upper) tercile corresponding to a low (high) hazard level. In this case, the values of these terciles are 10.6 m/s and 12.3 m/s, respectively. The hazard scale for the three future periods is defined as the fractional change from the baseline period (result of the future period divided by the result of the baseline period) and the spatial distribution sorted into terciles. The values of the lower and upper terciles correspond to the RCP4.5 scenario and have values of 0.98 and 1.00, respectively which correspond to a small reduction in the maximum daily wind speed. According to this definition, large parts of western Europe, northeastern Sweden, and the Balkan area can expect to experience a medium to high hazard level regardless of emissions scenario.

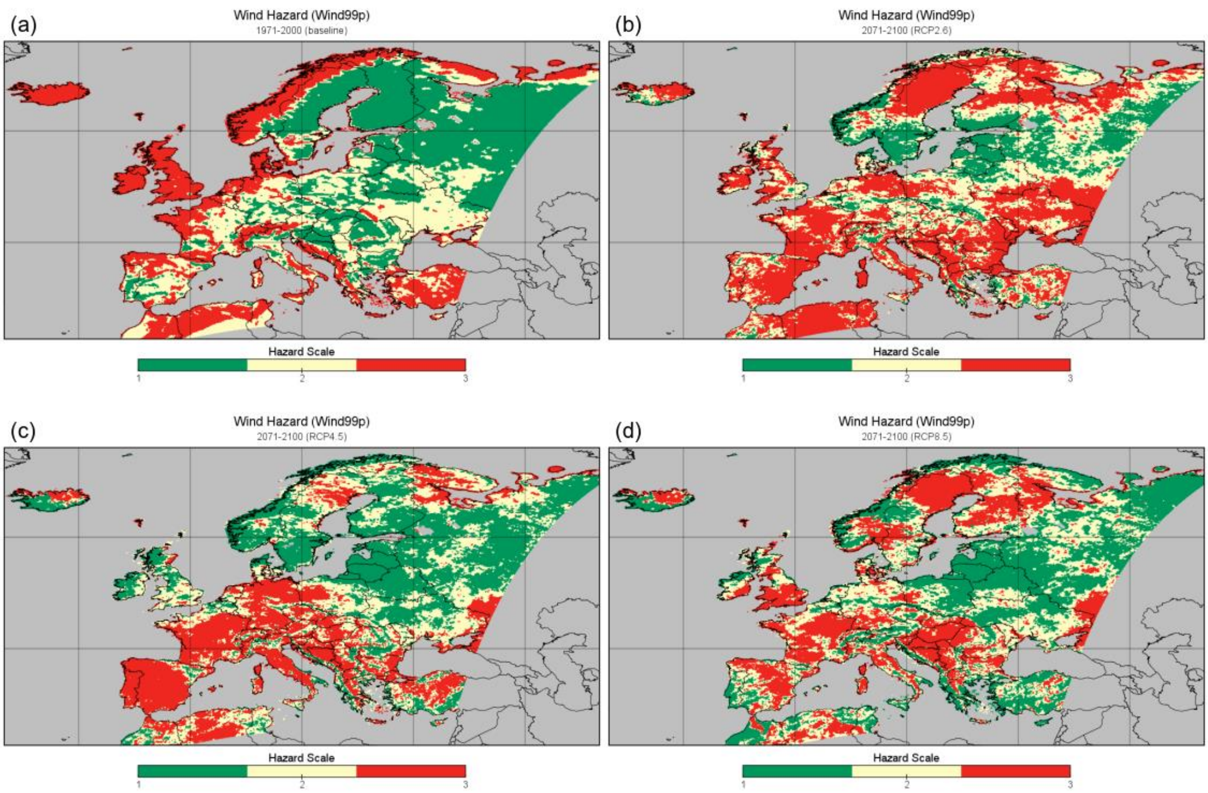


Figure 8: As in **Figure 7** but showing a representation for the hazard maps of the wind index Wind99p. The hazard levels 1=low (green), 2=medium (yellow), and 3=high (red) are defined within the text.

2.1.5 Droughts

Droughts will be characterised using the index CDD (see **Table 3** for definitions).

Figure 9 shows a measure for droughts in the form of the consecutive dry day index CDD. This is defined as the longest period of consecutive days in which the precipitation for each day is less than 1 mm (units days). Panel (a) shows CDD for the baseline period 1971-2000, and the values for the three emissions scenarios RCP2.6, 4.5, and 8.5 for the future period 2071-2100 are shown in the panels (b), (c), and (d), respectively. The most prominent features of the future scenarios of **Figure 9** are the long dry periods in the Mediterranean region and the shorter periods for central and northern Europe.

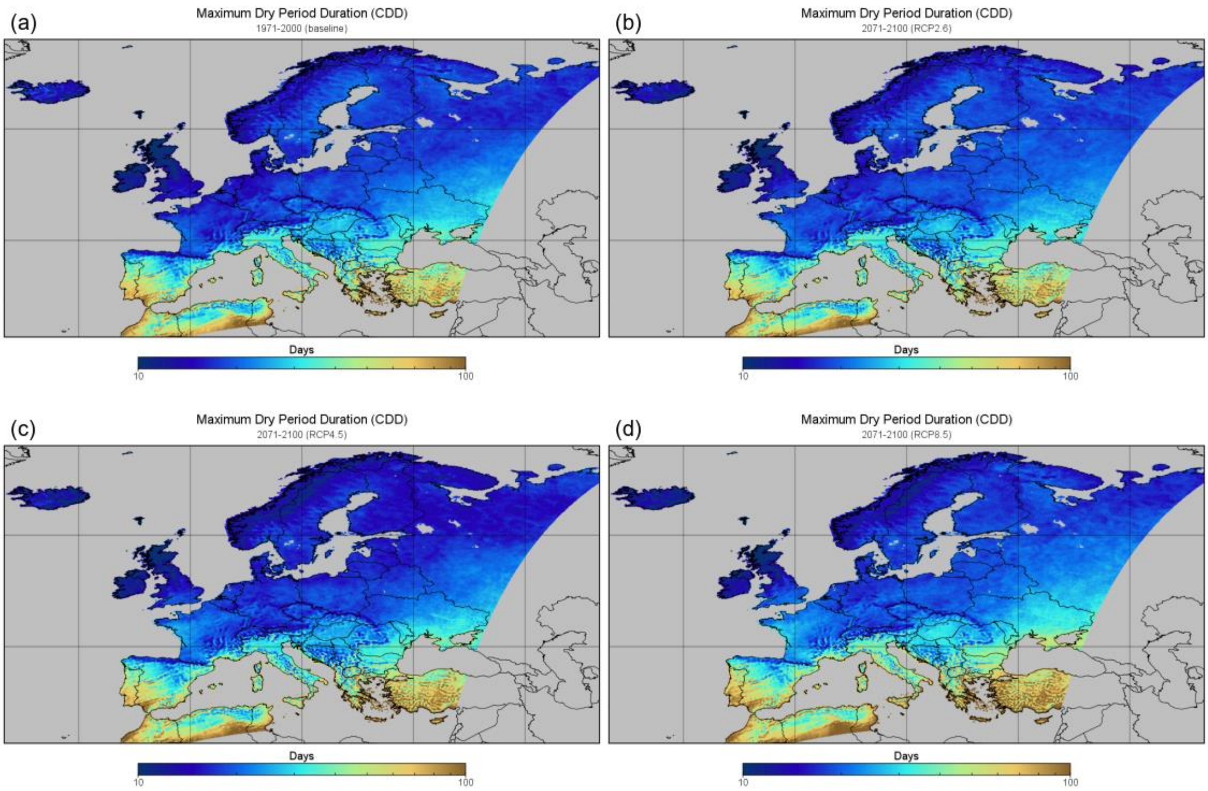


Figure 9: Drought index CDD for (a) the baseline period (1971-2000) and the three emissions scenarios (b) RCP2.6, (c) RCP4.5, and (d) RCP8.5 for the future period 2071-2100 for the SMHI/ICHEC-EARTH-EC/RCA4 climate model combination. The colours show the period length in days on a logarithmic scale.

Figure 10 shows a representation of the raw index values in terms of a hazard scale (1=low, 2=medium, 3=high). The hazard scale for the baseline period (1971-2000) is defined in terciles with the lower (upper) tercile corresponding to a low (high) hazard level. In this case, the values of these terciles are 18.0 and 26.4 days, respectively. The hazard scale for the three future periods is defined as the fractional change from the baseline period (result of the future period divided by the result of the baseline period) and the spatial distribution sorted into terciles. The values of the lower and upper terciles correspond to the RCP4.5 scenario and have values of 0.93 and 1.02, respectively. According to this definition, much of France and southern England consistently exhibit a high drought hazard level regardless of the emissions scenario.

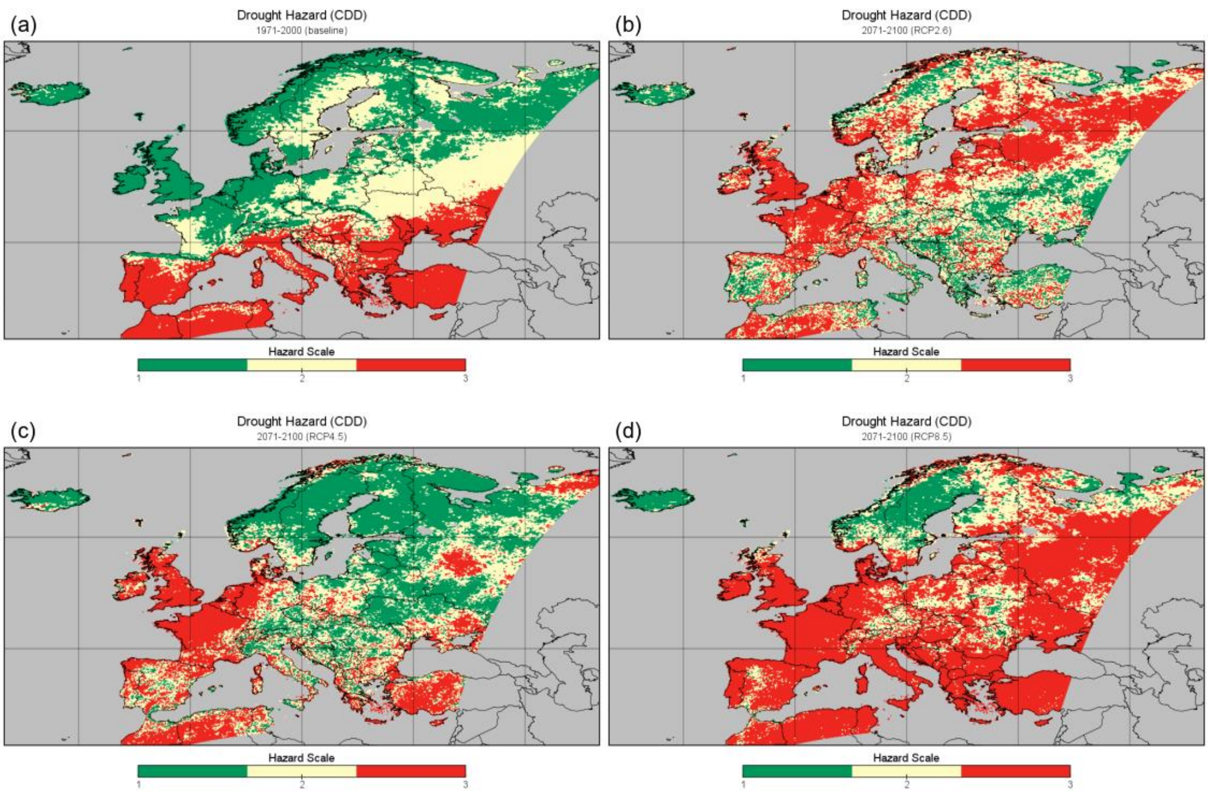


Figure 10: As in **Figure 9** but showing a possible representation for the hazard maps of the drought index CDD. The hazard levels 1=low (green), 2=medium (yellow), and 3=high (red) are defined within the text.

2.1.6 Forest fires

Forest fires are represented by the index FWI. The six components of the FWI (see **Table 3**) System for the effects of meteorological conditions and fuel moisture on fire behaviour [3] have been computed:

1) Fine Fuel Moisture Code (FFMC) – temperature, relative humidity, wind and rain.
2) Duff Moisture Code (DMC) – temperature, relative humidity and rain.
3) Drought Code (DC) – temperature and rain.
4) Initial Spread Index (ISI) – FFMC and wind
5) Buildup Index (BUI) – DMC and DC
6) Fire Weather Index (FWI) – ISI and BUI

The first three components are numeric ratings of the average moisture content of the 1) litter and other fine fuels, 2) loosely compacted organic layers of moderate depth, and 3) deep, compact organic layers. High values indicate dry fuels. Only the DC is capable of carrying over fall moisture conditions into the spring.

The last three components represent, 4) the rate of fire spread, 5) the fuel available for combustion, and 6) the frontal fire intensity. The values of these components rise as the fire danger increases.

The Daily Severity Rating (DSR) and its time-averaged value, the Seasonal Severity Rating (SSR), are extensions of the FWI System. The DSR is a transformation of the daily FWI value, calculated as follows:

$DSR = 0.0272\ (FWI)^{1.77}$

The DSR can be accumulated over time as the cumulative DSR, or it may be averaged over time as the SSR:

$$SSR = \sum_{i=1}^{n} \frac{DSR_i}{n}$$

where n is the total number of days, and DSR_i is the DSR value for day i.

For this study, fire weather severity was evaluated by comparing the projected monthly SSR over the 21st century against the hindcast SSR obtained with the corresponding model historical run. Not all the models listed before have been used for FWI and SSR analysis because relative humidity was not available for them all. The list of models used is offered below:

CNRM-CERFACS-CNRM-CM5	ALADIN53	rcp45, rcp85, HISTORICAL
DMI.NCC-NorESM1-M	HIRHAM5	rcp45, rcp85, HISTORICAL
KNMI.MOHC-HadGEM2-ES	RACMO22E	rcp45, rcp85, HISTORICAL
KNMI.ICHEC-EC-EARTH	RACMO22E	rcp45, rcp85, HISTORICAL
SMHI.CNRM-CERFACS-CNRM-CM5	RCA4	rcp45, rcp85, HISTORICAL
SMHI.IPSL-IPSL-CM5A-MR	RCA4	rcp45, rcp85, HISTORICAL
SMHI.MOHC-HadGEM2-ES	RCA4	rcp45, rcp85, HISTORICAL
SMHI.MPI-M-MPI-ESM-LR	RCA4	rcp45, rcp85, HISTORICAL
SMHI.IPSL-IPSL-CM5A-MR	RCA4	rcp45, rcp85, HISTORICAL
CNRM-CERFACS-CNRM-CM5	ALADIN53	rcp45, rcp85, HISTORICAL
DMI.NCC-NorESM1-M	HIRHAM5	rcp45, rcp85, HISTORICAL

At this moment the daily values of each of the indices have already been calculated and statistics are being obtained for the:

- 90th percentile of the FWI for periods of 20 years centred on the years of the different RCPs for each season.
- 90th percentile of the seasonal SSR for periods of 20 years centred on the years of the different RCPs.

2.1.7 Landslides

Landslides are represented by the Landslide Susceptibility index. This data has been downloaded from the European Soil Data Center (ESDAC[9]). This data accounts for actual landslide susceptibility but does not contain information about future trends.

In order to estimate the impact of climate change on this hazard, it is necessary to combine the exposure obtained from the aforementioned map with indicators of possible triggering effects such as maximum rainfall intensities in 1 or 5 days, already obtained as indexes associated with floods.

[9] https://esdac.jrc.ec.europa

2.2 Local Data versus Local Effect

Global climate models (GCMs) are commonly recognized as the best tools for estimating future global climate changes, even if the spatial resolution of their outcomes is currently in the range of 150–300 km, too coarse to analyse the impacts of climate change at urban scale. Therefore, there is a need to provide information on finer spatial scales through the application of downscaling techniques, generally divided into dynamical and statistical approaches [4]. In the first case (dynamical), a high-resolution regional climate model (RCM) is forced by GCM outputs; while, in the latter case (statistical), an empirical relationship is established between local features and large scale atmospheric variables, which GCMs can deftly simulate [5]. The resolution of outcomes produced by both approaches (10–50 km) is still not enough to describe the great complexity of the outdoor environment, in terms of variability, in space and time, and to analyse its influence on the elements at risks taken according to the considered hazard: heat wave and flooding. Therefore, an additional step, suitable for integrating the environmental information and for assessing the local effect, is required.

Regarding the heat wave hazard, the local effect can be evaluated through the application of various biometeorological indices, introduced and developed in order to take into account the effect of urban geometry, shadow patterns generated by trees and buildings, thermal and radiative properties of the surrounding surface materials, such as albedo, emissivity, and heat capacity on thermal comfort ([6] [7] [8] [9] [10]). Such indices include Apparent Temperature, Physiological Equivalent Temperature (PET), Universal Thermal Climate Index (UTCI), Wet Bulb Globe Temperature (WBGT; [11] [12] [13] [14]). However, those indices depend on a high number of variables, not available at a pan-European level and, in addition, are not directly connected with the environment. For those reasons, the Mean Radiant Temperature (Tmrt), widely adopted for urban thermal comfort studies thanks to its ability to connect human energy balance, thermal comfort (heat load) and environment features, was preferred ([6] [13] [14]). Moreover, [15] demonstrated that Tmrt is more suitable for analysing the impact of extreme weather conditions on people's well-being compared to air temperature or apparent temperature since it is strongly affected by urban morphology and vegetation. Therefore, it is able to more accurately detect risk areas where adaptation and mitigation options to reduce heat stress are necessary [4]. Tmrt can be estimated through several methods, such as two-sphere radiometers, globe thermometers, constant-air-temperature sensors [16] or numerical modelling ([7] [17]), even if model geometry and ambient conditions are often simplified. Considering the impossibility to directly measure the Tmrt at pan-European level, the last approach was preferred, and, consequently, a numerical modelling algorithm, based on that one proposed by [18], was developed (see section 2.2.1). That algorithm shows some weaknesses because it does not consider the influence anthropogenic activities (i.e. traffic, air conditioners, etc.) or meteorological information related to humidity and wind, and, in addition, is strongly affected by input layers accuracy. Nevertheless, it shows some crucial advantages, such as the possibility to estimate Tmrt at the European scale while drastically reducing the operational time. Its feasibility will be tested in the future validation phase, comparing its outcomes with the products generated from the commonly used software at local scale.

Regarding the flooding, several models have been developed since the 1970s to assess flood risk, ([21] [22]), flood damage ([23] [24]), real-time flood forecasting [25], and catchment hydrology ([26] [27]). For those reasons, a proper flood model can be selected, not just by considering the goal to be achieved but by taking into account also the output variables of predictive interest, their time and space scales, the level of accuracy required, and computational efficiency demands [28]. In particular, flood prediction applications may require considerations related to the operational time of implementation and real-time data assimilation. Consequently, even if in urban areas the accuracy of flood representation is essential, in order to have its prediction at the European level, the adequate model to be implemented has been chosen balancing complexity, run time, and available data, without forgetting urban geometry and features. Indeed, impervious materials which are characterized by reduced infiltration properties, covers much of the urban land surface: those conditions present accelerated runoff which causes flooding, and is also affected by the complexities in drainage infrastructure. Therefore, urban flooding is commonly described using a ‘‘dual drainage” approach, based on two components: a surface system (e.g., streets, channels), and a subsurface storm sewer network ([29] [30] [31]). Considering the lack of information related to subsurface storm sewer network at the European level, only a first component has been considered here. This involves applying two different approaches: empirical methods such as measurements, surveys, remote sensing, and hydrodynamic models, further grouped in one-dimensional (1D) (e.g. [32] [19]), two-dimensional (2D) (e.g. [20] [35]) and three-dimensional (3D) methodologies (e.g. [36] [37]). Although the 3D code provides better approximations, the operational time is too high and, therefore, it is not a viable option for study area bigger than 1 km. Conversely, 1D code is computationally efficient, but it is not able to simulate lateral diffusion of flood, to detect cross section location and orientation. These issues can be overcome using the 2D algorithms [38]. A 2D algorithm, chosen to estimate flood at European level, has been implemented using the base layers, basins and streams, provided by Copernicus and USGS –HydroSHEDS, to decrease the operational time and to exploit the data provided at a European level. The most important parameters to estimate the flood are: the time of concentration, flow velocity and flood depth. As discussed in section 2.2.2, the concentration time was computed using the Giandotti formula because it is relatively easy to implement. It is computed by taking into account only the morphological features of the basin, available at pan-European scale, and it can be applied for basins characterized by an area bigger than 100 km^2. The flow velocity, instead, has been computed using the simplified version of Manning equations. The flood depth has been computed by applying the travel-time method, a deterministic approach suitable for converting runoff into flow. The deterministic methodology has been preferred to the stochastic one since it is able to reduce the computational time [39]. The proposed approach is suitable for generating a physically-based estimation related to the urban flood at European scale within reasonable time. Nevertheless, it is strongly affected from the accuracy and resolution of input data and from the simplification introduced because of the lack of sufficient data.

The robustness of the proposed methods cannot as yet be quantified, as it will rely on them being implemented and their results validated. That is, these methods are at the “proof of concept” stage and the aim here is to demonstrate whether such methods i) produce physically realistic results, and ii) can be implemented in a tractable manner.

2.2.1 Heat wave local effect at screening level

The changes in urban microclimate that impact on people’s health and well-being, affecting their thermal comfort, depends on the combination of several factors, such as mean radian temperature (T_{rmt}), humidity and wind conditions. This combination can be described by several indices, such as the PET (Physiologically Equivalent Temperature) or PMV (Predicted Mean Vote). In the context of CLARITY “heat wave local effect” model, it has been made the choice of adopting the mean radiant temperature (T_{mrt}) as a proxy of perceived temperature, assuming that in heat wave conditions the presence of wind can be neglected, so to simplify the calculation procedure while preserving the reliability of the indicator adopted.

T_{mrt} is defined as the “uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual non uniform enclosure” [11].

Although several methods can be applied for computing T_{rmt}, as explained by VDI, (1994) [12] the most accurate approach involves the sum of all shortwave and longwave radiation fluxes (upward, downward and from the four cardinal points) to which the human body is exposed, multiplied for angular factors and human features, such as its emissivity. Therefore, T_{rmt} has been computed using the Stefan-Boltzmann law (equation 1):

$$T_{mrt} = \sqrt[4]{\left(\frac{R}{\varepsilon_p * \sigma}\right)} - 273.15 \qquad (1)$$

where σ is the Stefan-Boltzmann constant (5.67 × 10^{-8} Wm^{-2}K), ε_p is the emissivity of the human body, which standard value is 0.97 and R is the mean radiant flux density, computed through the equation 2 [12]:

$$R = \xi_k * \sum_1^6 K_i \times F_i + \varepsilon_p \times \sum_1^6 L_i \times F_i \quad (2)$$

where is ξ_k the absorption coefficient for shortwave radiation, which standard value is 0.7, K_i and L_i are the short and longwave radiation fluxes, respectively, and F_i are the angular factors between person and the surrounding surfaces. Considering the parameters related to a walking or standard person F_i have been set to 0.22 for the radiation fluxes from the four cardinal points and 0.06 for the fluxes above and below.

The incoming shortwave radiation has been modelled using equation 3:

$$K_{in} = \{I\times[S_b - (1 - S_v)\times(1 - \tau)]\times\sin(\eta)\} + \{D\times [\psi_b - (1 - \psi_v)\times(1 - \tau)]\} + \{G\times\alpha\times 0.5\times[1 - [(\psi_b - (1 - \psi_v)(1 - \tau)]\} \quad (3)$$

where I, D and G are the direct, diffuse and global shortwave radiation, respectively. Assuming to be in clear sky conditions and in order to reduce as much as possible the computational time, I and D have been set equal to 90% and 10% of the global radiation, respectively. ψ is the sky view factor, set according to the urban fabric, and S_b and S_v are the Boolean value that indicates the presence (0) or the absence (1) of building and vegetation shadow, respectively, α is the albedo and η is the sun's altitude angle above the horizon. In order to take into account the worst conditions of shading, η has been computed on the 21th of June, since in that date the shading is lowest possible. Average values for each land use category hav been used for evaluating the albedo.

The outgoing shortwave radiation (K_{out}) and the radiation from the four cardinal points have been assessed using equation 4 and 5, respectively:

$$K_{out} = K_{in} * \alpha \quad (4)$$

$$K_l = \{I\times[S_b - (1 - S_v)\times(1 - \tau)]\times\sin(\eta)\times \cos(\theta)\} + \{D\times [\psi_b - (1 - \psi_v)\times(1 - \tau)]\} + \{G\times\alpha\times 0.5\times[1 - [(\psi_b - (1 - \psi_v)(1 - \tau)] \quad (5)$$

where θ is the sun's azimuth angle. As anticipated for the sun's altitude angle above the horizon, also θ has been calculated on the 21th of June, in order to take into account the worst conditions of shading.

On the contrary, the incoming (L_{in}) and reflected (L_{out}) longwave radiation for each of four cardinal points (L_l) have been computed using equation 6 and 7, while the longwave radiation has been computed using equation 8:

$$L_{in} = (\psi_b + \psi_v - 1)\times \varepsilon_{sky}\times\sigma\times T_a^4 + (2 - \psi_v - \psi_b)\times\sigma\times T_a^4\times\varepsilon_{wall} + (\psi_v - \psi_b)\times \sigma\times T_s^4 * \varepsilon_{wall} + (2 - \psi_b - \psi_v)\times(1 - \varepsilon_{wall})\times\sigma\times T_a^4\times \varepsilon_{sky} \quad (6)$$

$$L_{out} = \varepsilon_s * \sigma * (T_s + (T_s - T_a))^4 \quad (7)$$

$$L_l = L_{out} * 0.5 \quad (8)$$

where ε_s, ε_{wall} and ε_{sky} are the surface, wall and sky emissivity, respectively; while T_a and T_s are the air and surface temperature, respectively.

Subsequently, the described model will be implemented weighting the mean radiant temperature on a grid with a resolution of 500 × 500 m, in order to obtain a reliable result at European level that will be investigated more in depth with future simulation at expert level.

The accuracy of that approach will be evaluated comparing its result with that generated at the expert level in the Demo Case of Naples (DC1). A calibration of the parameters used in the model will then be performed following the comparison on sample areas across the DCs.

2.2.2 Urban pluvial flooding local effect at screening level

Pluvial flooding refers to flooding caused by either intense or/and prolonged rainfall which generates a runoff volume greater than the capacity of existing drainage system. This phenomenon predominately occurs in urban areas, inducing extensive damages, and, from here the name "Urban Pluvial Flooding". Although the general definition of Urban Pluvial Flooding is pretty clear, there is still an open debate regarding its particular characteristics and how it relates to other types of flooding, such as surface water, minor watercourses and sewer flooding. Currently, it can be defined only referring to direct runoff flow before it enters a natural or man-made drainage system or water course Defra, (2010), Parker et al., (2011) and European Environment Agency (2016) [21] [43] [22], or as proposed by Smith et al. (2013) [45], Pitt (2008) [46] by considering, in addition to direct runoff, floodwater coming from surcharged sewers and/or urban minor watercourses the flow capacity of which has been exceeded as a result of heavy rainfall. Although the second definition is more accurate, it is much too broad and complex to be implemented at the European level and, for that reason, in this context, we only refer to the direct runoff flow, as a proxy for the ability of urban areas to absorb and/or divert rainwater during extreme precipitation events.

Runoff flow modelling aims to evaluate which part of the total rainfall amount is converted to flow over the urban surface. Therefore, soil type and land use/land cover acquire an essential role in all the possible models that could be applied.

In order to reduce the operational time and to exploit the data provided at a European level, basins and streams provided by Copernicus and USGS –HydroSHEDS have been applied. They were used as input for the Rational method (equation 1), developed in United States by Emil Kuichling in 1889. It was adopted since it is a simplified approach able to model the run-off in both urban and rural watersheds [40] [47]

$$Q = \frac{C \times F_t \times A_b \times h}{\frac{4 \times \sqrt{A_b} + 1.5 \times L \times 60}{0.8 \times \sqrt{z}}} \qquad (9)$$

In equation 9, Q is the peak discharge, A_b is the area of the basin, L is the length of the flow accumulation steams, h is rain intensity, z is the difference between the maximum and the minimum altitude of the flow direction steams, C is the runoff coefficient and F_t is a FUA tunnel coefficient. This latter parameter has been added to the original equation to consider the "channeling" effect occurring in urban areas in presence of narrow streets surrounded by buildings or other "hard" barriers. The concentration time was estimated through the equation proposed by Giandotti [41].

The runoff coefficient, C, is a key parameter for the rational method since it is able to convert the rainfall amounts to runoff. Although it can be estimated through various methods, it has been set according to the values reported, for each land use class, in the German DIN 4095.

2.3 Data Packages

In order to provide consistent climate analyses, the data which is on offer to the user will be presented in the form of a data package. That is, a data package will consist of a i) climate index which characterises a hazard (e.g. number of heat waves), ii) an additional local dataset (if available) or an algorithm to downscale the coarse data, and iii) a vulnerability curve to link the effect of the hazard on an exposure element which is of interest to the user. The idea behind this, is that the vulnerability function which links the hazard and element of exposure to the impact is often defined according to a specific climate hazard index and exposure dataset. This means that the vulnerability function can only produce physically realistic results when it uses as input, in this case, the number of heat waves and population in order to determine how many additional deaths would be expected.

An additional element of the data packages is that supplementary high-resolution data can be included where it is available. An example would be if, a user is interested in a particular city, and coincidently a high-resolution building dataset exists for this city which is freely available, then this would be included in this data set and subsequently used for the risk and impact analysis.

2.3.1 Data package for road transport

Specific data that could be on offer to a road infrastructure manager is also presented in the form of a data package. Such a data package has been developed for Spain under DC4 and consists of i) a set of specific indexes to characterise CC hazards suited for road infrastructure management, ii) an ad hoc methodology to assess CC risk in road projects, and iii) a collection of adaptation options that may potentially reduce the impact of CC on elements at risk in road projects. The need for an ad hoc methodology appears because of the lack of vulnerability curves to link the effect of CC hazards on road elements for all Europe, plus the fact that in CSIS for urban infrastructure all elements at risk of a certain type in a certain area are specified in terms of density (resulting in a per element at risk exposure raster map) whilst in transport infrastructure it's convenient to consider elements at risk individually.

2.4 Evaluation of Exposure

Once the hazard has been detected and the local effect has been characterized, the elements at risk (e.g. population, buildings, infrastructure, etc.) and, consequently, their exposure to the climatic risks can be evaluated. The term Exposure (E) applies to the space-time distribution of the elements at risk, previously classified according to their response to danger. These categories, called "vulnerability classes", have been extrapolated on the basis of specific characteristics, such as age (for population), structural-typology (for buildings), and so forth, able to underline the different behaviour of the elements exposed to the risks (**Table 9**).

Table 9: Elements at risk for each investigated hazard

Hazards	Element at risk	Classes	Unit
HW	**Population**	Age group 0-14	pop./km^2
		Age group 15-64	pop./km^2
		Age group >65	pop./km^2
FL	**Buildings**	Continuous Residential	m^3/m^2
		Med-Hi Density Discontinuous Res.	m^3/m^2
		Low Density Discontinuous Res.	m^3/m^2
		Non Residential	m^3/m^2
FL	**Infrastructure**	Roads	ml / m^2
		Railways	ml / m^2

Both the basic and the future exposure are taken into account: the former involves the quantification of the current distribution of the elements at risk in the area under investigation; the latter entails the planned distribution of elements at risk in the future. Therefore, the "Baseline Exposure" is computed separately for each exposed element by mixing the available data, e.g. population distribution, land use and land cover. On the contrary, the "Future Exposure" usually corresponds to the planned project and the expected distribution of the elements at risk must be provided by the user or by an expert working on their behalf. In order to take into account ethical and technical issues, all the elements at risk belonging to a specific category in a certain area will be grouped together, resulting in an element for each risk exposure map. Therefore, these groups have been assigned to some vulnerability classes, subsequently, discretized on the reference grid with a resolution of 500 × 500 m, in order to generate, for each cell, a geo-database characterized by the amount of population and buildings/roads data (m^2) for the heat wave and pluvial flooding, respectively.

Thus, the final result of this step is an inventory database composed by the distribution of the amount of population, in the case of heat wave, and buildings and roads, in case of pluvial flooding, for each vulnerability class and each grid cell in the study area.

The “Baseline Exposure” related to the element at risk, population, for the area of Naples is shown in **Figure 11**, while a detail of the contents of each cell is reported in **Figure 12**.

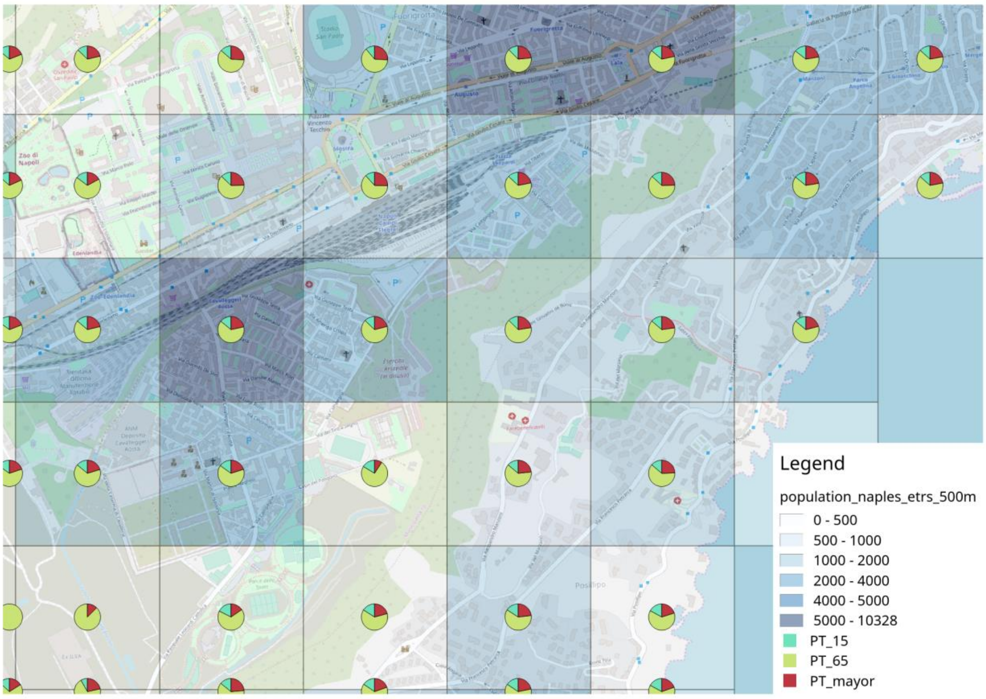


Figure 11: Example of population exposure and vulnerability classes.

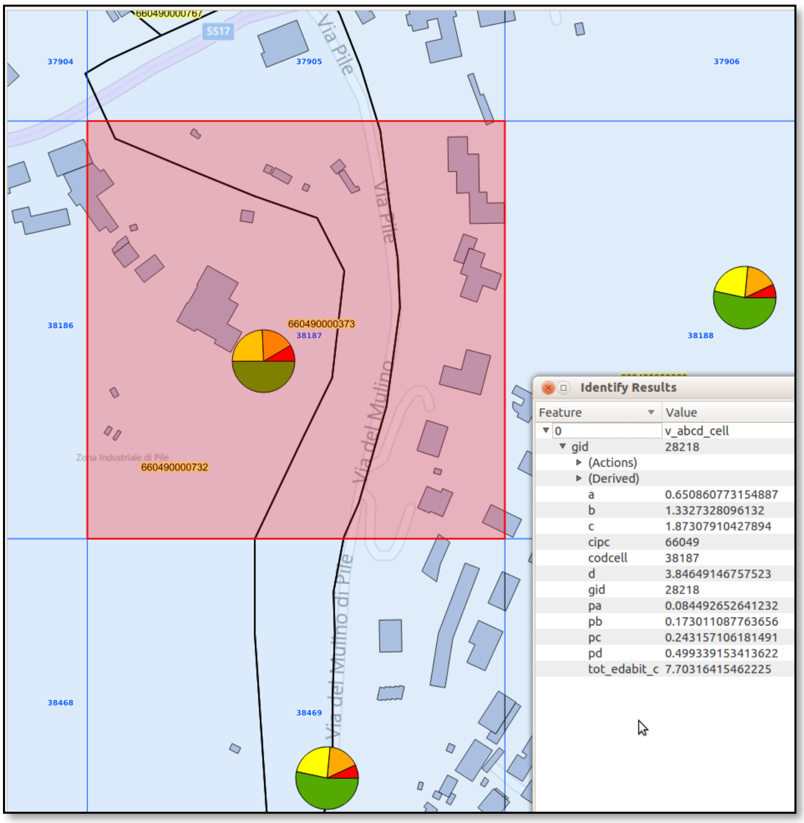


Figure 12: Details of population exposure distribution on a grid of 500 x 500 m.

2.5 Vulnerability Analysis

Once the local effect matrix has been characterised, the vulnerability classes and the corresponding vulnerability functions for each element at risk to climate may be evaluated. The vulnerability is defined as the probability that an element at risk, belonging a vulnerability class, experiences a level of damage, according a predefined damage scale, as a response to a hazard event of given intensity.

As an initial step, the vulnerability classes for the element at risk have been defined both for heat wave and pluvial flooding. For instance, population as a risk element in the case of heat waves, has been distinguished by age in three classes (under 14, 15 – 64 and over 65), spatially distributed on each cell of the grid and, then, ordered according to their ability to be damaged by the hazard from A to C (A: over 65; B: under 14; C: 15 – 64). In addition to population exposure, **Figure 11** and **Figure 12** show also the distribution of vulnerability classes for each cell. On the contrary, in the context of pluvial flooding, buildings and roads are classified according to their geographically location: Historical centre (HS), Suburb (S), Countryside (C).

Simultaneously, different levels of damage have been detected for each element at risk. An example of damages classification, that can affect people health in case of heat wave, is reported in **Table 10**.

Table 10: People damage classification.

Level of damage	Description
D0	No damage
D1	Fatigue, discomfort
D2	Heat cramps, heat exhaustion
D3	Heat cramps, heatstroke
D4	Heatstroke, sunstroke
D5	Death

A similar classification has been carried out also for the elements at risk in the case of pluvial flooding. In that context, two typologies of damages have been taken into account: direct and indirect cost. The former is related to the restoration cost, while the latter is due to the loss of production. Five levels of damages have been identified for both typologies. Therefore, the vulnerability is expressed in term of a vulnerability matrix that indicates the percentage of a certain type of element at risk belongs to each vulnerability class for the investigated local effect in the considered area. **Table 11** reports an example of such a matrix for a generic element at risk category, while **Table 12** and **Table 13** specify that vulnerability matrix for people and buildings (roads) for heat wave and pluvial flooding, respectively.

Table 11: Example of a vulnerability matrix of a specific vulnerability class of a given element at risk under effect of a specific hazard.

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%	...

Table 12: Vulnerability classes example definition: f(age,T) (i.e. D5).

TYPE	DESCRIPTION	Mortality rate (36°C) (prob. 50%)	Mortality rate (36°C) (prob 95%)
A_p	Age group >65	10	15
B_p	Age group 0-14	15	20
C_p	Age group 15-64	20	25

Table 13: Vulnerability classes example definition: f(D,Q). Hs: Historical Centre; S: Suburb, C: Countryside. DD: Direct Damage, ID: Indirect Damage.

mq	DD	ID
HC	€	€
S	€	€
C	€	€

Therefore, for all relevant element at risk types (e.g. low/medium/high/very high vulnerability classes for the element at risk "people", grouped by age in three classes: under 15, 14 - 64 and over 65), the vulnerability functions for each vulnerability class and hazard input have been defined (**Figure 13**). **Figure 14** shows the vulnerability curves in the case of pluvial flooding for the category Direct Damage (DD) on the basis of the hazard input. Indeed, for N defined classes of vulnerability, N graphs related to the vulnerability function exist, each with M damage probability functions for M classes of damage.

Once the vulnerability curves for the 4 pilot cases involved in the project have been detemined, the vulnerability functions will be adapted to all Europe by applying a latitude factor (**Figure 13**).

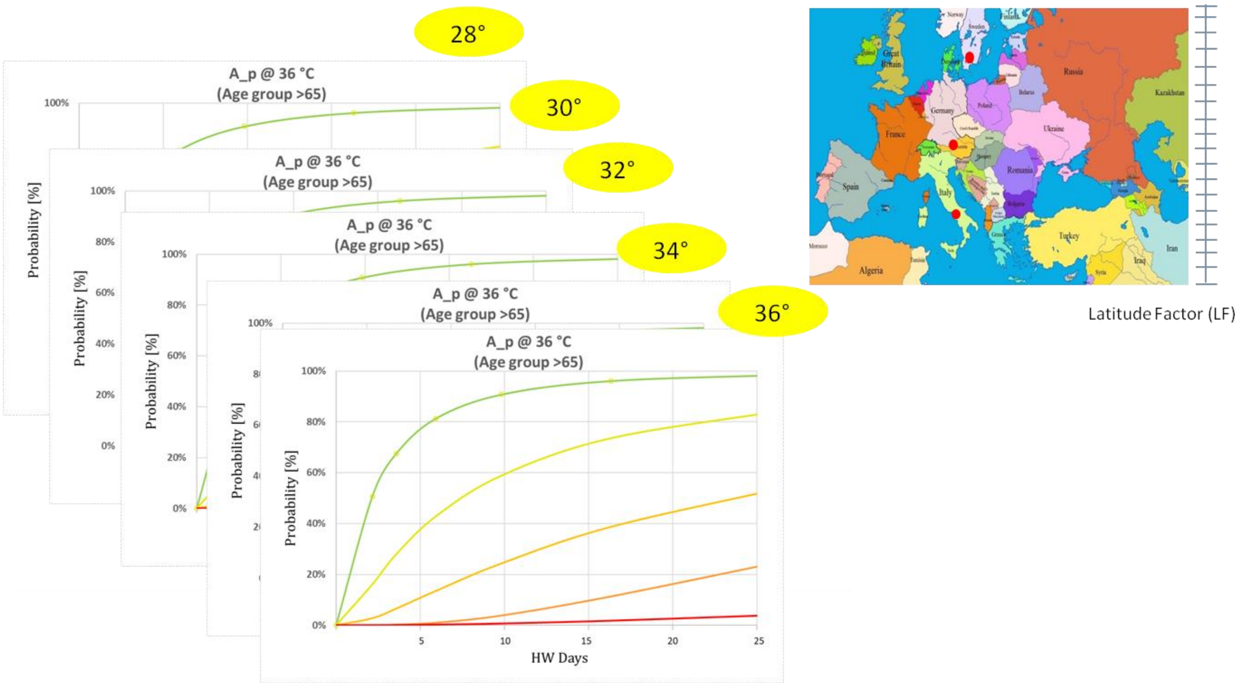


Figure 13: Damage probability functions and latitude factor (LF).

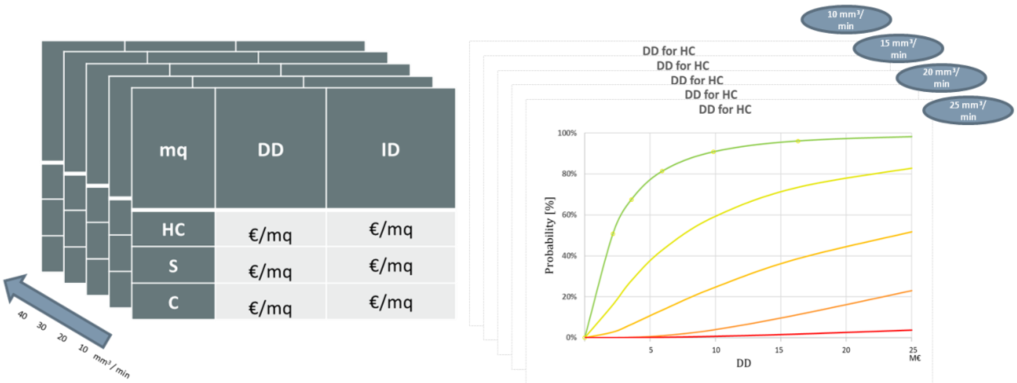


Figure 14: Vulnerability matrices according to pluvial flooding value and vulnerability curves for Direct damage (DD) class classified.

2.6 Impact Scenario Analysis

When one or more reference events are selected in a "deterministic" way, the corresponding "impact scenario analyses" shall be carried out by applying numerical impact models, suitable to provide detailed damage estimation on selected elements at risk as a result of specific events. Thus, the impact scenario analysis is intended to simulate 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, exposure and vulnerability characteristics to produce a detailed quantification of damage on elements at risk considered. The scenario impact evaluation is described by equation 10.

$$\text{Scenario}_{\text{l,i}} = \int_m E_m\left[(H_i)\cdot\left(V_{l,i,m}\right)\right] \quad (10)$$

The subscripts "i", "l" and "m" refer to the severity level of an event, to the "vulnerability classes" and to the "assigned damage level", respectively. Therefore, H_i is the probability of occurrence of an event characterized by a level of severity equal to "i" over a period of time and on a certain site; E_m is the percentage of elements for each vulnerability class "m" and $V_{l,i,m}$ is the probability of occurrence of an assigned damage level "l" following the event "i" for the particular vulnerability class "m" of elements at risk taken into account.

Basically, a table of numerical values, extracted by each vulnerability function, related to hazard and vulnerability class to damage level, is the basis of impact scenarios evaluation. An example related to heat waves is reported in **Table 14**. It shows, for each vulnerability class and for each duration of a given temperature, the occurrence of different levels of damages. This means that the number of tables is equal to the number of identified hazard events.

Table 14: Impact Matrix for each population vulnerability class at a given local effect temperature of 36 °C. Three vulnerability classes are shown as A, B, C; heat wave durations range from 5 to 12 days; five levels of damage classification (D0-D4) shown.

CLASS	HW	D0	D1	D2	D3	D4
A	5	0,663969	0,283354	0,04837	0,004128	0,000179
A	6	0,416681	0,398659	0,152567	0,029194	0,0029
A	7	0,202253	0,380885	0,286914	0,108064	0,021884
A	8	0,066991	0,240197	0,344494	0,247038	0,10128
A	9	0,009913	0,075153	0,227909	0,345576	0,34145
A	10	0,000685	0,011284	0,074333	0,244839	0,668859
A	11	5,51E-06	0,000283	0,005805	0,059602	0,934305
A	12	1,56E-11	1,12E-08	3,24E-06	0,000466	0,999531
CLASS	HW	D0	D1	D2	D3	D4
B	5	0,741371	0,228632	0,028203	0,00174	5,43E-05
B	6	0,561468	0,343526	0,084073	0,010288	0,000645
B	7	0,368274	0,407202	0,180098	0,039827	0,004598
B	8	0,202253	0,380885	0,286914	0,108064	0,021884
B	9	0,07962	0,262271	0,345571	0,227664	0,084874
B	10	0,01824	0,111938	0,274781	0,337261	0,257781
B	11	0,000843	0,013149	0,082031	0,255885	0,648093
B	12	2,03E-08	3,4E-06	0,000228	0,007665	0,992103
CLASS	HW	D0	D1	D2	D3	D4
C	5	0,823089	0,163408	0,012977	0,000515	1,03E-05
C	6	0,700381	0,258525	0,038171	0,002818	0,000106
C	7	0,561468	0,343526	0,084073	0,010288	0,000645
C	8	0,443703	0,391505	0,138179	0,024385	0,002228
C	9	0,32448	0,409584	0,206804	0,052209	0,006923
C	10	0,175317	0,365151	0,304215	0,126724	0,028593
C	11	0,025292	0,137388	0,298527	0,32433	0,214464
C	12	2,65E-07	2,6E-05	0,001025	0,020164	0,978785

Subsequently, the impact scenario, for a given hazard event and a selected level of damage, is generated by multiplying the probability of occurrence of each vulnerability class with the element of exposure and, finally, summing them together. **Table 15** shows an example for a given temperature of 36 °C with a duration of 7 days. In that case, selecting the level of damage D4, the impact scenario is obtained applying equation 11:

$$\text{Impact} = P_{A\_p} \times 0{,}021884 + P_{B\_p} \times 0.004598 + P_{C\_p} \times 0.000645 \quad (11)$$

where P_{A_p} , P_{B_p} and P_{C_p} are the number of people per vulnerability classes (A, B, C) in each cell.

Table 15: Impact scenarios evaluation for the duration of 7 days of the given temperature of 36 °C.

CLASS	HW	D0	D1	D2	D3	D4
A	5	0,663969	0,283354	0,04837	0,004128	0,000179
A	6	0,416681	0,398659	0,152567	0,029194	0,0029
A	7	0,202253	0,380885	0,286914	0,108064	0,021884
A	8	0,066991	0,240197	0,344494	0,247038	0,10128
A	9	0,009913	0,075153	0,227909	0,345576	0,34145
A	10	0,000685	0,011284	0,074333	0,244839	0,668859
A	11	5,51E-06	0,000283	0,005805	0,059602	0,934305
A	12	1,56E-11	1,12E-08	3,24E-06	0,000466	0,999531
CLASS	HW	D0	D1	D2	D3	D4
B	5	0,741371	0,228632	0,028203	0,00174	5,43E-05
B	6	0,561468	0,343526	0,084073	0,010288	0,000645
B	7	0,368274	0,407202	0,180098	0,039827	0,004598
B	8	0,202253	0,380885	0,286914	0,108064	0,021884
B	9	0,07962	0,262271	0,345571	0,227664	0,084874
B	10	0,01824	0,111938	0,274781	0,337261	0,257781
B	11	0,000843	0,013149	0,082031	0,255885	0,648093
B	12	2,03E-08	3,4E-06	0,000228	0,007665	0,992103
CLASS	HW	D0	D1	D2	D3	D4
C	5	0,823089	0,163408	0,012977	0,000515	1,03E-05
C	6	0,700381	0,258525	0,038171	0,002818	0,000106
C	7	0,561468	0,343526	0,084073	0,010288	0,000645
C	8	0,443703	0,391505	0,138179	0,024385	0,002228
C	9	0,32448	0,409584	0,206804	0,052209	0,006923
C	10	0,175317	0,365151	0,304215	0,126724	0,028593
C	11	0,025292	0,137388	0,298527	0,32433	0,214464
C	12	2,65E-07	2,6E-05	0,001025	0,020164	0,978785

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, since they enable a proper estimation of (human and financial) resources required for emergency management and resilience-based urban design and planning.

2.7 Adaptation Elements and their Economic Appraisal

The Risk Assessment and Impact Scenario Analysis is a crucial step since it provides a sound information base useful for selecting adaptation strategies to be adopted to tackle the local effect, and consequently, the hazards, identified in the first phase of modelling procedure. Therefore, adaptation options should be strongly connected to the impact model because they are able to reduce local effect intensity, decreasing the damages to which the elements at risk are subjected to, and to change the exposure, proposing a new geographic position of an element at risk towards a location with lower hazard intensity.

All the possible adaptation strategies have been identified taking into account the most recent literature [23] [24] and selected in consideration of the main hazards, in order to reduce the vulnerability and the local effect (for the complete list, see annex I). In particular, they have been listed and then grouped together into representative classes according to the local effect hazard that they affect. Subsequently, each strategy has been assessed in view of their ability to reduce local effect intensity and to modify the most relevant parameters descriptive of local effect, such as, for instance, albedo, emissivity and runoff coefficient., A cost-benefit analysis has been performed in terms of application field, through the assignment of qualitative parameters related to the costs both for new development and retrofitting in order to support the appraisal process for decision makers. Co-benefits relating to biodiversity, air quality, energy efficiency, social and economic importance and multifunctional space usage for each representative class were also identified. This is necessary for the cost-benefit analysis and will be used in the multi-criteria evaluation. Table 16 illustrates how the adaptation options catalogue in CLARITY will look like. This list also comprises the main adaptation options investigated in the demonstration cases: Increase in albedo of roofs, roof greening, increase in green infrastructure (street trees, parks) and unsealing of surfaces.

Table 16: Example of the proposed structure of adaptation options catalogue within Clarity.

ADAPTATION	TOWARDS WHICH HAZARD	VARIATION ON HAZARD'S LOCAL EFFECT	VARIATION ON VULNERABILITY OF ELEMENTS AT RISK	COST		CO-BENEFITS	Albedo (α)	Emissivity (εs)	Hillshade_green fraction (ψb)	Run-off coefficient (C)	FUA_tunnel (Ft)
				NEW DEVELOPMENT	RETROFITTING						
Porous pavements	Flooding	+++	+++	€	€	Biodiversity • Multifunctional space usage •	x	x		x	
Improve soil infiltration capacity	Flooding	+++	-	€	€	Biodiversity • Air quality • Multifunctional space usage •	x	x		x	
Adding green in streetscape	Flooding	++	-	€	€	Biodiversity •• Air quality • Energy efficency • Social and economic importance •••	x	x	x	x	
	Heat Wave	+++	-								
Use of groundcover and shrubbery	Flooding	+++	-	€€	€€	Biodiversity ••• Air quality •• Energy efficency • Social and economic importance •••	x	x	x	x	
	Heat Wave	+++	-								
Green roofs	Flooding	+++	+++	€€	€€	Biodiversity ••• Air quality • Energy efficency •• Social and economic importance ••	x	x		x	
	Heat Wave	+++	-								
Cool (reflective) roofs	Heat Wave	+++	-	€	€	Multifunctional space usage •	x	x			
Cool paving and building materials	Heat Wave	+++	-	€	€	Energy efficency • Multifunctional space usage •	x	x			

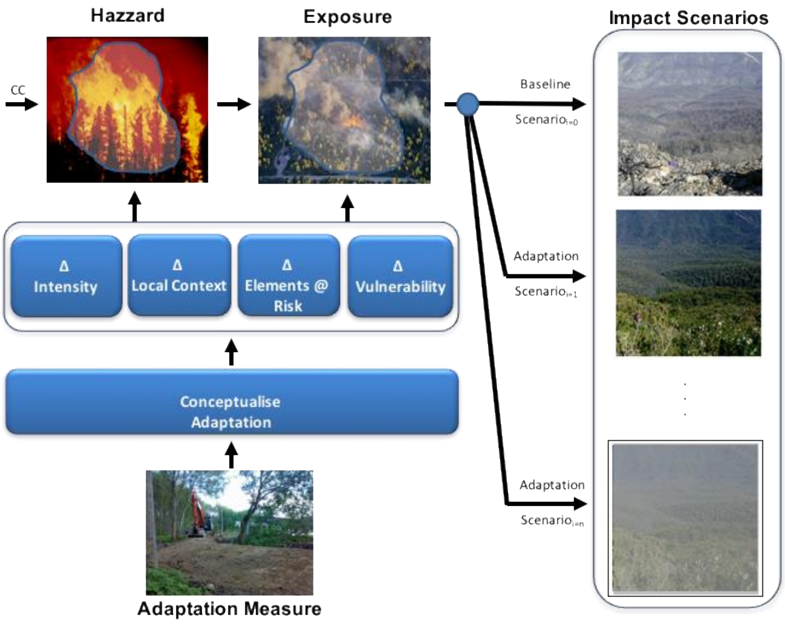


Figure 15: Conceptualisation of Adaptation Scenarios modelling.

The connection between a specific adaptation option and the Impact Model will be carried out through the collaboration of a group of experts belonging to the two application fields. Indeed, this connection allows one to implement the adaptation measures in local effect and exposure phases detection in order to create Adaptation scenarios, as illustrated in **Figure 15**.

In such way, the decision makers will have to choose among a complex set of scenarios, and, therefore, it will be very hard to identify the best option to be adopted. In order to reduce data complexity and to address user's choice, the main information related to adaptation strategies have been captured and aggregated in so called (key) performance indicators. This approach has been widely employed in several application fields [48]. These key indicators are able to quantify specific characteristics but not the overall performance of adaptation strategies and, consequently, they provide a too basic assessment for the user's choice. Therefore, Multi-Criteria Decision Analysis (MCDA) [49] offers a proper compromise to solve the problem.

This procedure can be schematised as follows (**Figure 16**):

1. Various Impact Scenarios generation (**Figure 16** #1);
2. Comparison of all the generated scenarios through synthetic indicators able to describe the scenarios to quickly assess and compare them (**Figure 16** #2-3);
3. Definition of a decision strategy by mapping performance indicators to decision criteria, by assigning weights to indicators in order to enhance the priorities, by assessing the level of "Andness" and "Orness" to be considered (**Figure 16** #4-5);
4. Application of the multi-criteria decision approach application in order to obtain a ranking of scenarios with respect to the selected decision strategy (**Figure 16** #6-7).

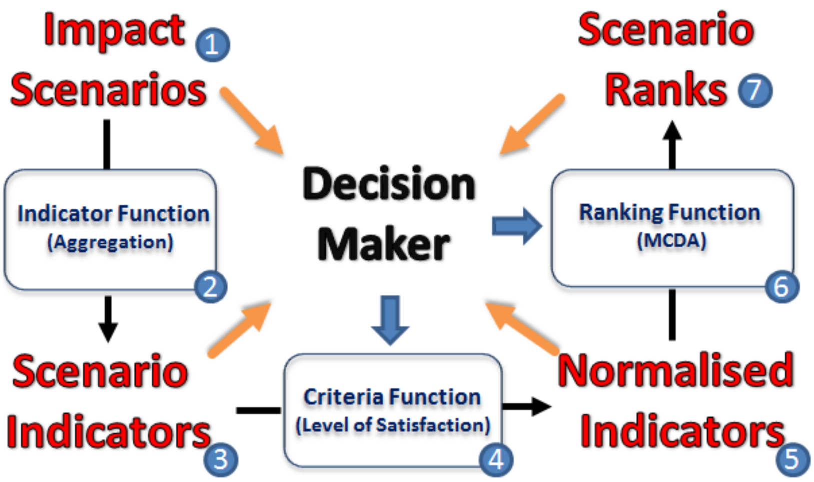


Figure 16: Conceptualisation of Decision Maker modelling.

The current work on the economic appraisal of the adaptation elements is being restricted to the demonstration cases, specifically DC1. Accordingly this work is described within Section 3.1.4. An explanation on how the results from the demonstration cases will be eventually upscaled to encompass all of Europe necessary for the ICT is also explained therein.

3 Expert Services

The work done on the demonstration cases is presented here.

While in deliverable D2.3 the work done in each demonstration case is described following the steps of the EU-GL methodology, the focus here is about the scientific background and the models/ tools used to get high resolution information at the local scale and to assess adaptation options. Tables at the beginning of each DC section provide an overview of the whole workflow in relation to the EU-GL methodology.

3.1 DC1

DC1 implementation aims to demonstrate the outcomes of CLARITY Expert Services in assessing the benefit of integrating adaptation measures in urban redevelopment/retrofitting projects, with a specific focus on heat waves, pluvial flooding and landslide hazards. The implications related to multi-risk conditions related to geophysical hazards, in particular earthquake and volcanic eruptions, will be considered at a later stage of the DC implementation, based on the previous studies already conducted on the Naples area by PLINIVS Study Centre, as centre of competence of the Italian Department of National Civil Protection.

The workflow of DC1 according to the EU-GL methodology described in D3.1 is summarized in Table 17.

Table 17: Overview of the workflow of DC1 and its relation to the EU-GL methodology.

Hazard Characterisation	**Element at risk**	**Vulnerability**	**Impact**	**Adaptation Options**
Heat waves	People	High for very young/old age groups	Excess heat mortality Productivity loss	Green roofs Air-conditioned public transport
Pluvial Flooding	Buildings Infrastructure	High for objects in poor drainage areas.	Damage Economic costs for repair / resource unavailability	Increased green areas
Landslides	Buildings Infrastructure	High for objects in mountainous/hilly terrains.	Damage Economic costs for repair / resource unavailability	Increased number of trees / green areas

As outlined in D3.1, the key objectives for the implementation are outlined by the DC1 "high-level" user stories:

- US-DC1-100 Climate Adaptive Planning;
- US-DC1-200 Adaptive Climate Design Guidelines and Construction Regulations.

The science support in this phase concerns the characterization of hazards at local scale, so to identify reference event(s) to be considered in the impact scenario analyses object of the Expert Service, in relation to which the opportunity of integrating adaptation measures in the urban infrastructure projects identified by the local end-user partner, the Municipality of Naples (see D2.2).

The study of the “local effect” determined by the feature of urbanized areas and geomorphology of the territory has implied the collection and transformation of relevant datasets used as input of MUKLIMO_3 model (heat waves), PLINIVS Flood simplified model (pluvial flooding) and PLINIVS Landslide model (**Figure 17**).

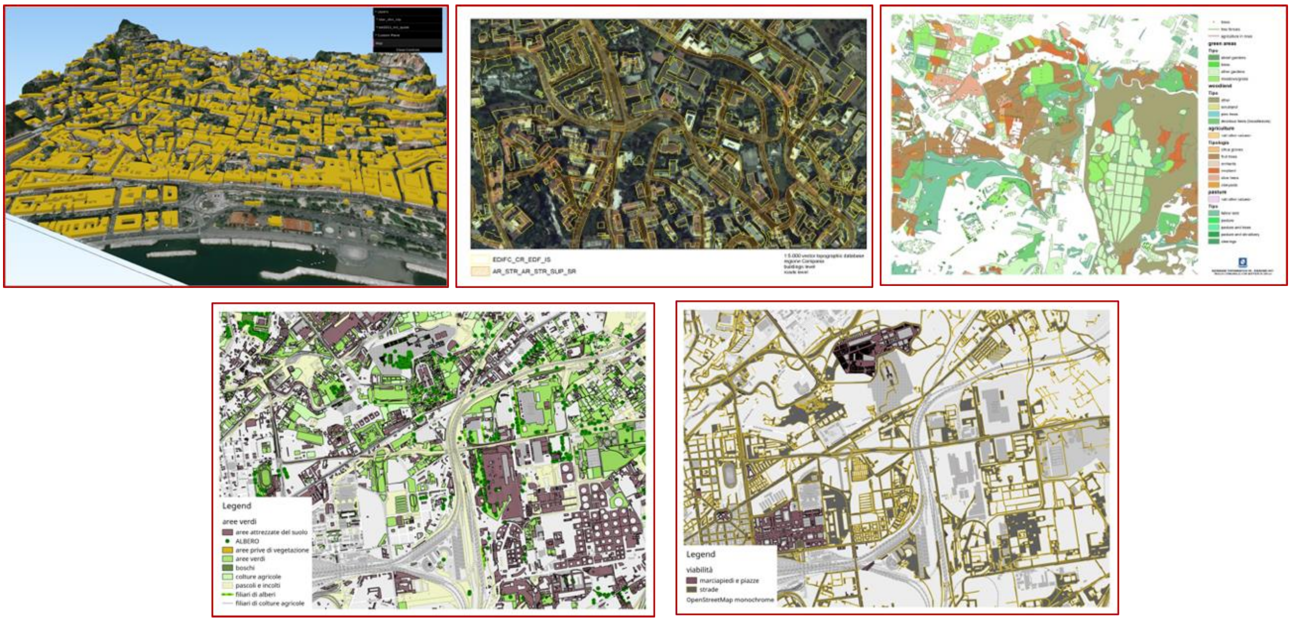


Figure 17: Example of data collected in Naples area used as input of the models applied to identify the “local effect” hazard conditions.

The following sections synthetically illustrate the work carried out in relation to the three identified hazards.

3.1.1 Heat Waves

To integrate the characteristics of the urban microclimate that strongly influence the risk conditions at the city level, it is necessary to downscale the high-resolution climate projections. While the impacts of climate change affect cities globally, adaptation measures must be identified and designed locally, as the specific conditions of settlement and microclimate – determined by the characteristics of the natural and built environment – play a crucial role in aggravating (or reducing) the intensity of extreme weather events. In this sense, a greater effort is dedicated to the integration of urban microclimate projections as a further refining phase of the traditional Global Climate Model (GCM-RCM) approach.

This method details the information derived from climate models such as EURO-CORDEX, which has a typical resolution of 10-12 km, thanks to the combination of high-resolution satellite data and specific site-specific meteorological data provided by time series.

Therefore, as a first step, a series of climate indices, such as the average annual number of summer days (maximum daily temperature exceeds 25 °C), hot days (maximum daily temperature exceeds 30 °C) and tropical nights (minimum daily temperature exceeds 20 °C), have been calculated using the cuboid method that combines urban climate simulations with long-term climate information of monitoring stations or regional climate projections of EURO-CORDEX.

Figure 18, **Figure 19** and **Figure 20** show first results for the mean annual number of summer days, hot days and tropical nights, respectively, for the baseline period 1971-2000. These are based on urban climate simulations at 250 m resolution and an ensemble of historical (but now yet bias corrected) EURO-CORDEX simulations listed in **Table 18**. Urban Atlas land use data[10] complemented with CORINE land cover data[11] and standardized representative parameters regarding building structure, percentage of soil sealing and vegetation information were used as input for the urban climate simulations.

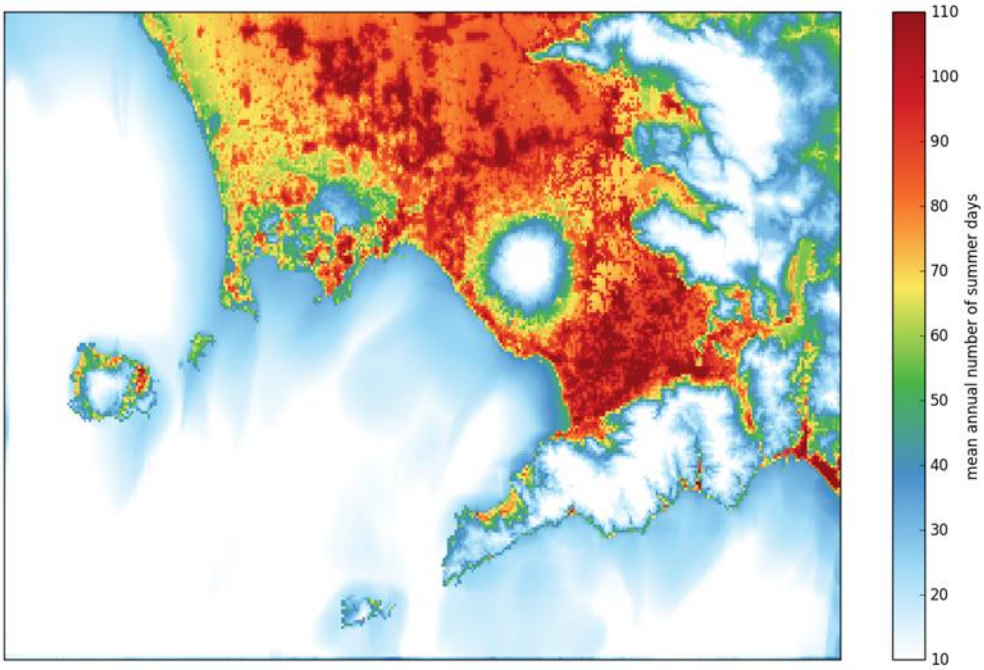


Figure 18: Mean annual number of summer days (daily maximum temperature > 25°C) derived from the cuboid method and MUKLIMO_3 urban climate model results, based on long-term climate information from EURO-CORDEX regional climate historical scenarios for the period 1971-2000.

[10] https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012
[11] https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

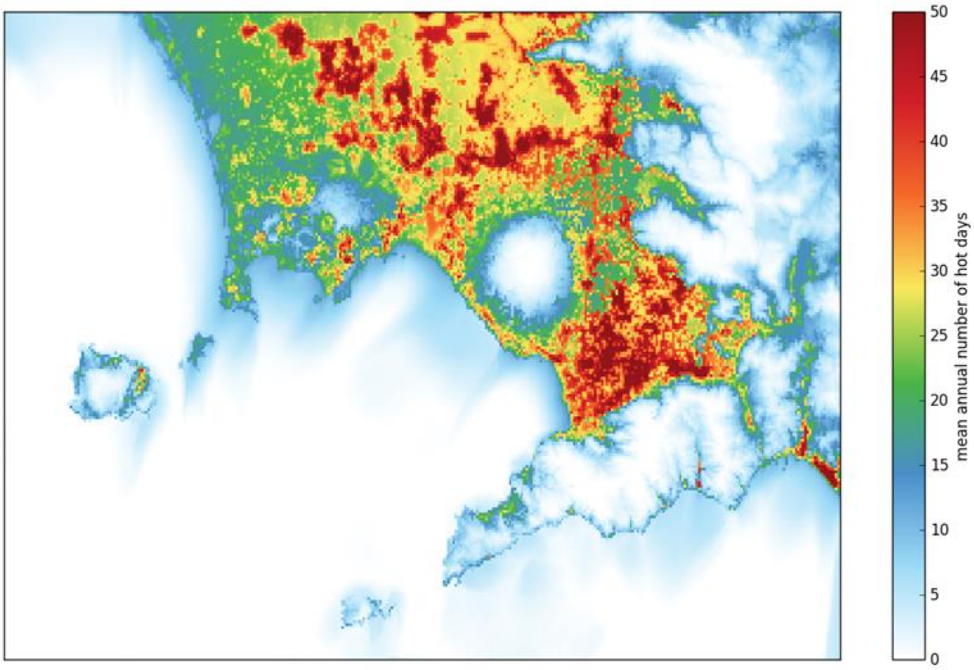


Figure 19: Annual average number of hot days (daily maximum temperature > 30 °C) during the period 1971-2000.

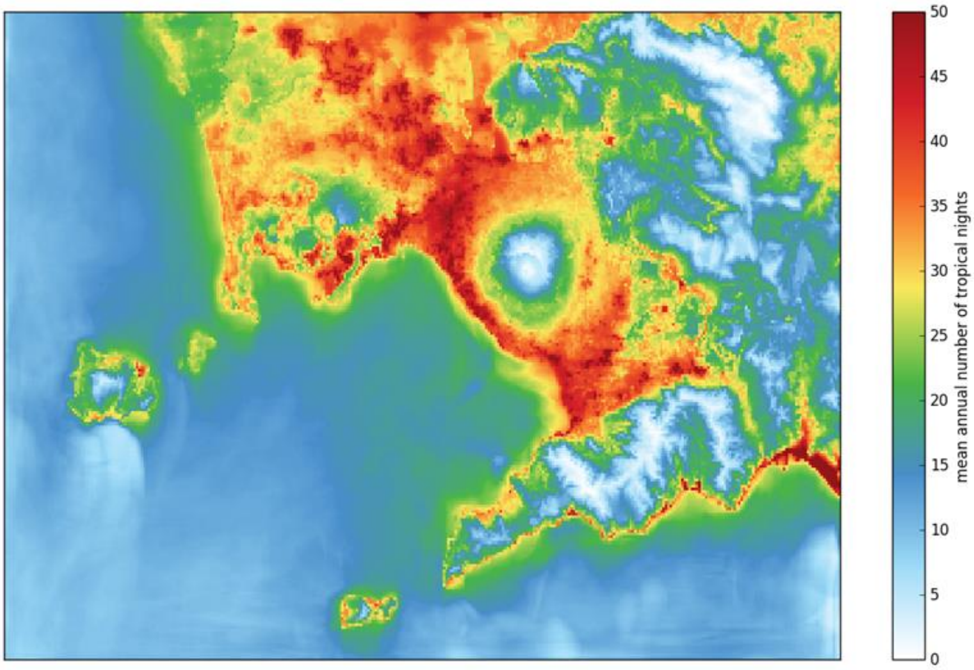


Figure 20: Annual average number of tropical nights (daily minimum temperature > 20 °C) during the period 1971-2000.

Table 18: Different EURO-CORDEX climate model configurations which are used as input for the derivation of urban climate indices.

Institute	**Driving GCM**	**RCM**
DMI	ICHEC-EC-EARTH	HIRHAM5
	NCC-NorESM1-M	HIRHAM5
KNMI	ICHEC-EC-EARTH	RACMO22E
SMHI	CNRM-CERFACS-CNRM-CM5	RCA4
	ICHEC-EC-EARTH	RCA4
	IPSL-IPSL-CM5A-MR	RCA4
	MOHC-HadGEM2-ES	RCA4
	MPI-M-MPI-ESM-LR	RCA4

Additionally, layers related to geomorphology, buildings, open spaces and vegetation – the latter obtained from PLEIADES satellite images processing – were provided for small test areas in Naples (see, for example, **Figure 21 Figure 21**). By integrating these site-specific data into the urban climate model MUKLIMO_3, high-resolution simulations (20 m) were carried out to obtain information about temperature and mean radiant temperature distribution during idealized heat load conditions. Initially, land use information from Urban Atlas was used as input for MUKLIMO_3 but the distribution of land use classes turned out to be very homogenous in large parts of the study area which influences, for example, the parameterization of buildings (**Figure 22**). Consequently, it was replaced by a land use classification developed by the Municipality of Naples because it represents the urban morphological structures in more detail (see **Figure 23**).

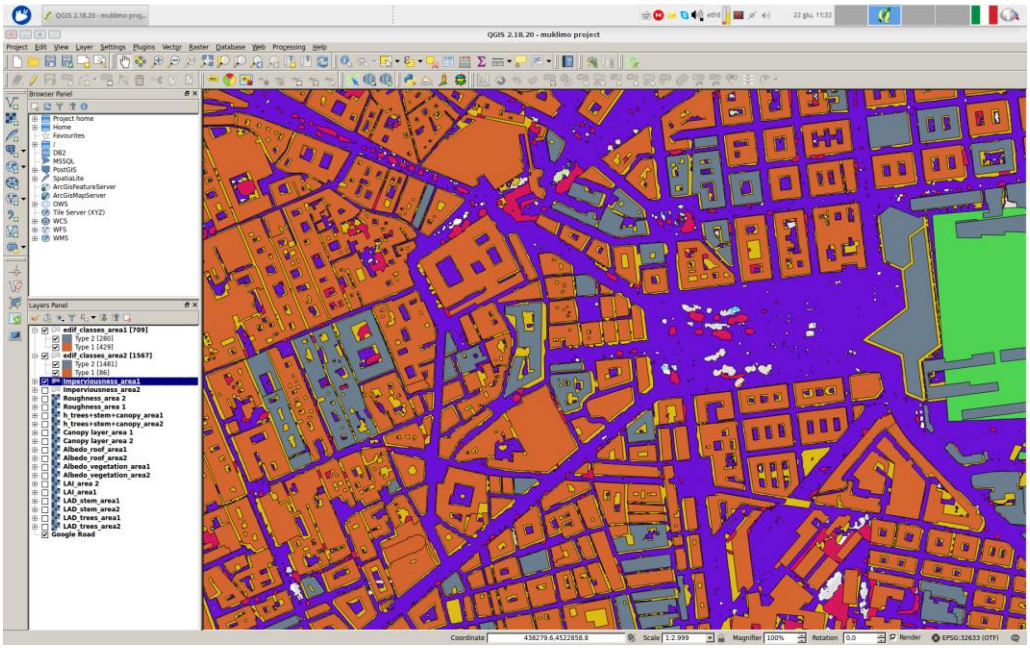


Figure 21: Detail of the albedo layer used as input in MUKLIMO_3.

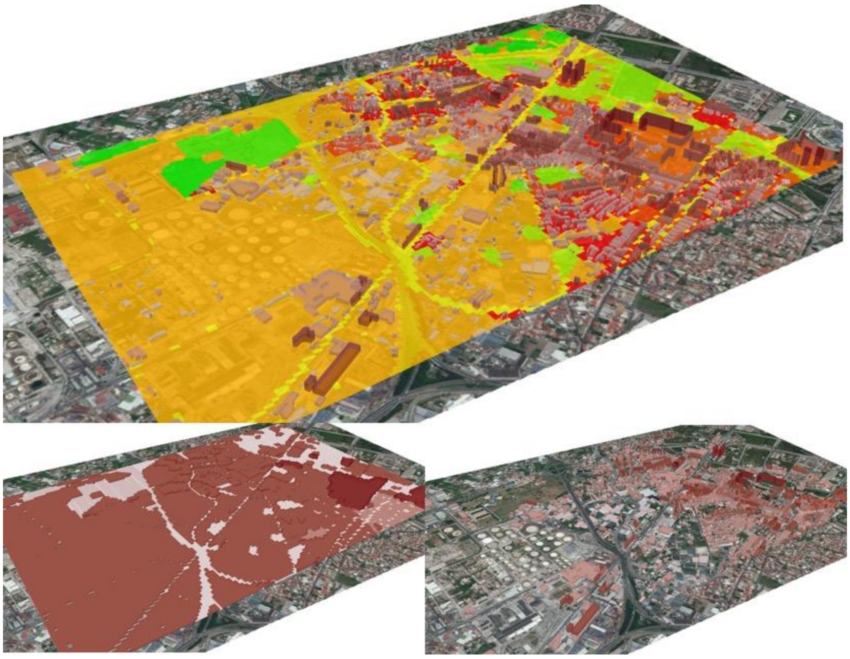


Figure 22: Urban Atlas land use classification (above) and corresponding parameterization of buildings in MUKLIMO_3 (below left) and actual building distribution (below right).

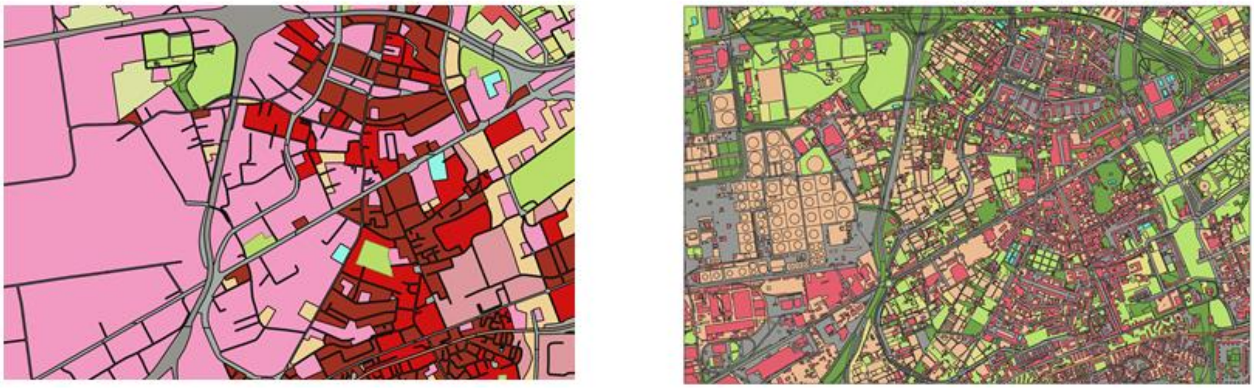


Figure 23: Distribution of land use classes for two different classification schemes for one of the study areas in Naples. Left: Urban Atlas 2012; Right: Local land use classification from the Municipality of Naples.

The preliminary outputs of MUKLIMO_3 model for an idealized simulation of 24 hours are currently available for the test site and they will be extended to the entire metropolitan area in the near future (**Figure 24**).

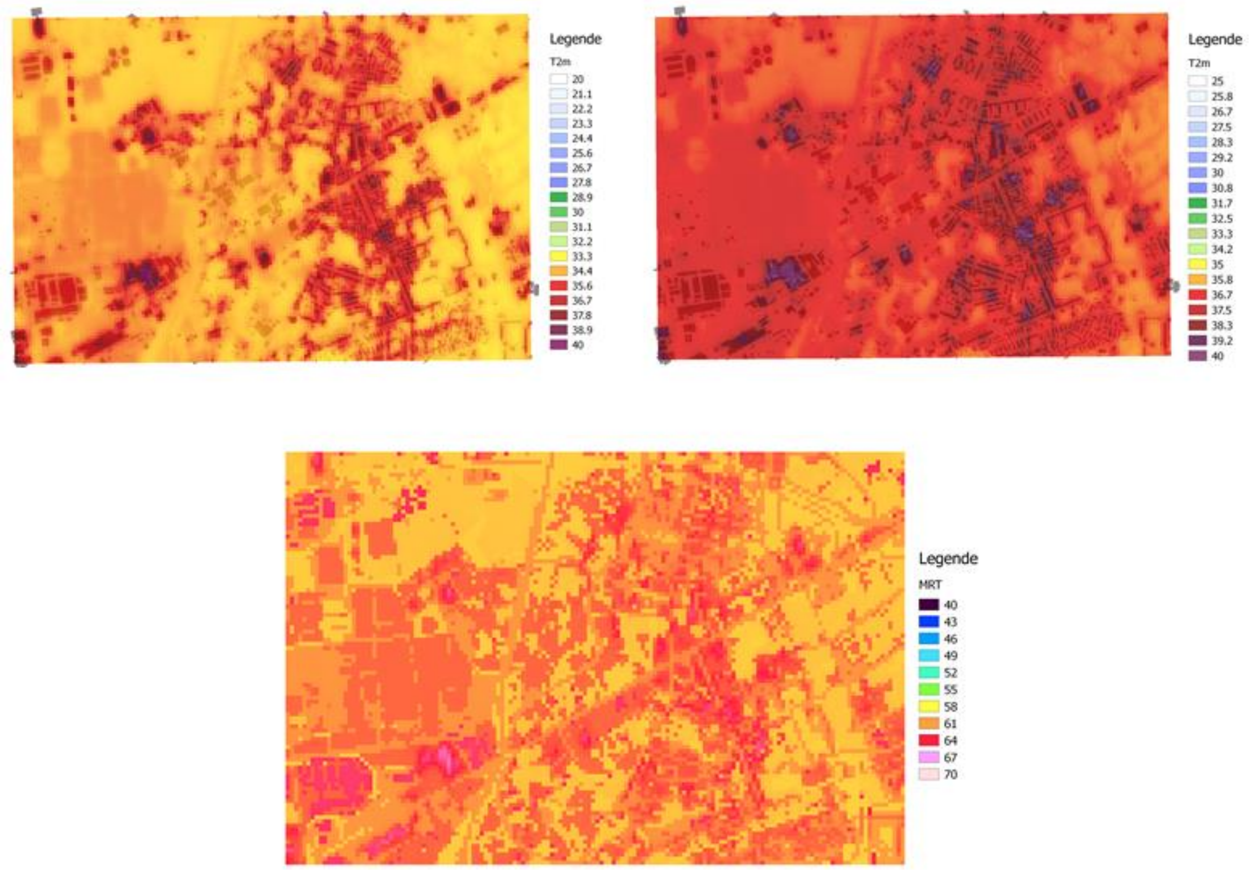


Figure 24: Examples of MUKLIMO_3 model output for one test study area, based on the land use classification scheme developed by the Municipality of Naples. Above: 2m-temperature at 11 UTC (left) and 14 UTC (right) for an idealized heat load day. Below: Near-surface mean radiant temperature at 14 UTC, based on the MUKLIMO_3 model output, combined with an energy-balance model (Klima-Michel-Modell, developed by the DWD).

3.1.2 Pluvial Flooding

The PLINIVS simplified model, described in Section 2.4, has been used to identify urban areas that are more prone to pluvial flooding, considering the key factors that could aggravate the impact of extreme precipitation events. Meteorological datasets, layers related to geomorphology, buildings, open spaces and vegetation, as well as hydrological data sets have been used as input for this model. Most of these data have been extracted from the processing of Naples' DSM and DTM provided by Municipality of Naples.

The model was preliminarily tested, as in the case of heat waves, on sample areas. The results will be subsequently extended to the entire Metropolitan area.

The implementation of the model involved several phases. Firstly, through the interpolation of the original points with the Kriging estimator, the digital elevation model (DEM) data has been converted to GRID format, which is more suitable for the following processing steps because of its regular structure. Subsequently, in order to remove small imperfections in the data, the identification and the filling of the "pits" has been carried out. In the meantime, using the eight-flow direction (D8) model, the surface flow direction has been defined. In the last step, the flow accumulation dataset has been extracted and that output allows one to detect different micro-basins by applying various outlets. Once this preparatory step is completed, the PLINIVS simplified model is finally computed (**Figure 25**).

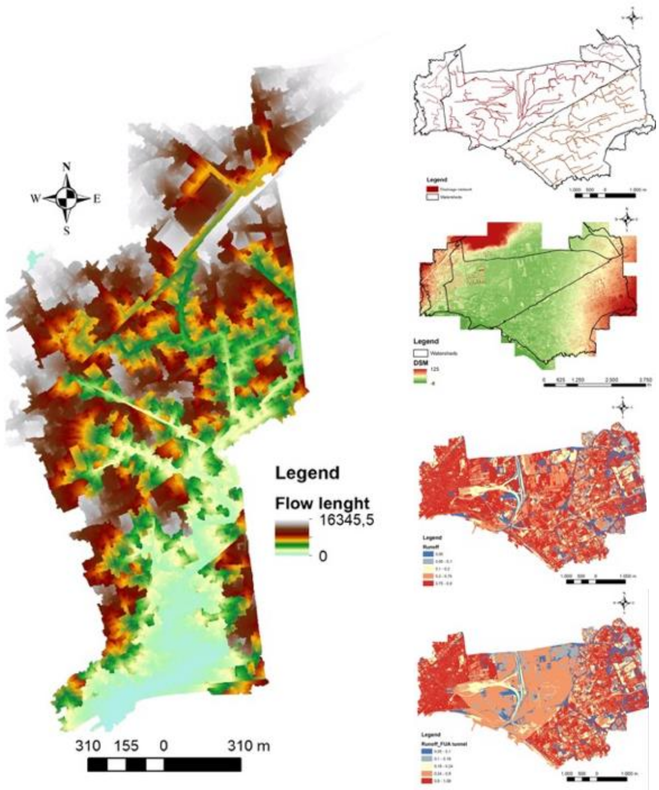


Figure 25: Examples of PLINIVS simplified model output.

3.1.3 Landslides

A landslide hazard analysis has been conducted in the municipality of Castellammare, since that area is commonly subjected to this phenomenon because of its geomorphological conformation and the lack of maintenance, that increase hydrogeological instability. This hazard has been defined by identifying the areas of possible slope failure subdivided in two typologies:

- "slopes" (flow slide – non channelized flows)
- "basins" (channelized flows)

For each detected category, the most relevant areas of possible invasion have been identified.

A preliminary survey of the buildings in the area object of the analysis has been carried out: in the areas of possible failure (slopes or basins) the impacted building is considered as "lost", while in the areas of invasions, further analyses are needed to classify the building vulnerability and on the effective dynamic pressure acting through the landslide flow. At this stage of development, the vulnerability of the building exposure it has been evaluated through the survey in situ of the main geometric characteristics and the structural typology using a specific survey form (**Figure 26**).

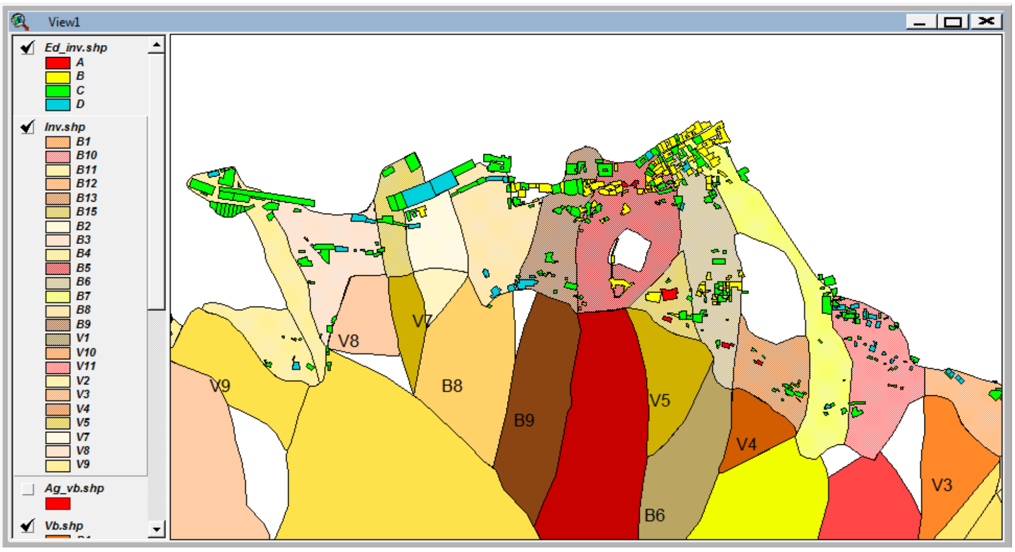


Figure 26: Identification of landslide-prone areas, with building exposure and vulnerability classification.

3.1.4 Adaptation Elements and their Economic Appraisal

The Economic Appraisal of the Adaptation Options will be performed after the Identification activity, when the unit cost of the Adaptation Options will be available. This unit cost and the volumes of the adaptation options adopted in a specific scenario will constitute the base information to appraise their economic impact to be used in the Cost/Benefit analysis. The nature of the costs (direct and indirect) depends on the type of damages on each element at risk and so it is necessary to define specific economic models for each hazard and element at risk. Then for each damage typology affecting the element at risk, it is necessary to collect information on the associated cost categories and cost parameters in order to build a realistic model. A schematic of this process is shown in **Figure 27**.

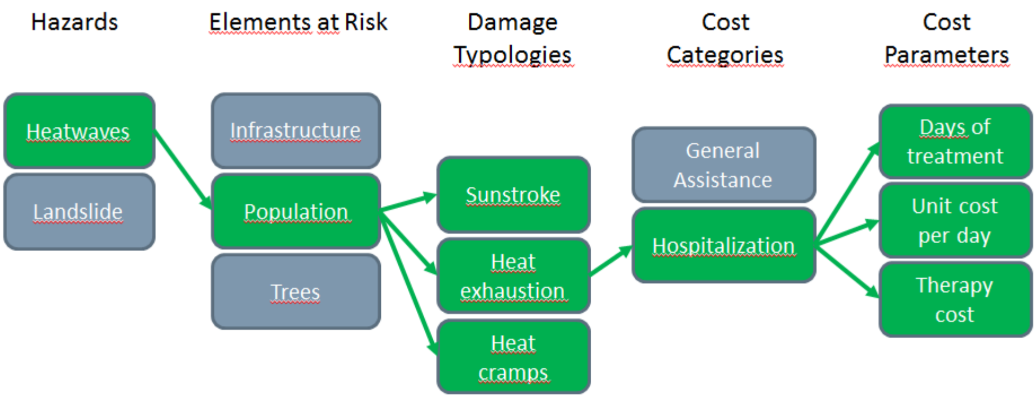


Figure 27: Example of cost categories and cost parameters with heat waves highlighted.

Focusing on heat waves, the main element at risk is people, where its affect is often dependent on age group. The corresponding cost categories and indicators of the cost are shown in **Table 19**. However, a database of such cost categories and cost parameters/indicators which is usable in economic models which covers Europe does not exist. Therefore, at this Screening study level, in order to provide an economic evaluation of the damage, the following assessments can be done:

- Direct costs:

- A rough order of magnitude of the direct costs in all Europe can be calculated by using the values calculated for Italy as a guide and applying an appropriate adjustment factor.

- Indirect costs:
  - The main parameters are currently available for the Naples Municipality only (obtained from the project CRISMA[12]).
  - No rough order of magnitude can be provided in Europe because the indirect costs are related to the economy of the scenario under analysis.

So the specification of the economic models and the cost/benefit analysis model will be applicable everywhere, but the models could be evaluated only at the Expert Climate Service level, after an economic analysis and economic data collection of each specific scenario under analysis.

Table 19: Cost categories and parameters/indicators for heat waves affecting people.

Hazards	Element at risk	Cost Categories	Parameters/Indicators
Heat waves	Population	• Dead cost	• Number of dead people. • Average distribution of population by age. • Average residual value of labour energy by age (Euro).
		• Medical Treatment × Illness cost	• Number of injured people. • Number of disability days × injury type: - Sunstroke - Heat cramps - Heat exhaustion: 1/2 gg - Heat wave: -2/4 gg • Average cost per day by injury type.
		• Energy Consumption cost for cooling	• Kwh per cubic meter
		• People information cost alerts, communications, etc.	• Unit cost per Kwh
		• Water distribution cost	• Total cubic meters
		• Psychic and chronic patients assistance cost	
		• Homeless assistance cost	
		• Senior citizens assistance cost	

A rough order of magnitude of the adaptation options costs in all Europe can be calculated based on the values calculated for Italy by using an adjustment factor. This factor for the various countries are presented

[12] http://www.crismaproject.eu/

in **Table 20**, but will be modified using additional data within Eurostat[13] to find more appropriate adjustment factors.

Table 20: Adjustment factors for each European country to be used as a basis to relate costs calculated for Italy to other countries.

Country	Coefficient	Country	Coefficient	Country	Coefficient
AT	104.8%	FI	116.6%	NL	104.3%
BE	100.0%	FR	111.0%	PL	76.4%
BG	71.5%	HR	97.5%	PT	89.1%
CY	91.8%	HU	76.2%	RO	68.3%
CZ	83.8%	IE	113.5%	SE	111.7%
DE	98.8%	IT	106.7%	SI	86.1%
DK	135.3%	LT	73.1%	SK	82.6%
EE	78.3%	LU	100.0%	UK	120.3%
EL	92.7%	LV	75.9%		
ES	97.6%	MT	89.6%		

The current status of the work performed for this task is shown in **Table 21**.

Table 21: Progress table for Task 3.5.

Economic Model: Heat waves on People		
1. Damage Analysis	Done	100%
2. Type of Costs – Identification	Done	100%
3. Economic Model Specification	In Progress	70%
Economic Model: Pluvial Flooding on Buildings		
1. Damage Analysis	In Progress	20%
2. Type of Costs – Identification	TBD	0%
3. Economic Model Specification	TBD	0%
Economic Model: Landslide on Buildings		
1. Damage Analysis	In Progress	20%
2. Type of Costs – Identification	TBD	0%
3. Economic Model Specification	TBD	0%
Cost/Benefit Analysis Model		
1. Design to be Model	In Progress	50%
2. Model Specifications	TBD	0%
Adaptation Options Costs		
1. Adaptation Options Analysis	TBD	0%
2. Algorithms for the Adaptation Option Cost	TBD	0%

13 https://ec.europa.eu/eurostat/

3.2 DC2

The DC2 user case focuses on expert services for Sweden. We are working with several sample expert services within two fields, water and health.

The workflow of DC2 according to the EU-GL methodology described in D3.1 is summarized in **Table 22**.

Table 22: Overview of the workflow of DC1 and its relation to the EU-GL methodology.

Hazard Characterisation	**Element at risk**	**Vulnerability**	**Impact**	**Adaptation Options**
Heat waves	People	High for very young/old age groups	Excess heat mortality Productivity loss	Investigate role of vegetation (location, type)
Pluvial Flooding	Buildings Infrastructure	High for objects in poor drainage areas and close to lakes	Damage Economic costs for repair / resource unavailability	Increased vegetation to control flow rates, infiltration
Air quality / Pollution	People	High for people with limited mobility	Reduced ventilation from vegetation results in locally high pollution concentrations	Change in the types / size of vegetation art

3.2.1 Water Hazards and Supply (US-DC2-100)

The user story US-DC2-100 is a parent story that summarizes common information needs for all water related user stories for Sweden in Clarity. All stories in this family address aspects of flooding and droughts caused by water supply from precipitation or rivers. The goal is to provide input to city planners to both present city structure and when planning new buildings, infrastructure and other actions related to water supply, intense precipitation and expected changes in the future.

3.2.1.1 Available hydrological data

The **SWICCA**[14] portal 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. Examples of data available in the SWICCA portal (see **Figure 28**) are: precipitation (seasonality, percentiles, intensity duration, intensity max), river data (river flow, runoff, flow duration, flood recurrence), wetness and aridity.

[14] http://www.swicca.eu

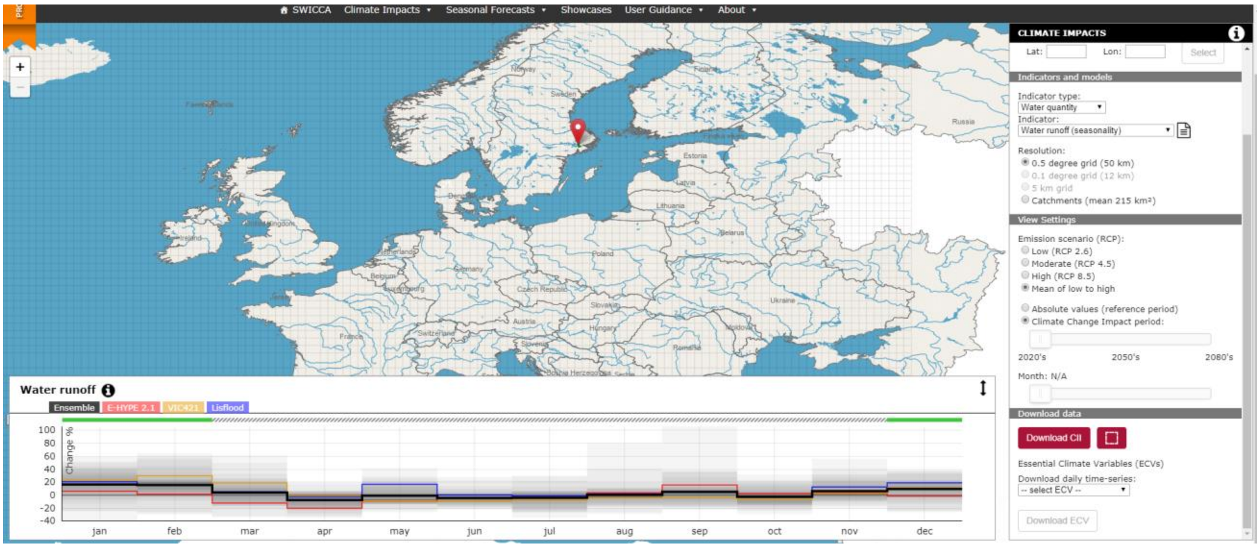
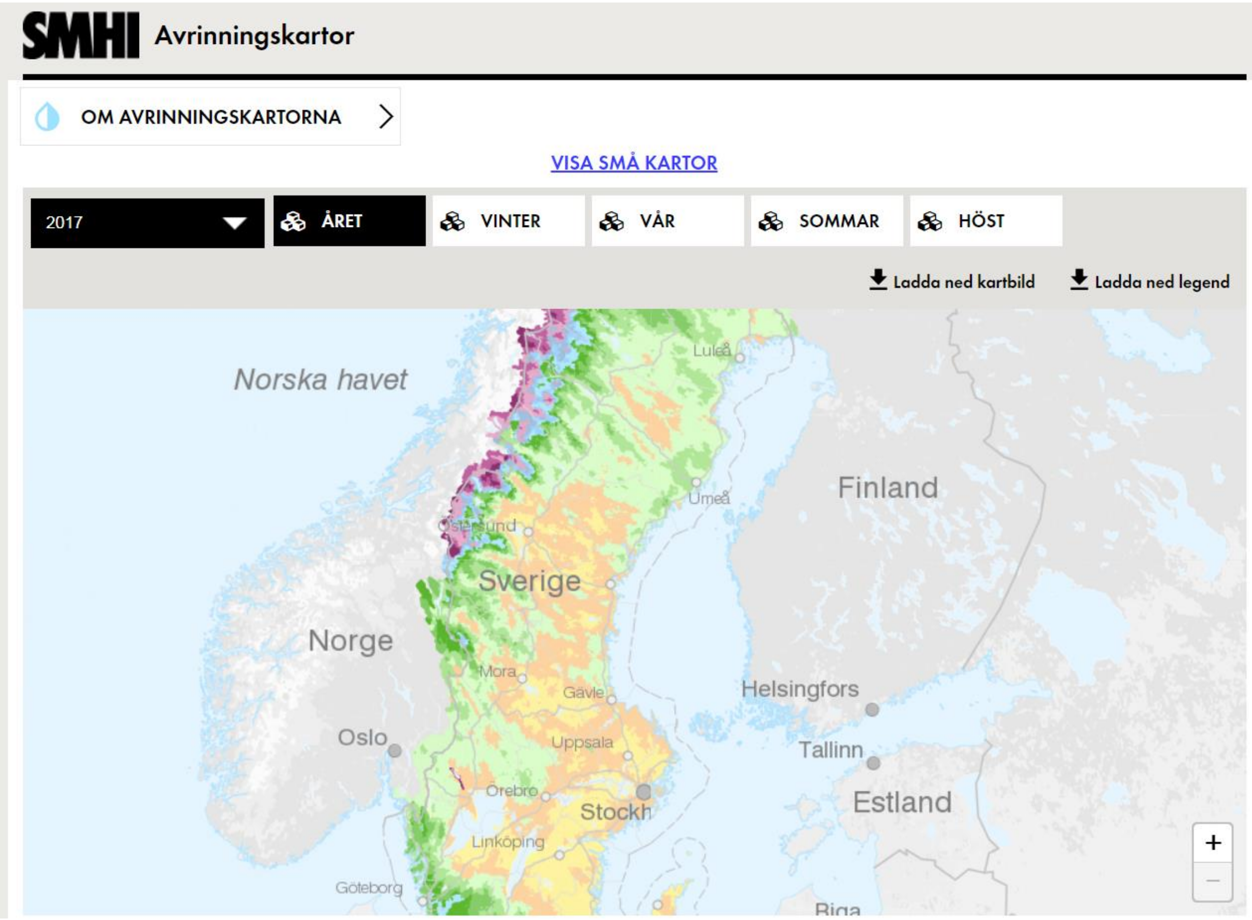


Figure 28: Example of seasonality for runoff from the SWICCA portal.

In addition to the data on European scale available from the SWICCA portal, several Swedish authorities produce open data of interest for expert studies in Sweden. One example is the Vattenweb[15] portal that offers hydrological data for Sweden. In **Figure 29** we give one example of runoff data available from Vattenweb.



[15] http://vattenweb.smhi.se

Figure 29: Example of runoff maps from the Vattenweb portal.

3.2.1.2 High resolution future hydrological data for Sweden Using 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 CLARITY, 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 is setup to run at hourly time step to enable simulation of discharge and runoff at a temporal resolution relevant for assessment of flooding due to intense precipitation events. As the focus is on urban settings, detailed urban land cover information is incorporated in the model by making use of the Urban-Atlas landcover data. The model is calibrated and validated for the southern part of Sweden using Radar based hourly precipitation (Berg et al., 2016) and hourly temperature from SMHI's reanalysis system MESAN (Häggmark et al., 2000).

Climate projections are performed using a subset of the EURO-CORDEX hourly data at 0.11° spatial resolution (see **Table 23**). The data received so far have emissions scenarios RCP4.5 and RCP8.5. The data are bias adjusted against gridded daily observed data covering Sweden.

A set of hydrological indicators that are relevant for the assessment of flooding will be derived from model simulations corresponding both to the present climate and scenario periods. These include: river discharge, total runoff, and flood recurrence.

Table 23: List of hourly EURO-CORDEX configurations used for climate projections of flooding for the Swedish demonstration case.

Name	**RCM**	**GCM**	**Institute**
RCA4-EC-Earthr12	RCA4	EC-Earth	SMHI
RCA4-CNRM-CM5	RCA4	CNRM-CM5	SMHI
RCA4-MPI-ESM-LR	RCA4	MPI-ESM-LR	SMHI
RCA4-IPSL-CM5A-MR	RCA4	IPSL-CM5A-MR	SMHI
RCA4-HadGEM2-ES	RCA4	HadGEM2-ES	SMHI
HIRHAM5-EC-Earthr03	HIRHAM5	EC-Earth	DMI
HIRHAM5-NCC-NorESM1-M	HIRHAM5	NCC-NorESM1-M	DMI

3.2.1.3 MIKE models for studies in Stockholm

The MIKE products are developed by the Danish Hydraulic institute (DHI) for modelling water environments. Mike 21 is a fully dynamic, two-dimensional model that calculates water level and flow conditions. The model 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 MIKE model will be used in DC2 for Stockholm to simulate future scenarios of extreme rain on a high resolution scale. The effect of vegetation on inundation depths and flow velocities will be investigated by including potential green areas in the model, 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.

3.2.1.1 Analysing future flooding risk from combined events

A methodology for assessing and evaluating multiple future flood risks will be developed in DC2 for Jönköping Sweden (CABJON). Available data sets and models with different scales will be used to analyse joint probabilities and to conduct a multi-risk assessment for river floods, flooding from the lake and extreme rain. Other climate effects may also be considered. The methodology will be GIS-based and could be further developed into a tool also to be used by other authorities. It is supposed to help municipalities to develop and prioritize adaptation measures to climate change and to serve as a basis for future infrastructure and urban planning.

3.2.2 Health and Environment (US-DC2-200)

The US-DC2-200 user story is a parent story that summarizes a set of user stories concentrating on health and health issues. For the work within Clarity the main focus will be on expert studies for Stockholm, however methods can be applied to other cities in Europe.

3.2.2.1 Health indicators from Urban SIS

Urban SIS was a proof-of-concept project within Copernicus Climate Change Service (C3S 441 Lot 3) providing city specific climate data and impact indicators to principally the infrastructure and health sectors acting in European cities. The demonstration of Urban SIS results is made for three 110 × 100 km^2 areas centered over Stockholm, Bologna and Amsterdam/Rotterdam.
The Urban SIS information is based on climate re-analysis and climate scenario data, downscaled to be useful for individual cities. The Essential Climate Variables (ECVs) proposed for urban downscaling include hourly ≈1 × 1 km^2 fields of several meteorological, air quality and hydrological variables. The ECVs are delivered for a historical 5-year period and for a climate scenario with two 5-year windows, one representing present and the other future conditions.

The ECVs can be accessed and downloaded as gridded time series or receptor point time series for use as input to further downscaling or impact modelling. Urban SIS also offers a series of statistical indicators for each ECV, e.g. daily/monthly/annual averages and extreme values. There is also available a list of impact indicators which have been specified by the health sector, e.g. Thom indices for heat waves, exceedances of EU´s air quality directive etc. Some examples of available indicators are listed in the figures below.

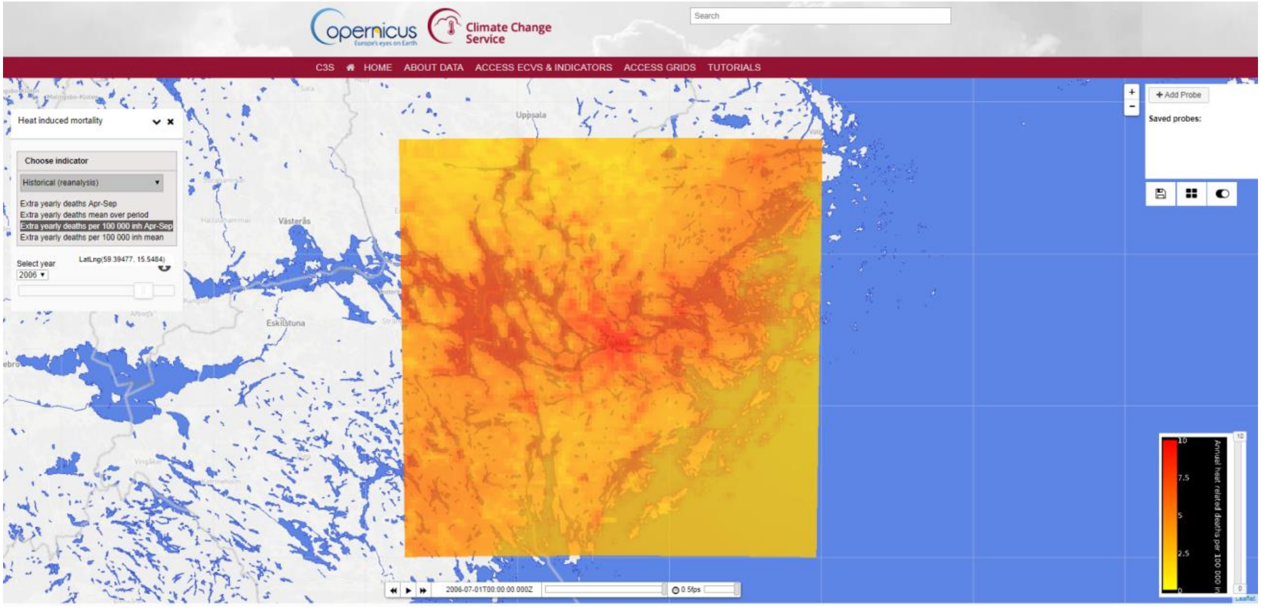


Figure 30: Example of heat induced mortality over Stockholm from the Urban SIS portal.

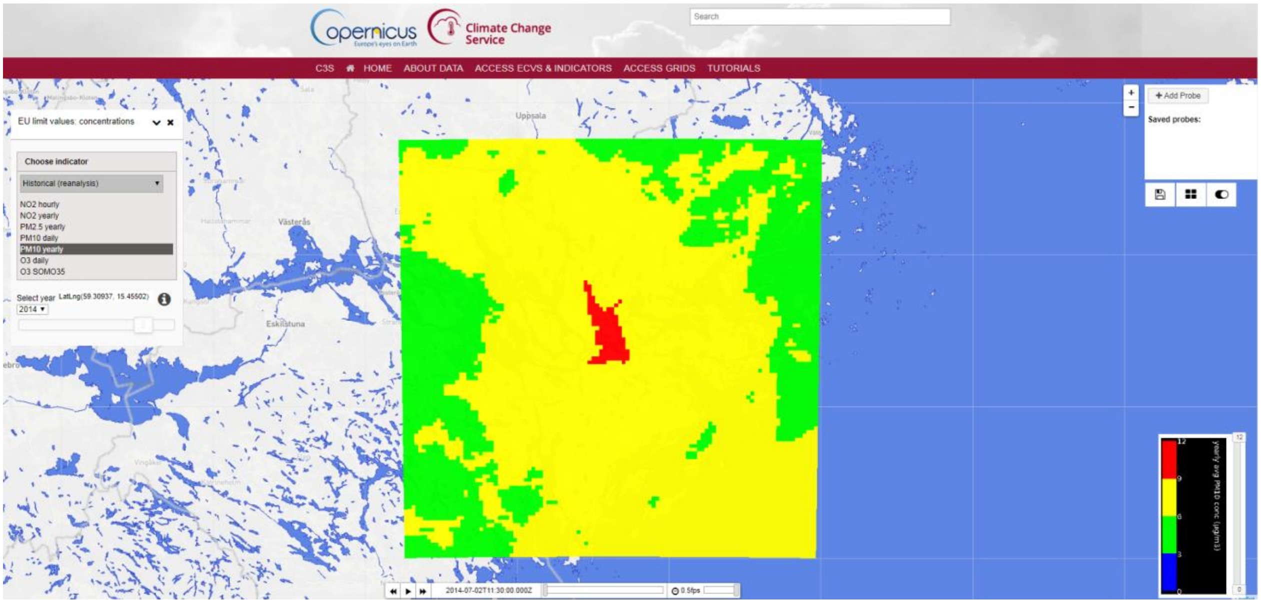


Figure 31: Example of PM10 concentrations over Stockholm.

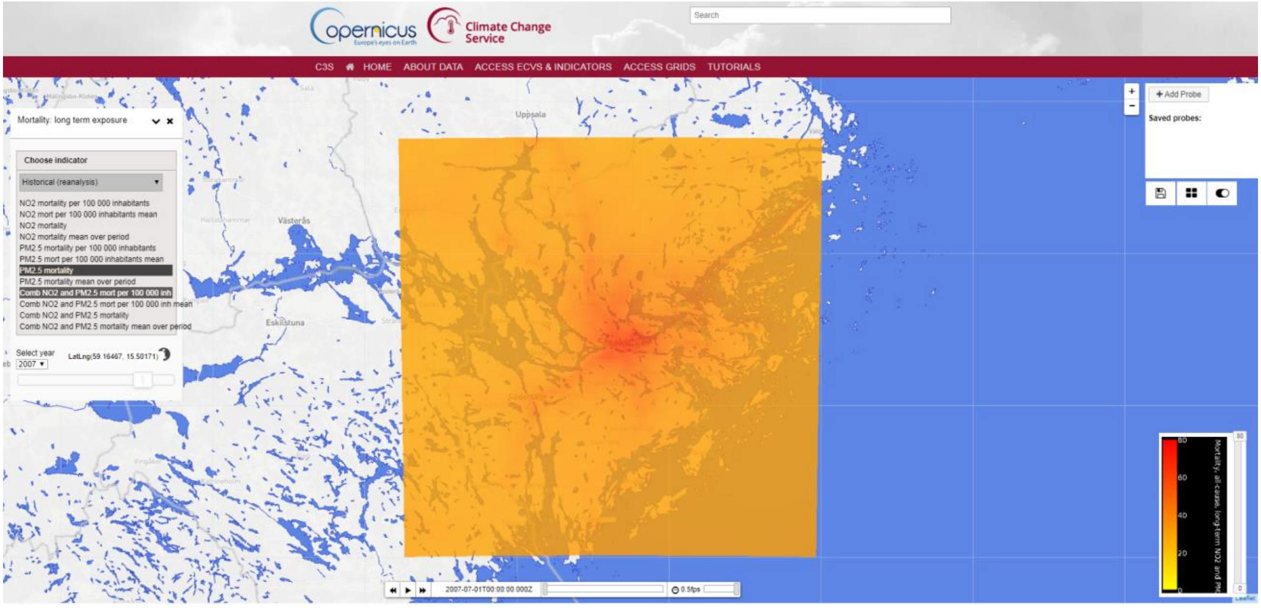


Figure 32: Example of combined NO2 and PM2.5 mortality per 100 000 inhabitants over Stockholm.

3.2.2.2 Heat scenarios over Stockholm

The city of Stockholm is facing a growing need of housing and roads, while the wellbeing and health of citizens needs to be safeguarded. To assess how the resilience of the city to climate-related hazards can be strengthened under intense on-going urban development is a priority. Measures combining grey, green and blue infrastructures have the potential to deliver robust and flexible solutions over long periods. In this context, SMHI is cooperating with Stockholm municipality, with the support of the Swedish Civil Contingency Agency, in the estimation of the effects of heat-waves in the well-being of city dwellers under current and future conditions.

In DC2 the urban climate of Stockholm is investigated, with a focus on the spatial variation of air temperature. High resolution climate simulations are carried out at 1 × 1 km^2 grid spacing using a dynamical downscaling technique developed and validated over different European cities within the Copernicus Climate Change Service Urban SIS.

For the dynamical downscaling, the Numerical Weather Prediction system HARMONIE-AROME cycle 40h1.1 is used, with lateral boundary data provided by the UERRA-ALADIN reanalysis and surface observations retrieved from the ECMWF MARS archive. Surface/atmosphere interactions are computed by SURFEX (version 7.3). Depending on the type of surface, different modelling schemes are used in SURFEX, namely the Town Energy Balance (TEB) model over urban areas and the Interaction Soil-Biosphere-Atmosphere (ISBA) land surface model for soil and vegetation, while the fluxes over the urban vegetation are simulated by a simplified version of ISBA that enables the interaction with impervious surfaces. While the tilling of surfaces that underlies SURFEX offers the capability to account for sub-grid heterogeneity, on the other hand, it requires that detailed and accurate physiography information is provided. For this purpose we have compiled, processed and aggregated different open-access databases and products: the spatial coverage of land cover types from Urban Atlas 2012 (Copernicus Land Monitoring Services), building polygons from OpenStreetMap, building heights from Lidar measurements (available at the Swedish Forest Agency) and time series of leaf area index (LAI) from the Copernicus Global Land Service. The resulting grids, with a spatial resolution of approximately 300 × 300 m^2, were then interpolated by SURFEX to the final model grid at 1 × 1 km^2 and combined with the default European ecosystem classification and surface parameters dataset ECOCLIMAP-II. This methodology has shown to accurately capture the spatial variation of building density and vegetation fraction, as also the intricate interface land/water that characterises the landscape of this region.

Four urban planning scenarios were defined for the city/region (see **Figure 33**):

- the planned construction of 140 000 new homes by 2030, including one of Europe´s largest urban development areas: the 'Stockholm Royal Seaport'. In this plan, the urban densification reduces the amount of vegetation in the intervened areas but the changes affect only the city;
- a "grey city" scenario that promotes the growth of the impervious surfaces in the region, mostly by increasing the density of buildings or constructing in areas that are currently occupied by forests. This scenario was calibrated against the regional development plan (RUFS 2050) and foresees a significant expansion and densification of the city,
- a "black city" scenario, with extreme densification and total absence of vegetation in the city. This is intended to quantify the current impact of vegetation over Stockholm´s climate,
- a "green city" scenario, with a strong increase of green infrastructure, including street trees, parks and green roofs. The potential for the implementation of green roofs is maximized in public buildings.

Baseline conditions for this comparative analysis were set for the summer of 2014, due to the hot weather conditions registered particularly during the last week of July. Meteorological boundary forcing was kept constant in all the experiments, and only physiography was changed according to the planning scenarios mentioned above.

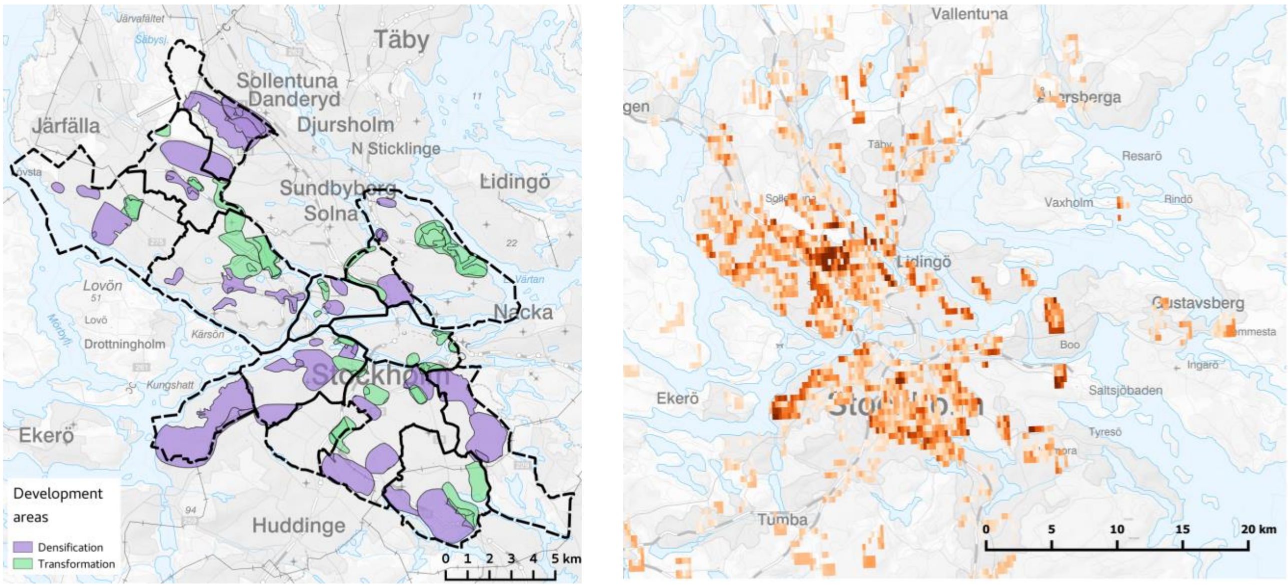


Figure 33: Planning scenarios developed for Stockholm. The construction of 140 000 new homes by 2030 (left) and the regional development plan for 2050 (right).

The high-resolution urban climate data provided over Stockholm region reveals the full spatial coverage of the city´s urban heat island (UHI), its intensity and temporal profile on a daily or seasonal basis. In addition to the urban-to-rural gradients, the dynamical downscaling applied in this work responds to the heterogeneity of the urban tissue, showing intense intra-city gradients that are intrinsically related, among other factors, with the interactions between impervious and vegetated surfaces. As an example, the local cooling induced by the 4 ha Observatorietlunden park was estimated as 1.82 ˚C in average during the summer, evidencing a strong diurnal cycle.

Results show that the monthly average temperature increases by 0.45 °C in 2030 if the construction of 140 000 homes occurs as planned, with larger differences found over forest lands that will be urbanized (see **Figure 34**, left). The stronger densification and sprawling given by the 2050 regional development scenario, however, induces an increase of up to 1.2 °C of the monthly average air temperature (see **Figure 34**, center). A preliminary analysis points out to an average cooling of 0.4 °C (in terms of monthly mean) as induced by Stockholm´s existing vegetation, with heavily vegetated areas evidencing a local decrease in temperature of up to 1.0 °C (see **Figure 34**, right).

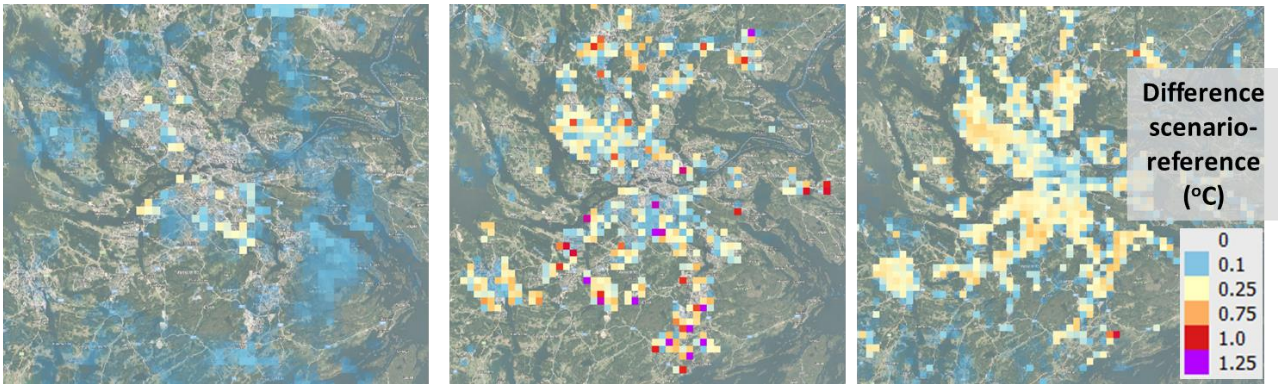


Figure 34: Monthly average temperature increase for future planning scenarios over Stockholm, 2030 with construction of 140 000 new homes (left), the 2050 regional development plan (middle), and a reference scenario where all urban vegetation is removed from today's city (right).

This dataset will be available in the CSIS as a demonstrator of an expert service focusing on heat in a Nordic city. Co-created climate services that include user-tailored downscaled urban climate data, in the example of Stockholm, provide new intelligence for urban planning that assimilates climate adaptation and fit-to-purpose Nature-based Solutions.

3.2.2.1 The Green Area Factor

The Green Area Factor (GAF), also known as Green Space Factor and Biotope Area Factor, is a planning tool that is used to create greener neighbourhoods in the city. This means that a certain portion of the plot of land must consist of vegetation and/or a water surface. The background is that greenery and water surfaces in the city environment contribute with many benefits: they provide an attractive appearance, they can be used for recreational activities and they contribute to increasing biodiversity, among other useful benefits. They also reduce the city's vulnerability to the adverse impacts of the climate change. More surfaces with vegetation can reduce vulnerability for flooding and lower the temperatures during heat waves and to some extent improve air quality.

The GAF is an urban site sustainability metric and a tool to enhance green infrastructure in the city. In Stockholm, GAF is used early in the urban planning process in order to ensure that sustainability goals are achieved, and also to create greener outdoor environments that attract outdoor living, social meetings and improve people's quality of life. Many projects have high ambitions early in the process. The problems arise when it starts to cost money and one realizes that there are no short-term economic gains. With the green surface factor one cannot haggle away the green issues.

GAF is equal to the ratio of the ecologically effective surface area to the total land area. Different target and minimum values are set to different land-use areas. The calculation requires knowing the areas covered with different green elements. GAF is a very flexible tool as it enables the target being met in several different ways through implementing different green elements.

Trees and other vegetation absorb and capture air pollutants, leading to the common perception that they, and trees in particular, can improve air quality in cities and provide an important ecosystem service for urban inhabitants. However, literature shows that different climatic conditions, plant configurations, degree of urbanization and the scale of a study area yield variable potential of urban vegetation to reduce the levels of air pollutants. Air quality can be affected both positively (improved) and negatively by green infrastructures. The effect depends on many different factors like e.g. the pollutant being considered, type of vegetation and if the focus is on a local scale (street canyon) or urban scale. This complexity is the reason why air quality is not considered as a criterion in the GAF used in Stockholm.

In order to improve the knowledge and implement air quality in GAF, dispersion model simulations of a street in central Stockholm have been undertaken (**Figure 35**). Concentrations of particulate matter (PM10) were calculated for a situation with and without trees and all other factors being the same.

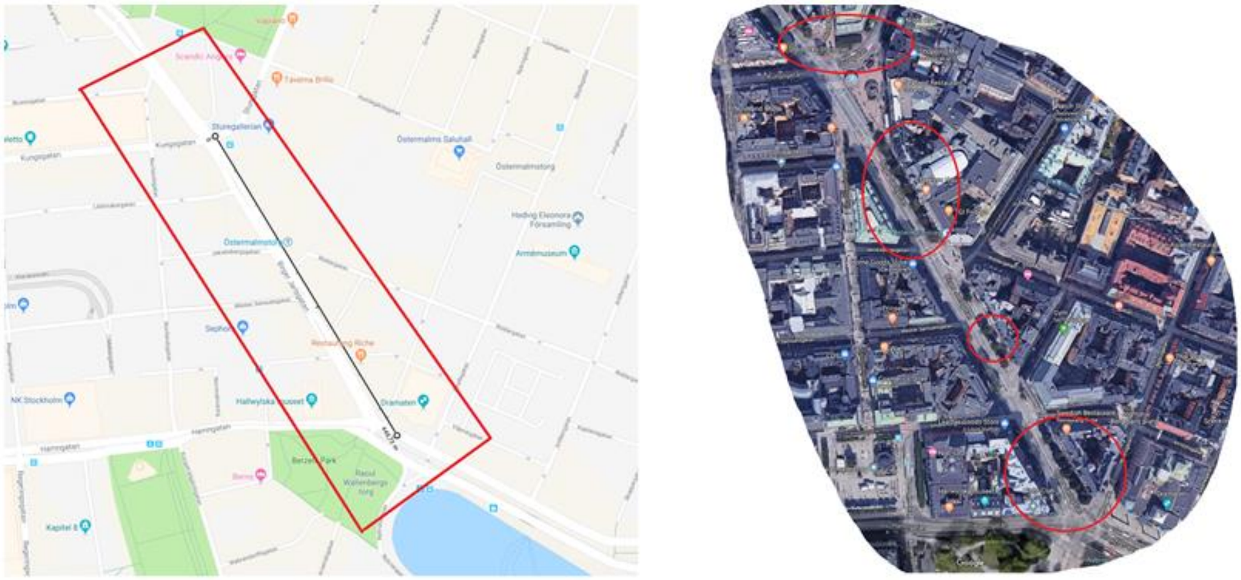


Figure 35: 3D modelling of a 450 m long street section in central Stockholm to see the effect of trees on air quality.

Figure 36 shows the effect of trees on the concentrations of PM10. Concentrations are higher with trees due to reduced ventilation (atmospheric dynamic effect). The deposition (filtering) of particles onto the leaves of the trees, even when assuming a very high deposition velocity, is far less important for the concentrations compared to the reduced dilution of the air. In conclusion, planting trees in street canyons may lead to higher air pollutant levels in the canyons. This result is consistent with other studies.

Lower vegetation, like hedges, would not have this negative effect on the ventilation. The uptake of different air pollutants on different types of vegetation depend the leaf area, location of the vegetation in relation to the emissions of the pollutants and on the properties of the pollutants.

The plan is now to summarize knowledge on effects on air quality of green infrastructures and make some recommendations for implementation in the GAF used in Stockholm.

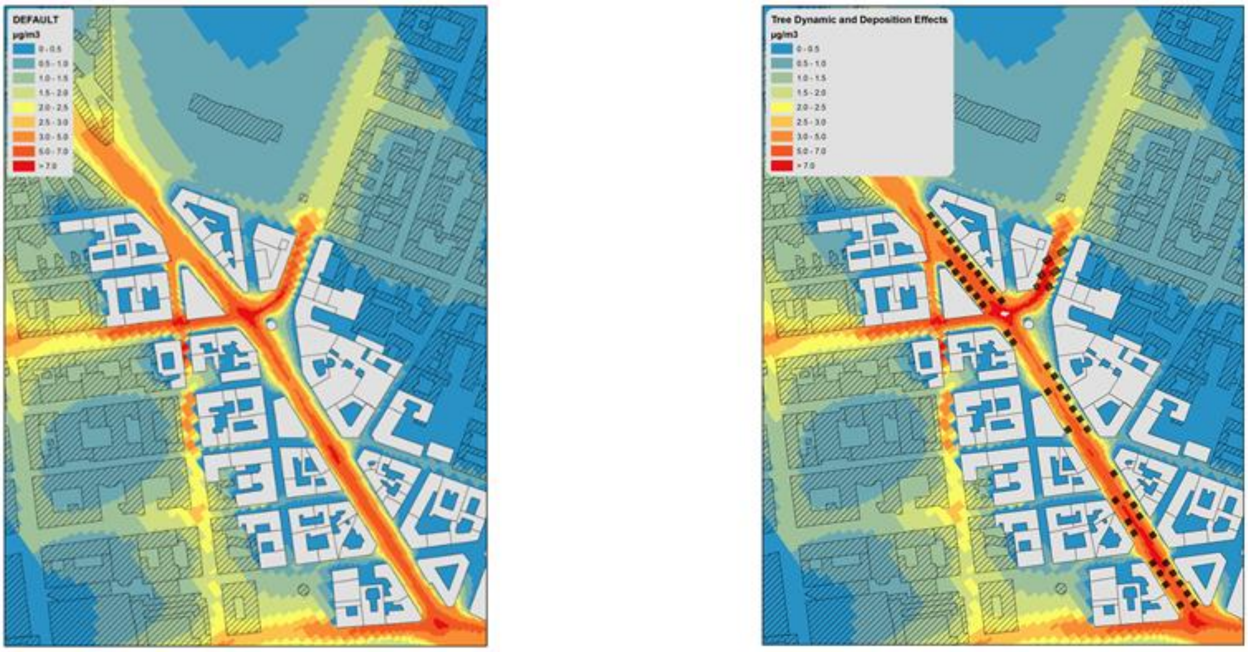


Figure 36: Effect of trees on street level annual PM10 concentrations along Birger Jarlsgatan in central Stockholm. Left: without trees, right: with trees (black dots). Colours indicate concentration in µg m-3 (including only local traffic emissions).

3.3 DC3

3.3.1 Regional Climate Modelling

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

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

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

The workflow of DC3 according to the EU-GL methodology described in D3.1 is summarized in **Table 24**.

Table 24: Overview of the workflow of DC1 and its relation to the EU-GL methodology.

Hazard Characterisation	Element at risk	Vulnerability	Impact	Adaptation Options
Heat waves	People	High for very young/old age groups	Excess heat mortality Productivity loss	Green roofs, increased vegetation, albedo changes, reduction in soil-sealing

As a background framework, AIT provided a 1km × 1km COSMO-CLM scenario run for the Linz region using the 10 km resolution HadCM3-A1B GCM results as forcing data for the higher resolution simulation. The main feature of this simulation is the usage of a regional climate model (RCM) with a special urban extension comprising a high-resolution surface sealing layer. Additionally, heat emissions from traffic and other anthropogenic activities are included. This enables the RCM to reproduce the UHI effect in a realistic manner. The domain of the simulations covers the greater Linz area with 100 × 100 raster cells covering an area of 100 × 100 km^2.

The historical control run, which is required for model validation, is based on ERA40 and ERA Interim data from the ECMWF which covers the period from 1960 to 2015. The time series which is produced by the model covers the period from 1960 to 2100 and reveals a possible development of the future regional and urban climate, providing temperature, precipitation and wind field data at an hourly basis. It should be noted that EURO-CORDEX results have not been used here as they do not provide hourly data, which is necessary to extract daily extreme event data.

The results of the simulations show the extreme event frequency changes for heat days, tropical nights, and heavy precipitation between the baseline/current climate and future climate scenarios. The spatial pattern of the simulation results and the climate change signals are shown in the following figures. **Figure 37** shows the annual mean temperature from the baseline period (1971-2000) to the future period 2021-2050 for the Greater Linz area. The increase in the annual mean temperature from the baseline to the future period is around 2°C and is shown in **Figure 38**.

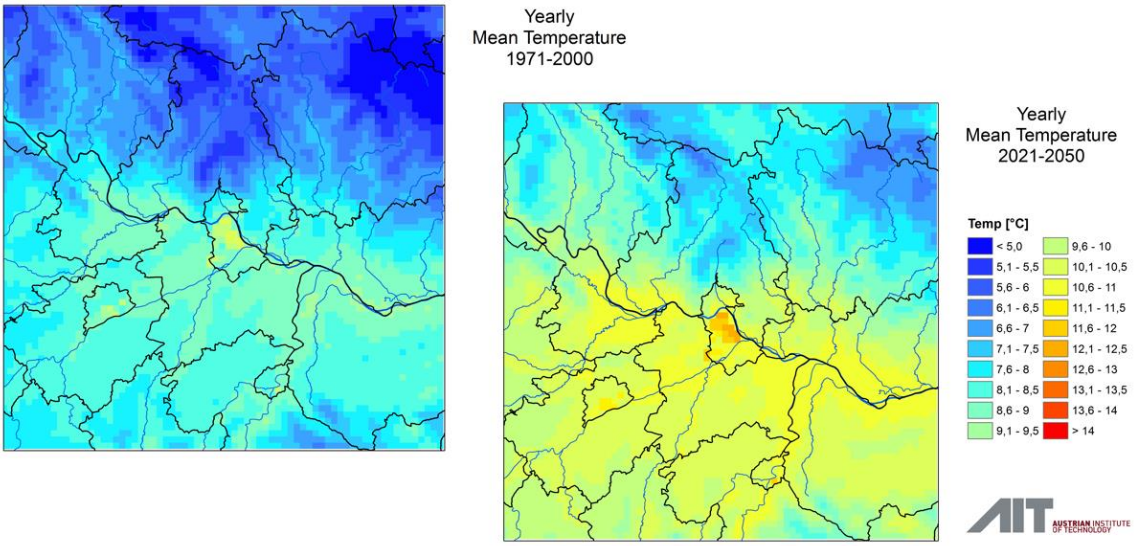


Figure 37: Annual mean temperature of the Greater Linz area during the period 1971-2000 (left) and the future period 2021-2050 (right).

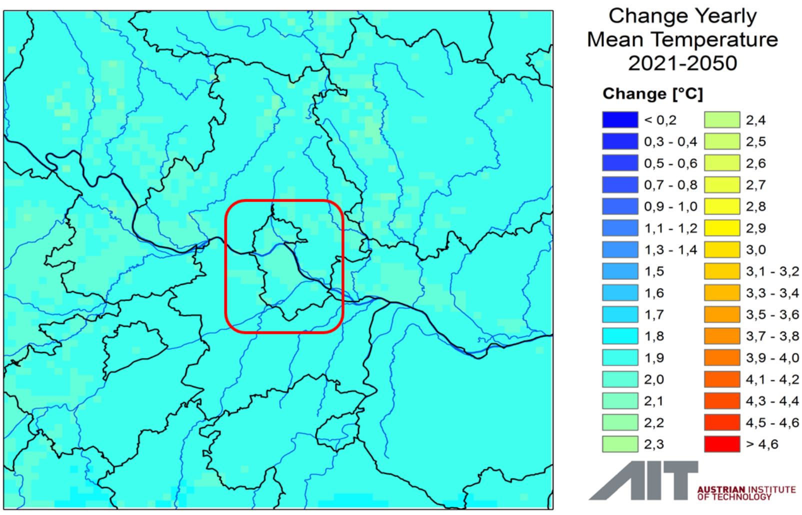


Figure 38: Climate change signal of the Greater Linz area shown as the difference of the annual mean temperature between the periods 1971-2000 and 2021-2050.

The number of hot days, which are days where the daily maximum temperature exceeds 30°C, is shown for the baseline period and the future period 2021-2050 in **Figure 39**. The increase in the number of such hot days is shown as the difference between the two time periods in **Figure 40**. The increases are around 10 days in the north of Linz and 13 to 15 days in the centre of Linz.

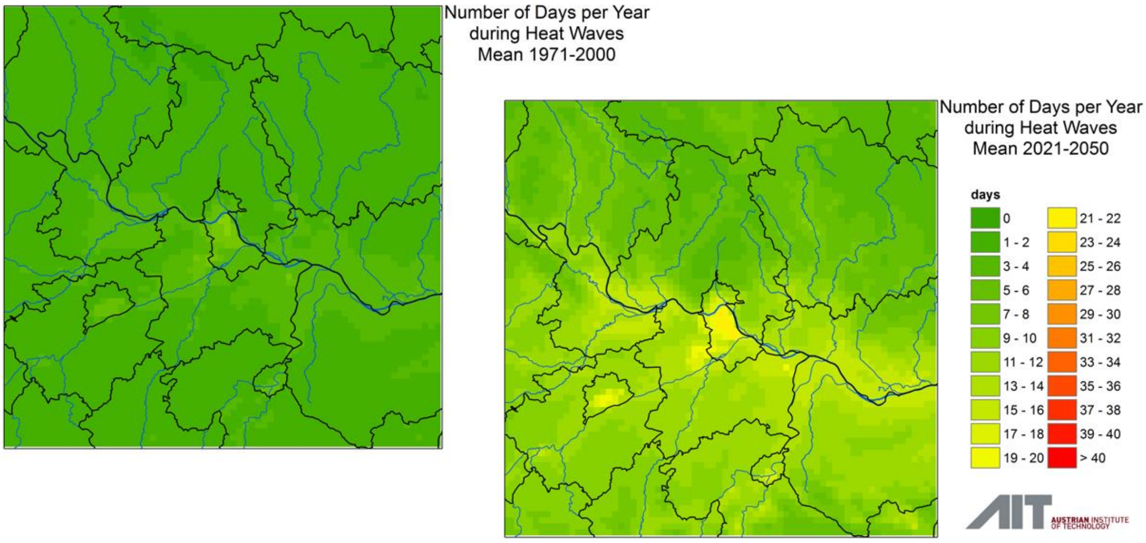


Figure 39: Annual average number of hot days (daily maximum temperature > 30°C) during the period 1971-2000 (left) and the period 2021-2050 (right).

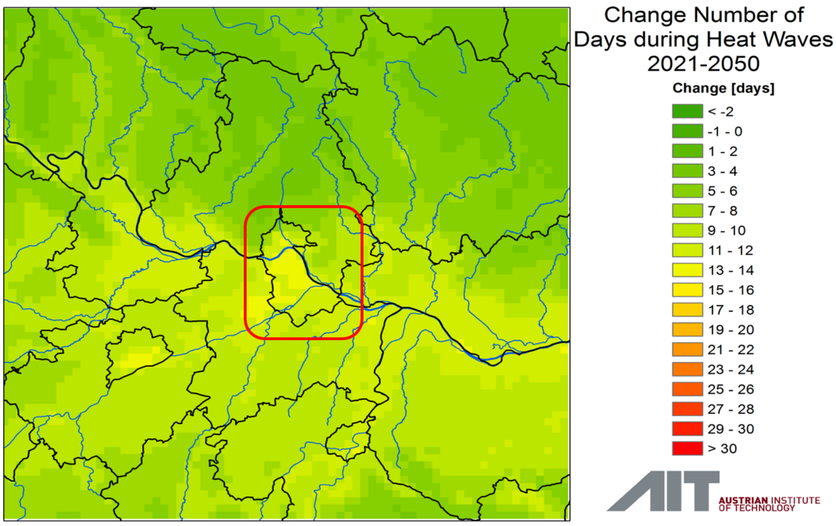


Figure 40: Climate change signal of the Greater Linz area shown as the difference of the average number of hot days (Tmax > 30°C) per year between the periods 1971-2000 and 2021-2050.

The number of tropical nights, which are days where the daily minimum temperature exceeds 20°C, is shown for the baseline period and the future period 2021-2050 in **Figure 41**. The increase in the number of such tropical nights is shown as the difference between the two time periods in **Figure 42**. The increases are around 11-12 tropical nights in the north of Linz and 17-18 tropical nights in the centre of Linz.

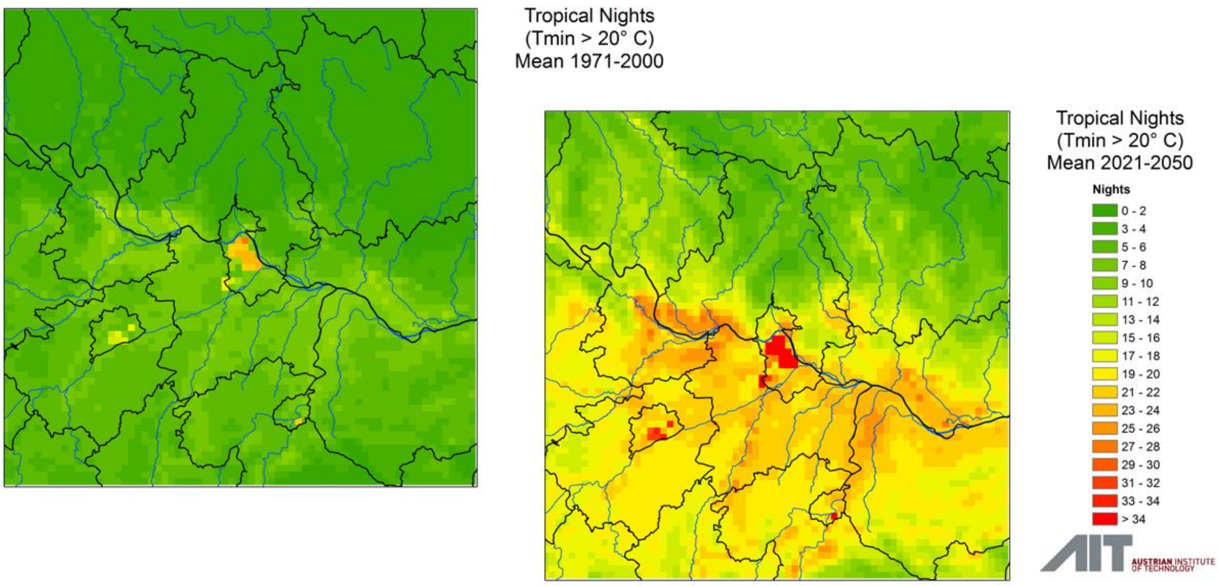


Figure 41: Annual average number of tropical nights (daily minimum temperature > 20°C) during the period 1971-2000 (left) and the period 2021-2050 (right).

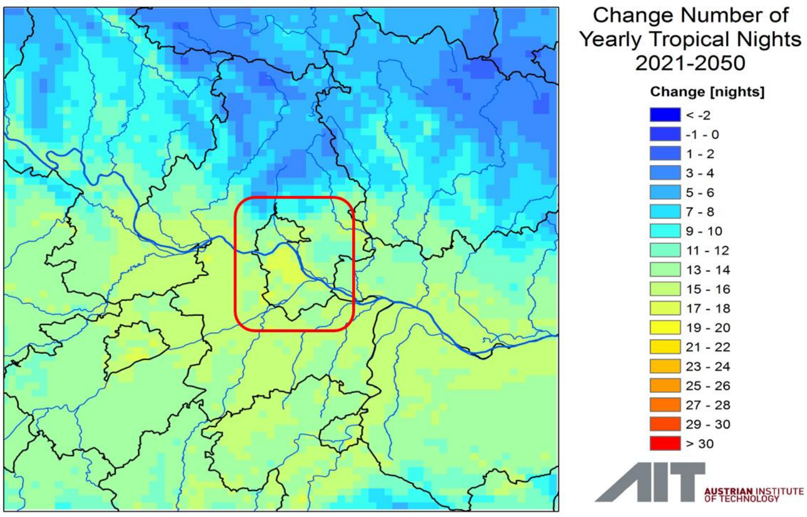


Figure 42: Climate change signal of the Greater Linz area shown as the difference of the average number of tropical nights (Tmin > 20°C) per year between the periods 1971-2000 and 2021-2050.

Heavy precipitation days have also been extracted from the simulation results and are shown in Figure 43 for the baseline period and the future period 2021-2050. Heavy precipitation days are defined as days where the daily accumulated precipitation exceeds 20 mm. The change in the number of such heavy precipitation days is shown as the difference between the two time periods in Figure 44. The differences in the Linz area are 2-3 additional days of heavy precipitation.

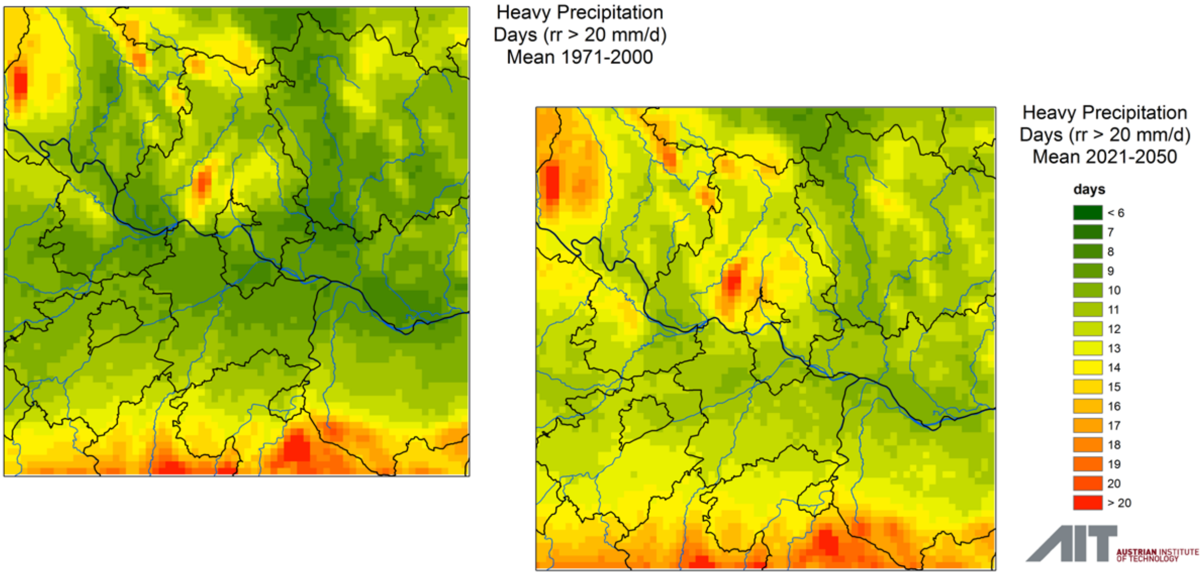


Figure 43: Annual average number of days with heavy precipitation (> 20 mm) during the period 1971-2000 (left) and the period 2021-2050 (right).

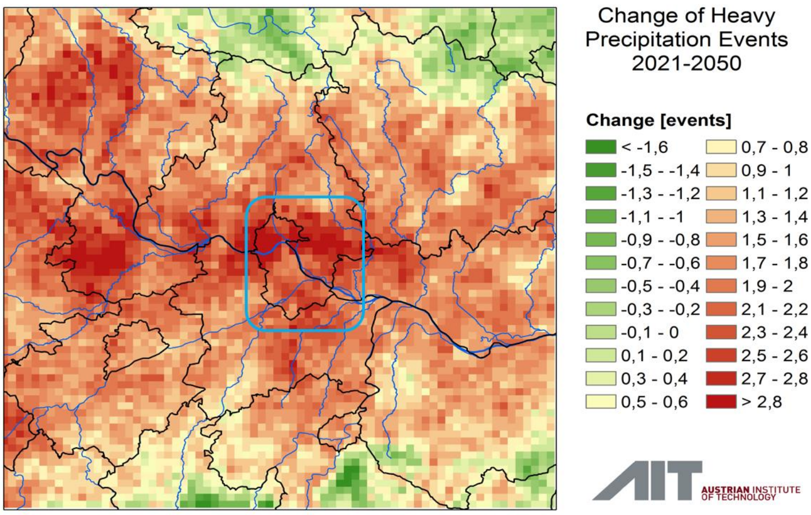


Figure 44: Climate change signal of the Greater Linz area shown as the change in the annual average number of days with heavy precipitation (> 20 mm) during the period 1971-2000 and the period 2021-2050.

Communication with the Linz planning authorities revealed that the heavy precipitation does not need be considered. The reason for this is that the flood protection for Linz is already sufficiently set up for the projected future changes in precipitation.

3.3.2 Microclimate Modelling

The results of the climate change signal presented above provide motivation for further microclimate simulations to be performed. The forcing data to be used as input for the future microclimate modelling activities is shown in **Figure 45**. This input will be used to carry out case studies for Linz using several tools: SOLWEIG, ENVI_MET, Grasshopper/Ladybug. Descriptions of these are provided in WP2.

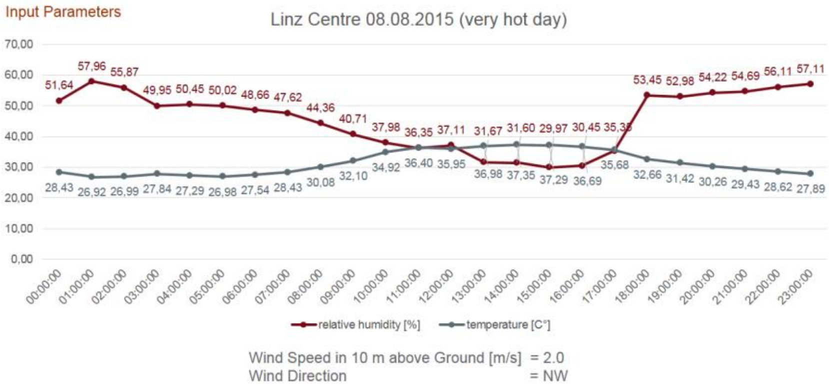


Figure 45: Diurnal variation of temperature (red) and relative humidity (grey) in hourly steps for the Linz microclimate simulations for a hot reference day on 8 August 2015. The wind speed and direction is shown at the bottom of the figure.

3.3.3 Urban Climate Modelling

To obtain information about hot spot areas and general climate adaptation options on the city level, the urban climate model MUKLIMO_3 was applied. A dynamical statistical downscaling approach, called the cuboid method ([50] [51]), was used to analyse the heat distribution for the city of Linz and its surroundings over long-term climate periods. Urban Atlas 2012 land use data and a digital elevation model were used as input for the urban climate model. Local city-specific data related to building structure, degree of soil sealing and vegetation information that had been provided by the city administration of Linz and further processed by AIT were used to derive statistical representative parameters for characterizing each of the land use classes. Some of the 27 land use classes provided by Urban Atlas were further split into subclasses, based on specific urban morphological structures related to building share and degree of soil sealing. High-resolution (100m) daily model simulations were carried out for situations potentially leading to urban heat stress. A series of climate indices, like the mean annual number of summer days, hot days and tropical nights, were calculated by combining the urban climate simulations with long-term climate information from monitoring stations or regional climate projections from the EURO-CORDEX initiative.

Past/current climate

Figure 46 shows the respective climate indices for the period 1981-2010, calculated by applying the cuboid method and by considering long-term meteorological data (temperature, relative humidity, wind speed and direction) from the monitoring station Linz Hoersching as background climate information. The results are used to identify hot spot areas for Linz and its surroundings and thus refer to the *Hazard Characterisation* step from the EU-GL methodology. The climate indices clearly indicate the existence of an urban heat island for the city of Linz with distinct gradients in the spatial distribution of urban heat load. Hot spot areas are found in the densely built-up city centre, as well as in port areas with heavy industries.

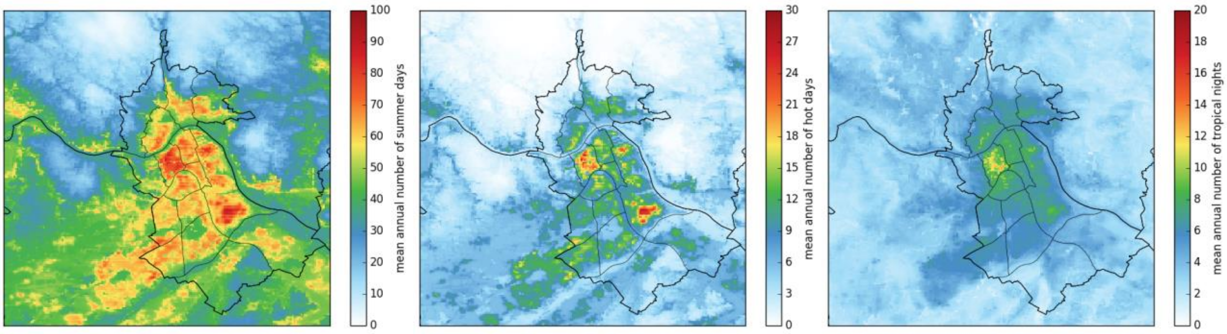


Figure 46: Left: Mean annual number of summer days ($T_{max} \geq 25°C$); middle: hot days ($T_{max} \geq 30°C$); right: tropical nights ($T_{min} \geq 20°C$) for the climate period 1981-2010 for Linz and its surrounding area.

Future climate

To provide information about future climate projections on urban scale, daily mean values of temperature, relative humidity, wind speed and direction for historical (1971-2000) and future (2011-2100) periods were extracted from the EURO-CORDEX regional climate simulations for 3 × 3 model grid points representative for the city's environment. To account for differences in topography, a height correction procedure was applied to the temperature data. Potential systematic biases in temperature data were removed by employing a bias-correction method called quantile mapping by considering observational data from the monitoring reference station. For relative humidity, the corrected temperature series were taken into account. The different GCM/RCM combinations used for this study are shown in **Table 25**.

Table 25: Different EURO-CORDEX climate model configurations, used as input for the derivation of urban climate projections.

Institute	Driving GCM	RCM
DMI	ICHEC-EC-EARTH	HIRHAM5
	NCC-NorESM1-M	HIRHAM5
KNMI	ICHEC-EC-EARTH	RACMO22E
SMHI	CNRM-CERFACS-CNRM-CM5	RCA4
	ICHEC-EC-EARTH	RCA4
	IPSL-IPSL-CM5A-MR	RCA4
	MOHC-HadGEM2-ES	RCA4
	MPI-M-MPI-ESM-LR	RCA4

Figure 47 shows the mean annual number of summer days for the emissions scenario RCP 8.5, based on an ensemble of the above listed EURO-CORDEX simulations for historical and future climate periods, thus indicating the future evolution of urban heat load under the "business as usual" scenario.

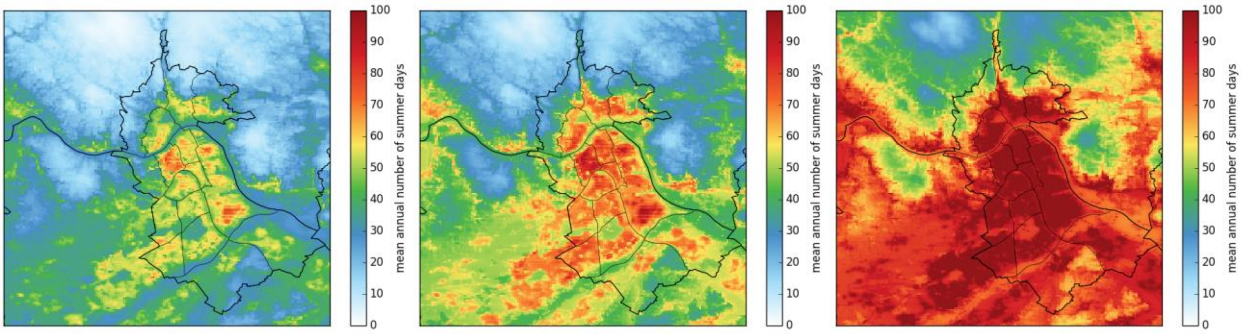


Figure 47: Mean annual number of summer days derived from the cuboid method, based on long-term climate information from EURO-CORDEX regional climate projections (ensemble mean) for the emission scenario RCP8.5. Left: Historical baseline (1971-2000); Middle: Future period 2021-2050; Right: Future period 2071-2100

The average change in the number of summer days by the end of the century, based on the EURO-CORDEX ensemble mean, is shown in **Figure 48** by comparing the future period 2071-2100 to the baseline 1971-2000 and by considering two scenarios (RCP 4.5 and RCP 8.5).

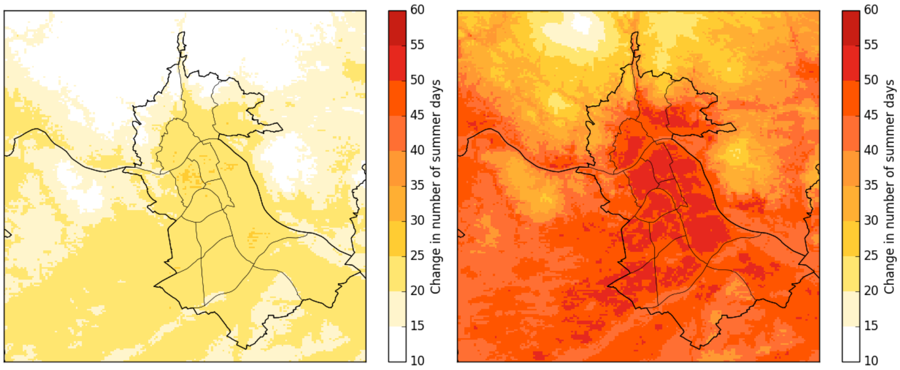


Figure 48: Average change in the number of summer days for the future period 2071-2100 compared to the baseline period 1971-2000 for the emission scenarios RCP 4.5 (left) and RCP 8.5 (right), based on an ensemble of EURO-CORDEX simulations.

Wind field analysis

To simulate the effect of thermally induced local wind systems and their importance with respect to cold air production during night, the wind field, simulated by MUKLIMO_3 for an idealized hot day with weak synoptic flow, was further analysed. Results show that the model is able to simulate the well-known wind systems (see **Figure 49**).

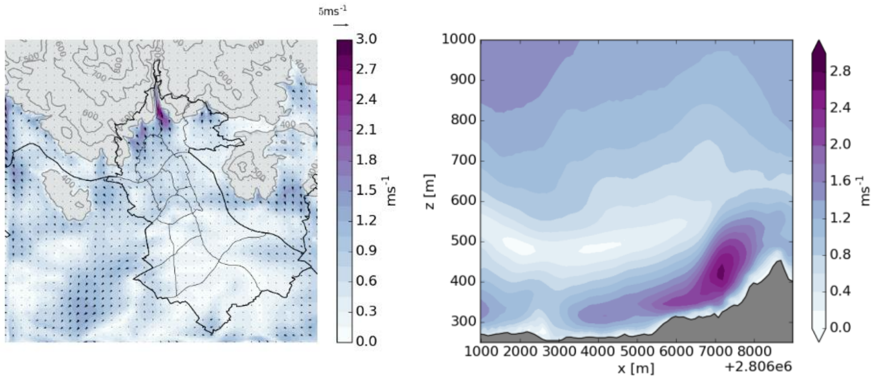


Figure 49: Thermally induced local wind systems based on the example of the *Haselgrabenwind* for an idealised hot day at 21:00 local time. Left: Absolute wind speed $[\mathrm{ms}^{-1}]$ and direction at model level 15 (≅ 400 m a.s.l.). The red line indicates the location of the vertical cross section; Right: vertical cross section of absolute wind speed $[\mathrm{ms}^{-1}]$.

Climate adaptation options

The model results were further used to evaluate the effects of a few general adaptation options with respect to a change in the underlying land use. These adaptation options include, among others, a reduction in soil sealing, roof greening, increasing albedo of surface and roofs. The cooling potential for each of these measures was assessed by deriving climate indices for the reference period 1971-2000 based on the modified land use and by comparing them to the original results. This concept is illustrated by **Figure 50**.

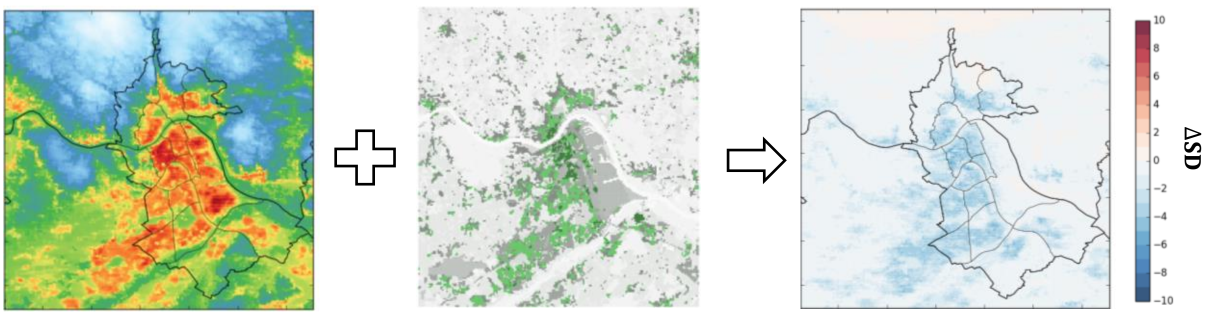


Figure 50: Methodology for assessing the potential of different adaptation measures on urban scale. Left: Future climate signal showing a measure of heat load for the reference scenario; Middle: adaptation options indicated by a change in land use; Right: Future climate signal including the adaptation options subtracted from the original climate signal showing their cooling effect.

Figure 51 shows a selection of results for three different adaptation measures. Depending on the scenario, moderate to strong cooling effects are found, with a local reduction of the mean annual number of summer days of 5 to 10 days are found.

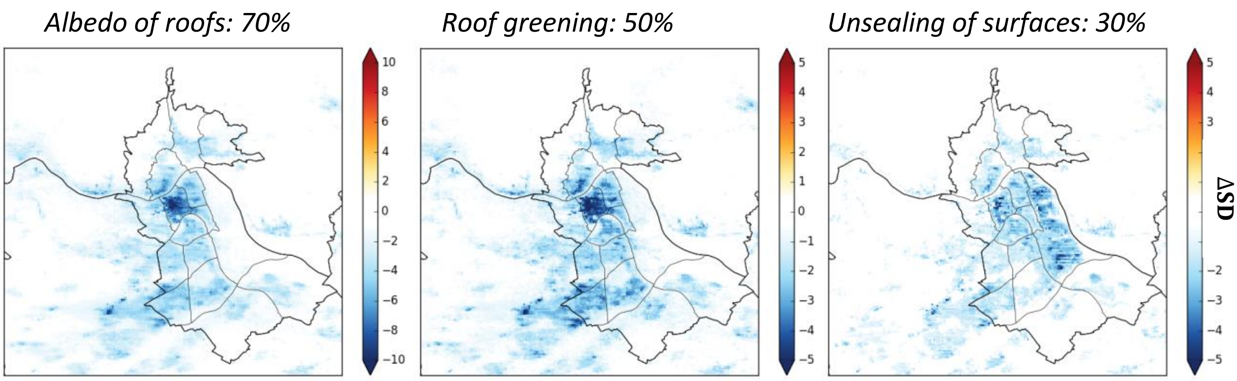


Figure 51: Cooling effect of different adaptation measures, indicated by the difference in the mean annual number of summer days (ΔSD) for the reference period 1971-2000. Left: Increased albedo of roofs (from 30% to 70%, all residential/industrial areas); Middle: Roof greening (50% of all buildings in residential/industrial areas); Right: Reduction in total degree of soil sealing by 30%.

3.4 DC4

DC4 partners are working at present in the preparation of a software tool to ease the implementation of the methodology adopted for the screening of CC risk in a road project. Such a tool is being designed to incorporate the following EU-GL steps: Evaluation of Exposure, Vulnerability Analysis, and Risk and Impact Assessment. The intention is to provide a tool fully coherent with the schematization of the CLARITY modelling workflow that is implemented for urban areas, although adjusted to the specific assessment needs of road infrastructure managers.

The workflow of DC4 according to the EU-GL methodology described in D3.1 is summarized in **Table 26**.

Table 26: Overview of the workflow of DC4 and its relation to the EU-GL methodology.

Hazard Characterisation	Element at risk	Vulnerability	Impact	Adaptation Options
Heat waves	Road infrastructure	High for extreme temperatures and extended durations	Surface deformities, rutting, damage	Changes in road orientation / shadowing
Cold waves	Road infrastructure, People	High during winter	Snow and ice buildup on elevated road surfaces	Changes in routes to lower elevations
Floods	Road infrastructure, People		Insufficient drainage	Increases in drainage sizes / channels

The purpose of this demo case is to document the results of the climate change risk assessment of the "Autovía A-2”, section Guadalajara - Alcolea del Pinar. This risk assessment has been carried out applying the recommendations contained in the "Climate Change Vulnerability and Risk Assessment Methodology for Road Projects", elaborated for its application in the Demonstration Case 4 of the Clarity Project.

The Project includes the section of the A-2 dual carriageway which is the object of the "Autovía de First Generation, N-II, from P.K. 62+000 to the limit of the province of Soria/Guadalajara, P.K. 139+500. Construction and Operation". This is a section of the State Highway Network located entirely within the province of Guadalajara with two lanes for each direction of circulation. From its link with the R-2 motorway in the municipality of Guadalajara crosses the municipalities of Torija, Trijueque, Muduex, Gajanejos, Ledanca, Almadrones, Mandayona, Mirabueno, Algora, Torremocha del Campo, Saúca and Alcolea del Pinar. The section, which is currently in operation, is concessioned by a 19-year period by shadow toll until 2026 to ACCIONA Construction.

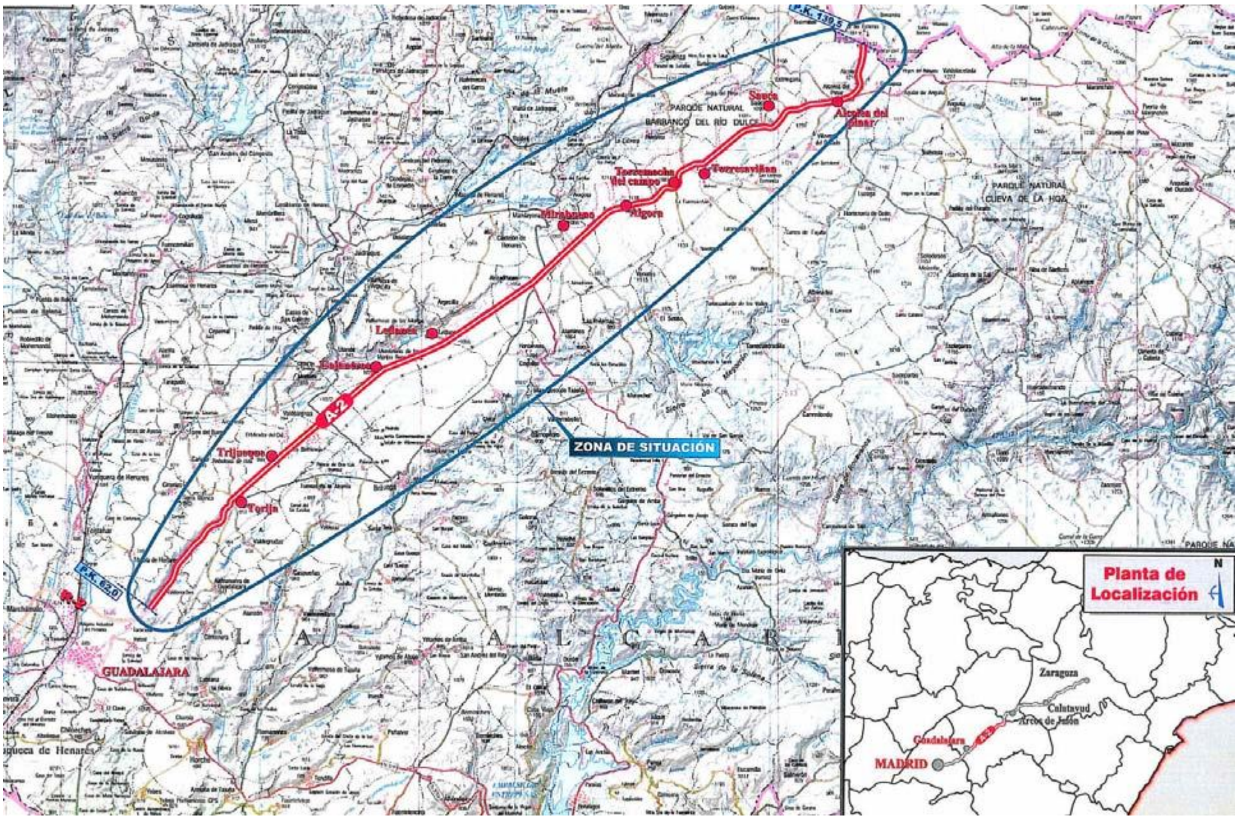


Figure 52: Map showing the region of interest.

The concession contract with ACCIONA Construction comprises three areas of activity:

- Adaptation, reform and modernisation works carried out at the start of the concession period, from 2007 to 2013, to adapt the infrastructure to the technical and functional characteristics required for the correct provision of the service. This entailed substantial modifications in terms of layout, construction and arrangement of links, etc. Also, it was necessary to carry out the rehabilitation works and replacement of existing infrastructure so that they were renovated and improved the initial conditions of the track. The works carried out include, in particular:
    - Route variants.
    - Population variants.
    - Improvement of curves with route variation.
    - Variations in the ground level that involve demolition and reconstruction of the road surface.
    - Construction or extension of service roads.
    - Construction or enlargement of collector roads.
    - Construction of links.
- Replacement, repair or rehabilitation work to be carried out during the life of the concession on those elements of the infrastructure whose estimated useful life is less than the term of the concession contract.

- Operation and maintenance work on the road from the entry into the contract and for the entire duration of the concession. It includes the ordinary conservation and the maintenance of the road, including during the execution of the works of adequacy and reform.

Current and expected future climatic conditions in the project area

The area through which the Project passes is characterized by its high altitude. The elevation of the layout of the motorway varies between 754 and 1,134 metres, with the highest point being at PK 136+000, at which reaches 1,216 m. The potential risk of snowfall and ice accumulation in shaded areas includes the whole section, in particular where it reaches 1,000 m. In fact, a study in the province of Guadalajara recorded for the winter period between 1971 and 2008, a yearly average of 19 days of snow and 114 days of frost.

With regard to the climate conditions foreseen for the future, Figure 2 shows changes in six indices for each province from the current climate. The projections of greatest interest available in the Change Scenario Viewer Climate developed for Spain by the Ministry for Ecological Transition are the two horizons of the evaluation 2048 and 2098.

The upper table in **Table 24** indicates the expected changes in absolute value, while the lower table shows an estimate of the percentage change that these values may imply for current climatic conditions. The maximum rainfall in 24 h (columns 2, 3), shows a general increase in the horizon to 80 years; while an increase in accumulated annual precipitation (columns 4, 5) is not expected. The maximum temperatures (columns 6, 7) in the area of the project will increase slightly more than 1 °C in a horizon of 30 years and by more than 2 °C in 80 years. It is foreseen as well as a very noticeable increase in the maximum duration of heat waves (columns 12, 13). As for minimum temperatures (columns 8, 9), their increase is also predicted, while an appreciable decrease in the number of days with a minimum temperature of less than 0 °C (columns 10, 11) is to be expected.

Table 27: Forecasted future climatic conditions in the project area.

Anomalías respecto de 2018												
Municipio	Precipitación máxima en 24 horas (mm)		Precipitación anual acumulada (mm)		Percentil 95 de la temperatura máxima diaria (ºC)		Percentil 5 de la temperatura mínima diaria (ºC)		Número de días con temperatura mínima inferior a 0ºC		Duración máxima de las olas de calor (días)	
	2048	2098	2048	2098	2048	2098	2048	2098	2048	2098	2048	2098
Guadalajara	0,7	2,7	-0,1	-0,1	1,1	2,2	0,4	1,0	-8,2	-18,3	5,8	12,3
Torija	0,6	3,6	-0,1	-0,1	1,2	2,2	0,4	1,0	-8,9	-19,3	6,0	12,1
Trijueque	0,8	3,8	-0,1	-0,1	1,2	2,2	0,4	1,0	-9,3	-20,4	6,0	12,0
Mudeux	1,0	3,9	-0,1	-0,1	1,2	2,2	0,5	1,0	-9,6	-21,2	5,9	11,6
Gajanejos	0,9	3,4	-0,1	-0,1	1,2	2,2	0,5	1,0	-9,8	-21,6	5,8	11,4
Ledanca	0,5	2,6	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,2	-22,4	5,5	11,0
Argecilla	0,5	2,6	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,2	-22,4	5,5	11,0
Almadrones	0,5	2,6	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,2	-22,4	5,5	11,0
Mandayona	0,9	1,6	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,6	-23,3	5,0	10,5
Mirabueno	1,1	1,7	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,7	-23,3	5,1	10,7
Algora	1,1	1,7	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,7	-23,3	5,1	10,7
Torremocha del Campo	1,2	1,1	-0,1	-0,1	1,2	2,2	0,5	1,1	-10,9	-24,2	4,6	10,2
Saúca	0,4	0,1	-0,1	-0,1	1,2	2,2	0,5	1,2	-11,1	-24,8	4,8	10,0

Municipio	Precipitación máxima en 24 horas (%)		Precipitación anual acumulada (mm)		Percentil 95 de la temperatura máxima diaria (%)		Percentil 5 de la temperatura mínima diaria (%)		Número de días con temperatura mínima inferior a 0ºC (%)		Duración máxima de las olas de calor (%)	
	2048	2098	2048	2098	2048	2098	2048	2098	2048	2098	2048	2098
Guadalajara	2%	6%	0%	0%	3%	6%	1%	2%	-19%	-54%	26%	42%
Torija	1%	8%	0%	0%	4%	7%	1%	2%	-18%	-51%	27%	43%
Trijueque	2%	8%	0%	0%	4%	7%	1%	2%	-17%	-47%	27%	42%
Muduex	2%	8%	0%	0%	4%	7%	1%	2%	-16%	-45%	27%	42%
Gajanejos	2%	7%	0%	0%	4%	7%	1%	2%	-16%	-44%	26%	41%
Ledanca	1%	6%	0%	0%	4%	7%	1%	2%	-16%	-43%	25%	40%
Argecilla	1%	6%	0%	0%	4%	7%	1%	2%	-16%	-43%	25%	40%
Almadrones	1%	6%	0%	0%	4%	7%	1%	2%	-16%	-43%	25%	40%
Mandayona	2%	4%	0%	0%	4%	7%	1%	3%	-15%	-40%	24%	39%
Mirabueno	3%	4%	0%	0%	4%	7%	1%	3%	-15%	-41%	24%	40%
Algora	3%	4%	0%	0%	4%	7%	1%	3%	-15%	-41%	24%	40%
Torremocha del Campo	3%	3%	0%	0%	4%	7%	1%	3%	-14%	-38%	22%	39%
Saúca	1%	0%	0%	0%	4%	7%	1%	3%	-14%	-38%	23%	39%
Alcolea del Pinar	3%	3%	0%	0%	4%	7%	1%	3%	-14%	-38%	22%	39%

3.4.1 Main potential hazards and impacts to the project

Potential hazards associated with climatic events that may have a major impact on the project include:

- Sliding of slopes, and fall of materials and erosion of slopes in embankments.
- Structural movements in the factory site due to the presence of water.
- Insufficient capacity of transverse drainage works due to heavy rainfall.
- Insufficiency of channeling capacity due to heavy rains.
- Insufficiency of bearing capacity due to the presence of water on pavements.
- Formation of pavement rutting as a result of elevated pavement temperatures.
- Insufficient drainage capacity of the road surface (road section).
- Affectation to snow circulation (road section).
- Affectation to the circulation by ice (road section).
- Affectation to circulation by snowdrifts (road section).
- Affectation to the circulation by fires (road section).
- Affectation to the circulation by fog (road section).

In order to determine this list, we have taken into account:

- The list of the main potential impacts that the "Climate Change Vulnerability and Risk Assessment Methodology for Road Projects" suggests using the following as a reference for the Network of Carreteras del Estado,
- The specific characteristics of the project,
- The experience acquired by ACCIONA Construction since the start of the concession for the same in 2009.
- The projected climate change projections for the project area.

The previous relationship focuses on direct impacts, without including possible secondary or synergic effects, such as the negative effect that the use of salt to prevent the formation of ice in the roadway may have on the pavement or on the visibility conditions of the vertical signalling; or the incidence that a fire may produce on the runoff of a basin and the dragging of materials.

3.4.2 Elements of the project that are likely to be further compromised by climate change

Indicated and described below are those locations or sections of the project that are likely to be further compromised by the threats listed above. In all cases, these are sites or sections that are already compromised today, to a greater or lesser extent, by current climatic conditions. It is not expected that any new ones will emerge as a consequence of future climate change.

Land-Clearings

The most compromised are the following:

- Clearance PK 64+500, decreasing carriageway: Slope in lands, with absence of vegetation, of 250 m long and 14 m high, and an intermediate berm. Due to its composition it is affected by the effects of rain, snow and ice-thawing processes, which cause gullies and differential detachments on its surface.
- Clearance PK 72+900 to 73+150, decreasing roadway: Slope 250 m long and 8 m high composed of land and stony material, with the presence of vegetation. It has areas of coating by gunning carried out during construction works. The lithology of the slope and the groundwater cause visible deformations in it, in the area without gunite, which cause landslides that can influence traffic due to the proximity to the motorway's carriageway. Rains, snowfalls and ice-thaw cycles also affect it superficially.
- PK 129+300 to 129+400 cuttings: Slope 100 m long and 5 m high made up of clayey rock. The nature of the material and environmental factors such as rain, snow and processes of ice-thaws cause gullies, cracks and detachments.

Works of passage

- The pontoon located at PK 63+775, 37 m long, lacks drainage and therefore has a relative movement in the fins that is currently affected by rainfall and the corresponding increase in the water table. Given that the trunk of the A-2 is above it, these movements could affect road traffic if there were a notable increase in the phreatic level.

Transverse drainage works

The Project has six transverse drainage works (ODT) that have insufficient drainage and water evacuation capacity in the face of heavy precipitation:

- ODT PK 77+850 (drainage work for pedestrian crossings and drainage).
- ODT PK 93+230.
- ODT PK 126+600.
- ODT PK 130+230.
- ODT PK 132+700.
- ODT PK 137+300.

Water stream channeling

- The channeling of the Torija Valley stream that drains into the junction located at PK 64+000, on the left bank, can overflow in the face of high concentrations of water, causing damage to the slope located at this junction due to the effect of surface runoff.

Pavements

There are two threats to pavements which are of concern. On the one hand, there are four points on the dual carriageway where there are problems of bearing capacity due to the presence of water in the immediately lower layers to the package of firm, which cause seats and deformations in the same. These deteriorations become more visible in rainy seasons:

•PK 64+000, decreasing carriageway:

•PK 73+000, increasing carriageway.

•PK 88+500, decreasing carriageway.

•P.K. 112+000, increasing carriageway.

On the other, there is one point where pavement melting may cause problems to road traffic.

•In the section of curve between PK 88+500 and 88+800, on both roads, potholes are produced by the melt of the bituminous binder due to the combination of the high temperatures of the asphalt in summer and the tangential stresses transmitted by heavy traffic.

Roads Availability

Finally, the main climatic factors that affect road conditions without necessarily damaging infrastructure are the following:

- Accumulation of water on the road from PK 112+000 to 113+000, decreasing roadway, by insufficient capacity of the longitudinal and transverse drainage. The lack of drainage prevents the water coming from the runoff originated by the rains is drained by the drainage work present in the area, which also has small dimensions.
- Snow impact between PK 71+000 and 103+000: section with an altitude between the 900 m and 1000 m that is conducive to snowfall.
- Snow impact between PK 103+000 and 139+500: section with an altitude between the 1000 m and 1200 m in which the bulk of precipitation in the form of snow is concentrated. Snow precipitations tend to lead to restrictions on the heavy vehicle traffic and mandatory use of chains and only exceptionally, the total closure to circulation.
- Ice impact between PK 121+000 and 139+500: section with an altitude between the 1100 m and 1200 m where the lowest temperatures are recorded, which, in combination with the strong ramps and slopes of the layout, increase the risk for the circulation of vehicles by ice formation.
- Formation of snowdrifts from PK 92+700 to 93+300 and from 120+400 to 123+300, both in the decreasing carriageway: areas with possible presence of snow on the carriageway as a result of the strong wind prevailing in the area of snowfall on terrain adjacent to the roadway.
- Potential effect of fire between PK 124+000 and 132+000 as it is located within the Barranco del Río Dulce natural park, which occupies an area of more than 8,000 hectares, and is especially sensitive to fire during the summer season.

3.4.3 Risk assessment of elements that are most likely to be compromised by climate change

It is difficult to apply the theoretical approach proposed in the EU-GL methodology to transport networks due to the absence of reliable statistics that allow the definition of reliable vulnerability functions on the vulnerable elements of the transport network. Accordingly, it has been decided to directly facilitate the characterisation of the vulnerability of each section of the network to the personnel in charge of its management and operation, using their deep knowledge of the threats affecting the roads in their charge as a tool. This approach has been already been successfully implemented in the study "Sections of the state land transport network potentially more exposed due to climate variability and change"; CEDEX June 2018. The methodology implemented here is that from [25].

This document collects the results of the identification analysis of those sections of the road network of the State of Spain and of the railway network potentially most exposed to climate variability and change. In general, each impact has been treated as linking a component of the infrastructure or traffic conditions with a climate factor or hazard, whereby it should be pointed out that this factor may not necessarily be the only cause of the impact.

To evaluate project vulnerability it has been taken into account that this is a combination of two aspects: 1) how sensitive the project's components are to climate hazards (sensitivity) and, 2) the probability of these hazards affecting the component location now and in the future (exposure). Examples of potential climate hazards for transport networks and climate variables or indexes that can give an idea of the possible severity of their occurrence include:

- Extreme precipitation events
    - maximum annual daily rainfall
    - average annual daily rainfall
    - recurrence of maximum daily precipitation
    - accumulated rainfall in 30 days
- Heat waves
    - 95th percentile of maximum daily temperature
    - meteorological risk of forest fires
    - 99th percentile of maximum temperature
    - 99th percentile of the diurnal temperature range
    - accumulated rainfall in 30 days
    - 99th percentile of maximum daily global solar irradiation
- Cold waves
    - 5th percentile of minimum daily temperature
    - 99th percentile of the diurnal temperature range
    - number of days with temperature less than 0 °C
    - number of days with snow risk
    - number of days with probability of ice formation
- Windstorms
    - maxima wind gust
- Forest fires
    - Canadian forest fire weather index (FWI)
    - RSS index.

Possible impacts on elements of the transport network associated with these threats include:

- Sliding of slopes, and fall of materials and erosion of slopes in embankments
- Structural movements in the factory site due to the presence of water
- Insufficient capacity of transverse drainage works due to heavy rainfall
- Insufficiency of channeling capacity due to heavy rains
- Insufficiency of bearing capacity due to the presence of water on pavements

- Formation of pavement rutting as a result of elevated pavement temperatures
- Insufficient drainage capacity of the road surface (road section)
- Affectation to snow circulation (road section)
- Affectation to the circulation by ice (road section)
- Affectation to circulation by snowdrifts (road section)
- Affectation to the circulation by fires (road section)
- Affectation to the circulation by fog (road section)

The depth or detail of the necessary evaluation study will depend on the type of project addressed and the severity of the threats that may develop in the geographical area of the project. As the project types may spread in a wide range, the responsibility for identifying climate hazards that could be important or relevant rests upon technical engineers and other specialists. This analysis should be performed per project component and consider both the current climate variability and future climate change.

The vulnerability assessment combines the sensitivity and exposure analysis to determine which climate hazards are relevant for the project as a result of the project type and its location. The more detailed the assessment is, the more useful the results will be in informing decision making at the various project development phases.

The level of detail, which the risk assessment goes into, depends on the scale of the project (in terms of the type, its size and relative importance), and the project development stage at which the assessment is undertaken. For example, early in the project cycle the assessment is likely to be more high-level than a risk assessment undertaken at the later stages.

In order to understand the risks in more detail, it is important to understand the relationship of the probability of the risk occurring and the severity of the impact if it did occur:

Probability × Severity → RISK

Probability represents how likely the identified climate hazards are to occur within a given timescale, and the levels shown in **Table 28**. The severity accounts for the consequence of the event occurring in terms of the intensity of the possible hazardous events over time, and the levels are shown in **Table 29**. The level of risk is calculated by combining the possible level of affectation with the probability of occurrence of that type of event. The way in which the influence of each of these factors has been considered is shown in the **Table 27**.

Table 28: Scale for Assessing the Probability of Hazards affecting the project.

1	2	3	4	5
Rare	Unlikely	Possible	Likely	Almost Certain
Highly unlikely to occur	Unlikely to occur	Incidents have ocurred in similar sites	Incident is likely to occur	Incident is very likely to occur

Table 29: Scale for Assessing the Severity of Hazards affecting the project.

1	2	3	4	5
Insignificant	Reduced	Moderate	Remarkable	Important
Minimal impact with no special needs for adaptation	The impact resolution is compatible with routine maintenance actions	Modest and very localized repairs and/or replacements are required.	The effect on the integrity of the element is remarkable. Its repair requires a punctual rehabilitation / reconstruction of the element	The effect on the integrity of the element can be total. Its repair requires a generalized rehabilitation / reconstruction of the element

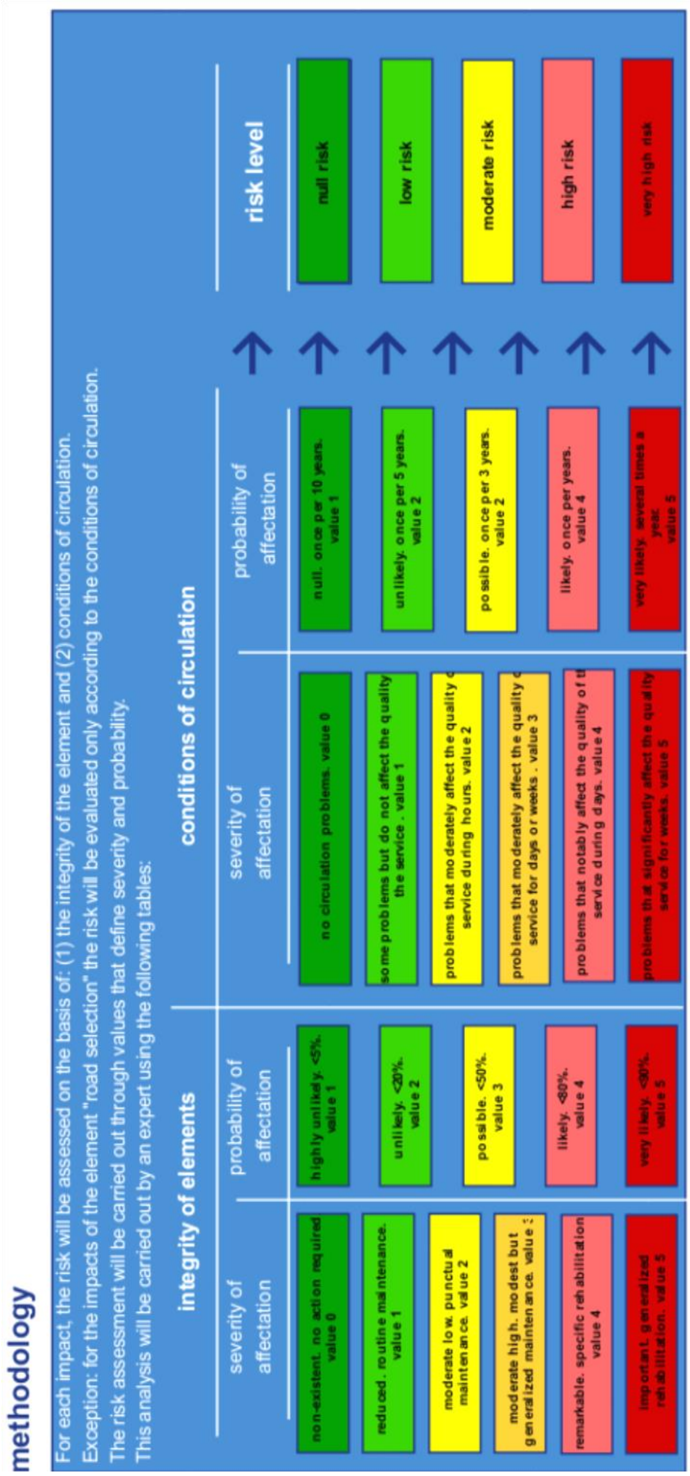


Table 30: Level of risk.

The following is a summary (in Spanish) of the results of the vulnerability and risk characterization of the elements identified in the Project.

EVALUACIÓN DEL RIESGO

Deslizamiento de laderas y caída de materiales y erosión de taludes en desmonte			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
Talud-1	P.K. 64+500 (Enlace)	Severidad afectación	4	4	4	3	3	3
		Probabilidad afectación	3	3	3	3	3	3
		Nivel del riesgo	Riesgo bajo	Riesgo bajo	Riesgo bajo	Riesgo bajo	Riesgo bajo	Riesgo bajo
Talud-2	P.K. 69+300 (Enlace)	Severidad afectación	4	4	4	4	4	4
		Probabilidad afectación	4	4	4	4	4	4
		Nivel del riesgo	Riesgo medio	Riesgo medio	Riesgo medio	Riesgo alto	Riesgo alto	Riesgo alto
Talud-3	P.K. 128+200 a 130+200	Severidad afectación	2	2	2	2	2	2
		Probabilidad afectación	3	3	3	2	2	2
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable

Movimientos estructurales en la obra de fábrica por presencia de agua			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
Pontón	P.K. 64+000	Severidad afectación	5	[illegible]	[illegible]	2	4	4
		Probabilidad afectación	4	4	4	2	3	3
		Nivel del riesgo	Riesgo alto	[illegible]	[illegible]	Riesgo despreciable	Riesgo medio	Riesgo medio

Insuficiencia de capacidad de las obras de drenaje transversal por lluvias intensas			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
ODT-1	P.K. 77+100	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo
ODT-2	P.K. 93+600	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo
ODT-3	P.K. 126+600	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo
ODT-4	P.K. 130+300	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo
ODT-5	P.K. 132+700	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo
ODT-6	P.K. 137+200	Severidad afectación	3	4	4	3	3	3
		Probabilidad afectación	3	3	3	2	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo despreciable	Riesgo bajo	Riesgo bajo

Insuficiencia de capacidad de los encauzamientos por lluvias intensas			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
Arroyo del Valle de Torija	P.K. 64+000	Severidad afectación	4	4	4	2	2	2
		Probabilidad afectación	3	4	4	2	2	2
		Nivel del riesgo	Riesgo bajo	Riesgo medio	Riesgo medio	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable

Insuficiencia de capacidad portante del firme por presencia de agua			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
	P.K. 64+000	Severidad afectación	3	3	3	3	3	3
		Probabilidad afectación	3	3	3	3	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo bajo
	P.K. 73+000	Severidad afectación	3	3	3	3	3	3
		Probabilidad afectación	3	3	3	3	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo bajo
	P.K. 88+500	Severidad afectación	3	3	3	3	3	3
		Probabilidad afectación	3	3	3	3	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo bajo
	P.K. 112+000	Severidad afectación	3	3	3	3	3	3
		Probabilidad afectación	2	2	2	3	3	3
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo bajo	Riesgo bajo	Riesgo bajo

Formación de roderas en el pavimento como consecuencia de temperaturas elevadas			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
	P.K. 88+500 a 88+800	Severidad afectación	3	3	3	2	2	2
		Probabilidad afectación	3	3	3	2	2	2
		Nivel del riesgo	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable	Riesgo despreciable

Insuficiencia de capacidad de desagüe de la superficie de la calzada como consecuencia de lluvias intensas			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
	P.K. 112+000 a 113+000 Calz. Izq.	Severidad afectación				3	3	3
		Probabilidad afectación				4	4	4
		Nivel del riesgo				Riesgo medio	Riesgo medio	Riesgo medio

Afectación a la circulación por nieve			Integridad del elemento			Condiciones de circulación		
			2018	2048	2098	2018	2048	2098
	P.K. 71+000 a 103+000	Severidad afectación				3	2	2
		Probabilidad afectación				4	3	3
		Nivel del riesgo				Riesgo medio	Riesgo despreciable	Riesgo despreciable
	P.K. 103+000 a 139+500	Severidad afectación				4	3	3
		Probabilidad afectación				[illegible]	4	4
		Nivel del riesgo				[illegible]	Riesgo medio	Riesgo medio

3.4.4 Risk assessment results

The previous section details the evaluation of all the elements of the project that have been considered to be at risk in the assessment. In order to assess the severity of the effect in 2048 and 2098, it has been assumed that no improvement or replacement actions are undertaken throughout the period covered by the assessment, except in the case of pavements, in which it is assumed that action is taken at the end of their expected useful life. It has also been assumed that the project's ordinary maintenance standards are maintained over time at a level similar to the current one. From the evaluation carried out, it is concluded that:

- The level of risk in the three cuttings considered to be at risk is not expected to vary over the time horizon covered by the assessment (80 years). The slope with the highest risk level is the one from PK 72+900 to PK 73+150, with medium risk to the integrity of the element and high risk to the conditions of circulation.
- The level of risk from the effect of the water on the pontoon located at PK 63+775 will increase in the future, but not so much as a result of climate change but by the effect of the passage of time. If no action is taken in the short term, the level of risk reached in 2048 may become very high for the integrity of the factory site and pose a medium risk to the environment and circulation of vehicles.
- With regard to the six transverse drainage works which are considered to be at risk, the following measures are taken: estimates that the severity of the impact on the works may increase slightly as a result of the increase in maximum daily rainfall, although this will not lead to an increase in the maximum daily rainfall. This is likely to lead to an increase in the level of risk, which will remain low. With regard to the channelling of the Torija Valley stream, it is presumed that an increase in the frequency of heavy rainfall will result in a possible increase in the level of risk from low to medium with regard to the integrity, although this does not translate into an increase in the level of risk to health, and to the traffic conditions on the motorway, given the location of the channeled stream section with respect to roadways.
- The level of risk in the four pavement sections that currently present problems due to lack of bearing capacity due to the presence of water is not expected to vary over the course of the year. Nor is the level of risk of road markings on the road surface expected to change in the future. Over time as the maximum temperatures rise, assuming that – at the end of the day the case where such a rise in temperature would pose a risk to the pavement – the standards for the design and rehabilitation of pavements to be applied at the time of collection this eventuality. As a result, the level of risk is considered negligible, except in the case of the four sections already pointed out, where the risk level for circulation is low.
- With regard to road safety, climate change is expected to lead to some relaxation in the following areas as to the current high demands of winter maintenance of the section.
- On the contrary, it is foreseeable that - as a consequence of the increase in temperatures and the duration of heat waves - increase the level of risk by 8 km of the Project where there is a greater risk of fire. In any case, it is estimated that the level of risk for road safety will remain low, assuming that the increased efforts they make the administrations (in terms of prevention and provision of means for extinction) will be in accordance with the possible increase that may occur over time in the risk of fire.
- With regard to fog, in the absence of projections, it is assumed that the level of risk for the circulation of vehicles will not vary over time and will remain as at present, with low risk.

Risks requiring possible adaptation measures

For the "Autovía A-2 Tramo Guadalajara - Alcolea del Pinar" project, it is considered that high or very high risks to the integrity of the infrastructure should not be admitted. Nor should risks be allowed for traffic circulation conditions that are of medium or higher level. With this criterion, the risks in this project for which – with priority – it is necessary to consider eventual adaptation measures are the following:

- Due to falling materials and erosion as a consequence of intense rainfall: the clearing located at PK 72+900 to 73+150, due to its impact on traffic conditions.
- Due to structural movements owing to the presence of water: the pontoon located at PK 63+775, due to its impact on the integrity of the work and, from 2048, due to the additional impact on traffic conditions.
- Due to insufficient drainage capacity of the road surface during episodes of very heavy rainfall: left lane of the section from PK 112+000 to 113+000, due to its impact on traffic conditions.
- Due to snow throughout the project (although especially between PK 103+000 and 139+500) and due to snowdrifts from PK 92+700 to 93+300 and from PK 120+400 to 123+300 on the left side of the dual carriageway, due to its impact on traffic conditions.

These are, in all cases, threats that require attention already at present because of current conditions of climate variability, rather than because of climate change that is expected to occur in the future.

In the future, climate change will fundamentally mean that the risk from structural movements on the pontoon located at KP 63+775 will reach not only the integrity of the work but also may have repercussions on traffic circulation conditions. In return, climate change is expected to lead to a reduction in the level of risk to traffic as a result of snowfall.

4 Future Work

Although some mention of future work may have been included in the description of work provided in Chapters 2 and 3, the future work will be elaborated here in this chapter separately. The work plan for the future concerning the screening level and expert level services is provided in the following two sections.

4.1 ICT (Screening) Services Workflow

The original workflow for ICT Climate Services proposed in deliverable D3.1 is summarised in **Table 31**. Additional comments are made within the table in red to indicate the progress and changes which have been made.

Table 31: 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 (done) 2. Select elements at risk (moved to Evaluate Exposure step) 3. Select hazards and indices (done) 4. Prepare hazard maps (offline) (ongoing) 5. Prepare maps with elements at risk (offline) (moved to Evaluate Exposure step) 6. Upload hazard maps or provide link (ongoing) 7. Upload data for elements at risk (to do) 8. Visualize hazards and elements at risk (to do) 9. Analyse Hazards Prepare Report (to do)	**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	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	Concentrate the analysis on the heat and flooding hazards. (ongoing)	**EU-GL**: RA – E **User Stories:** US-CSIS-100 **Test Cases:** TC-CSIS-2000

of the CLARITY EU-GL Methodology.	affect the response of project options to 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 "Vulnerability Analysis" 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 "Vulnerability Analysis" 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 third step "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).	Concentrate the analysis on the heat and flooding hazards. (ongoing)	**EU-GL**: RA – V **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).	Concentrate the analysis on the heat and flooding hazards. (ongoing)	**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 climate variables in relation to each of four key themes (elements at risk).	Concentrate the analysis on the heat and flooding hazards. (ongoing)	**EU-GL**: IAO **User Stories:** US-CSIS-100 US-CSIS-123 **Test Cases:** TC-CSIS-5000
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).	Recently started.	**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			

4.2 Expert Climate Services Workflow

The original workflow for Expert Climate Services proposed in deliverable D3.1 is summarised in **Table 32** (DC1), Table 33 (DC2), **Table 34** (DC3), and Table 35 (DC4). Additional comments are made within the table in red to indicate the progress and changes which have been made.

Demonstration Case 1 – Italy

Table 32: Expected workflow for DC1

Service Name	*Climate adaptive planning / Hazard (Multi-Hazard Analysis)*		
Objective	**Context**	**Workflow summary**	**References**
Visualize heat wave, landslide and pluvial flood hazard maps in relation to climate change projections for the area of the Metropolitan City of Naples	Identify the most exposed areas in terms of buildings and population density, considering the expected hazard exposure variation due to climate change.	1. Select location, hazards and elements at risk (done) 2. Prepare hazard maps (offline) 2a Heat wave hazard 2b Surface flood hazard 2c Landslide hazard 2d Seismic hazard 2e Volcanic hazard Concentrate the analysis on the heat and flooding hazards. (ongoing) 3. Upload hazard maps and elements at risk (ongoing) 4. Visualize hazards and elements at risk (ongoing) 5. Analyse Hazards 6. Prepare Report	**EU-GL**: RA / IA Decision Support **User Stories:** US-DC1-110
Description of the scientific support planned for this			
ZAMG, PLINIVS (Experts) CSIS BB			
Service Name	*Climate adaptive planning / Impact and Visualization of results*		
Objective	**Context**	**Workflow summary**	**References**
(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.	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	1.Select location/project (done) 2.Vulnerability analysis (offline) 2a Heat wave vulnerability 2b Surface flood vulnerability 2c Landslide vulnerability 2d Seismic vulnerability 2e Volcanic vulnerability 2f Integrated vulnerability Concentrate the analysis on the heat and flooding hazards. (ongoing)	**EU-GL**: RA / IA Decision Support **User Stories:** US-DC1-120 US-DC1-150 US-DC1-160

	jointly with Regional or State level authorities.	3.Impact analysis (offline) 3a Heat wave impact (Economic Impact is ongoing) 3b Surface flood impact (Economic Impact just started) 3c Landslide impact 3d Seismic impact 3e Volcanic impact 3f Integrated impact Concentrate the analysis on the heat and flooding hazards. (ongoing) 4. Visualize results 5. Prepare Report	
Description of the scientific support planned for this			
PLINIVS (physical impact), EUREKA (economic impact) CSIS BB			
Service Name	*Climate adaptive planning / Comparison and Adaptation* *Climate adaptive design guidelines and building regulations / Multi-risk 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 (Cost/Benefit Analysis is ongoing)	**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 33: 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 (done) and selects an expert from a list of available experts. (to do) 2. Expert gets in contact with the user requiring more information (to do) 3. Expert applies models for the risk assessment (offline) 3a Surface flood 3b Intense precipitation 3c Lake and sea levels 3d Hydraulic conditions (ongoing) 5. Expert delivers results and reports (to do)	**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 is interested in IGU for adaption and reads about the GAF in the CSI or myClimateServices. 2. Depending on the area and the users problem he can then choose to: 2a Download more information to get started with using the GAF. 2b Contact an expert to order services on using the GAF. (Development of the GAF is completed, integration with the CSIS or myClimateservices need to be done)	**EU-GL**: **User Stories:** US-DC2-210
Description of the scientific support planned for this			
SMHI, STOCKITY (Experts) CSIS BB			

Demonstration Case 3 – Austria

Table 34: Expected workflow for DC3

Service Name	*Preparing climate maps for heat hazard analysis on city scale*		
Objective	**Context**	**Workflow summary**	**References**
Provide high resolution climate maps for heat load at city scale;	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.	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	**EU-GL**: HC RA/IA **User Stories:** US-DC3-100 US-DC3-110 US-DC3-140 **Test Cases:** TC DC3 01
Description of the scientific support planned for this			
AIT, ZAMG (Expert) CSIS BB			
Service Name	*Evaluating the impact of greening measures on the heat load of urban areas*		
Objective	**Context**	**Workflow summary**	**References**
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	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.	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	**EU-GL**: HC RA/IA IAO AAO **User Stories:** US-DC3-100 US-DC3-130 **Test Cases:** TC DC3 02
Description of the scientific support planned for this			
ZAMG, AIT (Experts) CSIS BB			
Service Name	*Evaluating the impact of building characteristics on ventilation within*		

	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 35: 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. (ongoing)	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 (ongoing)	**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	**EU-GL**: RA / IA **Test Cases:** TC DC4 050

		typology	
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 (ongoing)	**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 (ongoing)	**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 (ongoing)	**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			

5 Conclusions

The main objective of this deliverable is to give a report on the work performed in WP3 since the project start, and to provide an updated plan for the remaining work until project end.

The first period of CLARITY has seen work begin on all tasks of WP3 concerning the ICT (Screening) Services and the four Demonstration Cases of the Expert Climate Services. As the tasks follow the EU-GL methodology, it is the case that the results from the main task depend on the results from the previous task – that is, the results of Risk and Impact cannot be completed until the calculations relating to hazard characterisation, element exposure and vulnerability are performed. Thus it is here the case that the methodology for each task can be developed, but the ability to generate final results may be delayed until those of the previous step have been finalised.

As the methodology for the calculation of Risk and Impact has evolved during this period, it was realised that focus needs to be on just the heat and flooding hazards in order to show that the proposed method to downscale the data to the urban scale produces physically realistic results. Consequently, work concerning the other hazards which was planned to be investigated within CLARITY have been limited to hazard characterisation or put on hold until the desired results are achieved with the heat and flooding hazards. Once this “proof of concept” proves to be success, focus will be on the remaining hazards initially proposed to be investigated within CLARITY.

It is to be realised that as much of this work is ongoing – some results presented may represent preliminary results and can be subject to change when the following deliverable D3.2.2 is produced in a year’s time.

6 Acknowledgement

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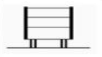
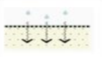
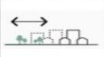
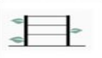
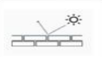
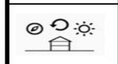
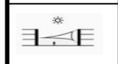
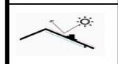
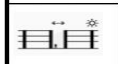
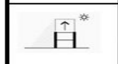
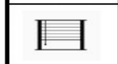
8 Annex I adaptation options

ADAPTATION		TOWARDS WHICH HAZARD	VARIATION ON HAZARD'S LOCAL EFFECT	VARIATION ON VULNERABILITY OF ELEMENTS AT RISK	COST		CO-BENEFITS	Albedo (α)	Emissivity (εs)	Hillshade_building (ψb)	Hillshade_green fraction (ψb)	Run-off coefficient (C)	FUA_tunnel (Ft)
					NEW DEVELOPMENT	RETROFITTING							
	Constructions on piles	Pluvial Flooding	-	++	€€	N/A	Biodiversity • Multifunctional space usage ••	x	x	x		x	x
	Porous pavements	Flooding	+++	+++	€	€	Biodiversity • Multifunctional space usage •	x	x			x	
	Gutter	Flooding	+++	+++	€	€	Social and economic importance •					x	
	Rainwater retention ponds, with or without infiltration possibilities (precipitation can be used in buildings)	Flooding Heat Wave	+++ ++	- -	€€	€€	Biodiversity ••• Air quality • Social and economic importance •• Multifunctional space usage •••	x	x			x	
	Reduced paved surfaces	Flooding Heat Wave	+++ +++	+++ -	€€	€€	Biodiversity ••• Air quality • Energy efficency • Social and economic importance •• Multifunctional space usage ••	x	x		x	x	
	Use of groundcover and shrubbery	Flooding Heat Wave	+++ +++	- -	€€	€€	Biodiversity ••• Air quality •• Energy efficency • Social and economic importance ••• Multifunctional space usage •••	x	x		x	x	
	Green roofs	Flooding Heat Wave	+++ +++	+++ -	€€	€€	Biodiversity ••• Air quality • Energy efficency •• Social and economic importance •• Multifunctional space usage ••	x	x			x	
	Green facades	Heat Wave	+++	-	€€	€€	Biodiversity ••• Air quality • Energy efficency • Social and economic importance •• Multifunctional space usage ••	x	x			x	
	Cool (reflective) roofs	Heat Wave	+++	-	€	€	Multifunctional space usage •	x	x				
	Cool paving and building materials	Heat Wave	+++	-	€	€	Energy efficency • Multifunctional space usage •	x	x				
	Optimize orientation to wind and sun	Heat Wave	+++	-	€	€	Energy efficency •• Multifunctional space usage •			x			
	Pergolas and canvas above streets	Heat Wave	++	-	€	€	Social and economic importance ••	x	x	x		x	
	Thermal insulation	Heat Wave	+++	-	€	€	Energy efficency •• Social and economic importance •	x	x				
	Narrow streets	Heat Wave	+++	-	€€	N/A	Energy efficency •• Multifunctional space usage •		x	x		x	x
	High-rise buildings (shade)	Heat Wave	++	-	€€	N/A	Energy efficency • Social and economic importance •		x	x			
	Blinds	Heat Wave	+++	-	€	€	Energy efficency • Social and economic importance • Multifunctional space usage •	x	x				