CC-ARP-CE TOOLBOX MANUAL – BETA VERSION FOR TESTING BY PPs

WORK PACKAGE T2 - INTEGRATION: CC-ARP-CE TOOLBOX FOR CLIMATE CHANGE ADAPTATION AND RISK PREVENTION IN CE

ACTIVITY A.T2.1 INTEGRATED TOOLBOX FOR CLIMATE CHANGE ADAPTATION AND RISK PREVENTION - VERSIONS FOR TESTING

DELIVERABLE D.T2.1.2 TOOLBOX OF INTEGRATED TOOLS (CC-ARP-CE) - BETA VERSION FOR TESTING BY PPS WITH INSTRUCTIONS

Lead Institution	University of Ljubljana
Lead Author/s	Jerca Praprotnik Kastelic, Barbara Čenčur Curk, Ajda Cilenšek, Primož Banovec, Ana Strgar
Version	V-01
Date last release	01.08.2021

List of contributors

- Infrastruktur & Umwelt – Professor Böhm & Partner (PP3):
  Anna Goris, Stefanie Weiner, Anne Lehmann, Birgit Haupter
- Warsaw University of Life Sciences (PP4):
  Ignacy Kardel, Tomasz Stańczyk, Paweł Trandziuk
- Euro-Mediterranean Center on Climate Change Foundation - CMCC (PP5):
  Guido Rianna
- Federal Research and Training Centre for Forests, Natural Hazards and Landscape (PP7):
  Viktoria Valenta
- Middle Tisza District Water Directorate (PP9):
  Judit Palatinus, Gabor Harsanyi

Table of Contents

List of abbreviations

AHP	Analytic hierarchy process
BMP	Best Management Practices
BWT	Bathing Water Directive
CC-ARP-CE	Integrated toolbox for Climate Change Adaptation and Risk Prevention in Central Europe
CC	Climate change
CE	Central Europe
C3S	Copernicus Climate Change Service
DSS	Decision Support System
DST	Decision Support Tool
DTP	Danube Transnational Programme
DWD	Drink Water Directive
FD	Floods Directive
GIS	Geographic Information System
GWD	Groundwater Directive
GDE	Groundwater Dependent Ecosystems
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control Directive
MCDA	Multi-Criteria Decision Analysis
NSWRM	Natural Small Water Retention Measures
ND	Nitrate Directive
PSD	Priority Substances Directive
SDG	Sustainable Development Goals
RCM	Regional Climate Models
RCP	Representative Concentration Pathway
UWWTD	Urban Waste-water Treatment Directive
WDE	Water Dependent Ecosystems
WFD	Water Framework Directive
WISE	Water information system for Europe

1. Introduction

The main objective of the TEACHER-CE project is to develop an Integrated toolbox for Climate Change Adaptation and Risk Prevention in Central Europe – CC-ARP-CE – which focuses on the adaptation of the water management sector to Climate change (CC) to mitigate the risk of floods/heavy rain/drought as far as possible, e.g. by small water retention measures or protection of drinking water resources through sustainable land-use management.

The TEACHER-CE toolbox is the main component of the project having a specific role as a central online platform to support stakeholders for the integrated consideration of different fields of action of the water management sector that are affected by climate change. The project is integrating and harmonizing results of previously funded projects dealing with CC adaptation and risk prevention, focusing on:

- Management of the effects of heavy rainfall and floods (CE project RAINMAN);
- Exploitation of small water retention measures (CE project FRAMWAT);
- Protection of drinking water through sustainable land use (CE project PROLINE-CE);
- and proper management of forests under CC (CE project SUSTREE).

And on integration of other projects (CE: LUMAT; H2020: FAIRWAY, LifeLocalAdapt; DTP: DRIDANUBE and DAREFFORT, Copernicus Climate Change Service (C3S): Sectoral Information System Disaster Risk Reduction and Demo Case “Soil Erosion”). Moreover, synergies with additional selected projects were built. The conceptualization of the toolbox was performed in a way that it meets the defined aim, but at the same time it is user-friendly and operational.

Building on the tools from the existing projects, TEACHER-CE developed a decision support tool to support **C**limate **C**hange **A**daptation and **R**isk **P**revention in **C**entral **E**urope (CC-ARP-CE) in the water management sector. All these aspects are included into the CC-ARP-CE toolbox logo (Figure 1): vertical blue lines are presenting rainfall (heavy rain), inclined yellow lines are presenting sun (rising temperature), blue curls are presenting water (runoff and floods) and brown horizontal lines soil (drought) and all these elements are affected by climate change.

Figure 1: Logo of the CC-ARP-CE (TEACHER-CE) Toolbox: Integrated toolbox for Climate Change Adaptation and Risk Prevention in Central Europe

The User Experience Design is especially important. In addition to the selected projects named above, the project partners have identified that a plethora of tools supporting water management on national level as well as EU level already exists. These tools have been put into perspective as the potential users of the toolbox should not be confused with one more tool having similar features as comparable, already existing tools. Some of the tools which exist on the national level are official tools providing information on water bodies and especially their status (according to EU WFD), information on flood hazards and program for the implementation of flood risk reduction measures (EU Floods Directive). A collection of maps for the Water Information System for Europe (WISE) can be found in the Floods Directive section (Floods Directive 2007/60/EC).

The toolbox is defined as the main objective of the project in the TEACHER-CE application form. Tools will be developed, prepared/programmed for an online platform and validated in pilot activities with the aim to support stakeholders of water management in integrated strategies and actions for climate change adaptation and prevention/reduction of associated risks. We have recognized the need for and positioning of the toolbox in the area where it can help integrate cross-use strategies for specific catchment (i.e. size of the TEACHER-CE pilot actions) where interests of different user groups meet and confront the challenges related to the climate change adaptation process in the water management sector.

To link multiple sectors involved in the decision-making process on the level of sub-basins and catchments which are close to the municipalities in longer-term strategic vision (e.g.: potential drinking water source), the idea of the capitalization of the aforementioned tools is to:

(a) make the tools "climate proof" and applicable in a climate change perspective and

(b) Integrate the tools in a comprehensive Toolbox to tackle interacting water-related issues affecting CE.

The aim of the TEACHER-CE Toolbox is also that of stimulating the exchange of different views and visions on the development of water in specific catchments with different stakeholders. Therefore, it is supporting the learning process along with the participatory process which is already envisaged by the WFD CIS Guidance Document No 8 - Public Participation in Relation to the Water Framework Directive (European Communities, 2003).

TEACHER-CE is therefore having a holistic approach focusing on water issues. It contributes to the improvement and implementation of the EU WFD, FD, GWD, DWD and SDG6 by:

(i) developing the TEACHER-CE Toolbox and recommendations considering climate change (CC);

(ii) promotion of policy recommendations to stakeholders that have not been approached before;

(iii) linking the Toolbox for CC adaptation and risk prevention with other tools from the broad field of action in integrative and participatory water and land use management.

It is therefore well embedded in the context of existing WFD and FD processes, but at the same time attempting to avoid the multiplication of the existing tools.

In order to support the use of the toolbox CC-ARP-CE this manual was created to present the theoretical basis of the toolbox of integrated tools - beta version. After the toolbox has been revised and reviewed by the Project Partners and other experts, the toolbox will be further updated into version 1.0 (Figure 2). The Toolbox version 1.0 manual (D.T2.1.3) will provide tutorials (step-by-step instructions) to assist stakeholders and other users in the water management sector.

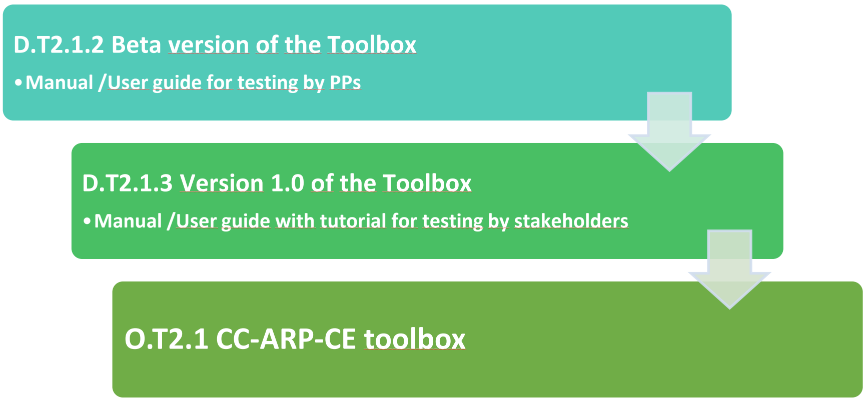


Figure 2: CC-ARP-CE toolbox development

2. CC-ARP-CE

The CC-ARP-CE aims at the integration of different views. The users provide their ideas/issues/problems within a specific sub-river basin (Figure 3) and overview about the national tools is available. The toolbox includes a web map service which provides spatial orientation and provides information about expected variations induced by climate change in weather forcing impacting water related issues by means of widely consolidated climate indicators.

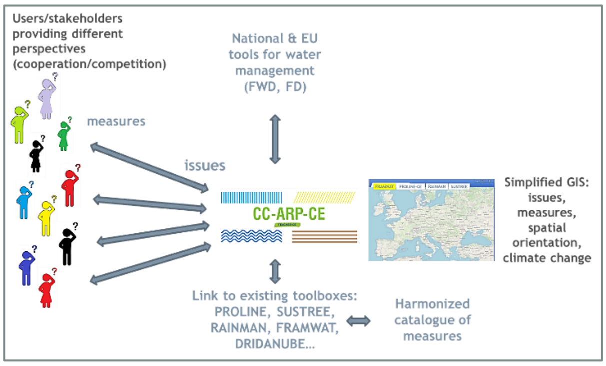


Figure 3: Conceptual scheme of the Toolbox

Each specific user can identify and enter his/her issue (Figure 4) in the toolbox, gets an overview about the evaluation tools developed in other projects. The user can understand the issues and the proposed measure from the other users, sees these issues on the map, gets an overview about CC impacts on a NUTS level and gets information related to the national tools for water management (WFD & FD).

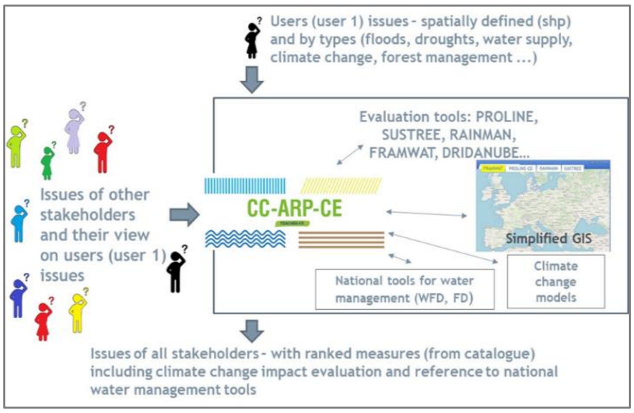


Figure 4: Toolbox workflow

The result of using this tool would be the issues of all stakeholders identified on a platform with a ranking of the measures from the catalogue (described in Chapter 2.5), including the assessment of the impact of CC and the reference to the national water management tools. This will support the development of river management plans and the integration of Green Infrastructure and Nature Based Solutions in specific river basins.

2.1. The Toolbox Structure

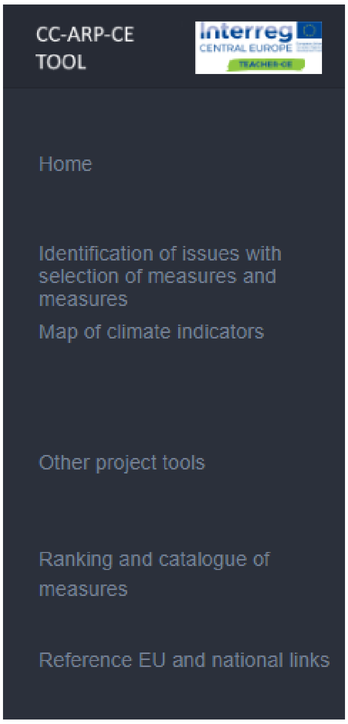


Figure 5: CC-ARP-CE toolbox functions.

I. Identification of Issues with selection of measures
II. Map of Climate indicators
III. Other Project Tools
IV. Catalogue of measures
V. Reference of EU and National links

The Toolbox can be found at: http://teacher.apps.vokas.si/

The user name and the password are assigned when contacting the administrator (ajda.cilensek@fgg.uni-lj.si). Each user should be registered for better identification of users, as the information inserted in the toolbox is sensitive in nature and can be easily manipulated, so we need to have a control over (reliable) users.

2.2. Identification of Issues

The CC-ARP-CE tool focuses on the identification of potential water related issues such as floods, heavy rains and droughts and connecting them with measures for flood and drought risk prevention, for adaptation to climate change and for protection of water resources through sustainable land-use management. It aims to identify potential climate impacts on water availability and water quality which could affect surface and groundwater. Users can insert recognised issues related to impacts of climate change on the water management sector in the CC-ARP-CE toolbox. Issues are documented in the toolbox by using a GIS feature and locating the issues at a specific point on the map. For each issue it is also possible to connect them to the relevant field of action (described in chapter 2.2.1), land use and administrative level. Based on this information, a set of measures applicable for this specific issue is proposed by the toolbox – the user has the possibility to make an individual selection out of this set of measures.

The tool helps the user with defining the issue, enables the comparison with other similar issues in other countries, checks the proposed measures, and provides the expected variations in different climate indicators, proxies for water-related issues, under two time horizons and concentration scenarios for a selected area. The proposed measures help improve the capacities of local and regional stakeholders to adapt to different impacts with the focus on climate-proof water management.

The issues are shown on the map and are listed in a table below the map. The issue is presented with the icon relevant to the Field of action and the colour represents the category as shown in the legend (forestry, general water management, and more).

The identification of the issues procedure:

1. click new issues, locate the issue on the map
2. describe the issue

3. choose the relevant field of action
4. the location level (as attribute) should be added: e.g. point, municipality, region
5. evaluation of the proposed measures - select the most relevant ones. If the user is not sure about the selection, he/she can first use the feature “Catalogue of measures - ranking of measures”, where with the help of AHP method he/she can browse the measures which will be prioritized according to his/her choice.
6. the climate indicators computed at NUTS level are shown sorted by importance - which are relevant for the selected Field of action.
7. The report of the specific issue includes all the selected measures (by type of evaluator).

The user can comment an issue proposed by other users, when choosing an issue and clicking: comment an issue (button below the issue description). This comment will be seen in the report of the specific issue.

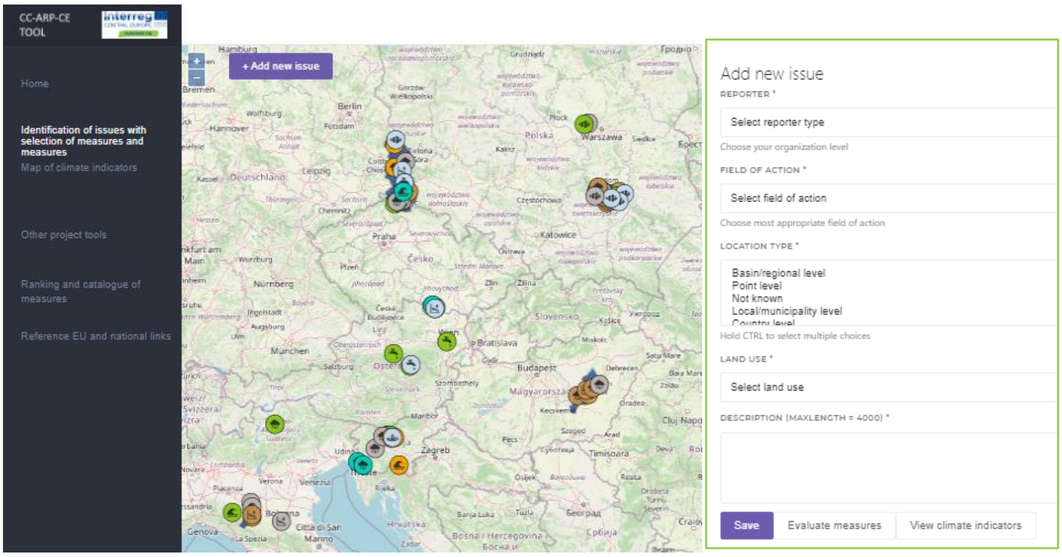


Figure 6: Add new issue option (Screenshot from CC-ARP-CE)

2.2.1. Fields of Action in Water Management

The potential water related issues are categorized according to the relevant field of action. This is due to the broad scope of the term “water management”, which comprises many different fields of action on all administrative levels, regarding water quantity as well as water quality and concerning a wide variety of management tasks of freshwater and other waters (e.g. waste water) in different geographic circumstances (e.g. rivers, lakes, marine). In this compilation, this scope has been narrowed to the main aims of the TEACHER-CE Tool within the D.T1.1.3 deliverable (TEACHER,2020) to achieve a targeted input. In this way several fields of action of the water management sector were identified that are affected by climate change.

The terminology used in D.T1.1.3 was updated with expressions used in EU legislation and strategies and from other strategies (WMO, GWP, WHO, etc.). Seven fields of action of the water management sector were identified that are relevant for TEACHER-CE:

- Fluvial flood risk management
- Pluvial flood risk management
- Groundwater management
- Drinking water supply management

- Irrigation water management
- Water scarcity and drought management
- Management of water-dependent ecosystems

The identified issue is shown on the map with the icon of the relevant Field of action and coloured according to the relevant category (forestry, general water management, agriculture, wetland, grassland, river training and erosion control structures and urban) as shown in **Napaka! Vira sklicevanja ni bilo mogoče**

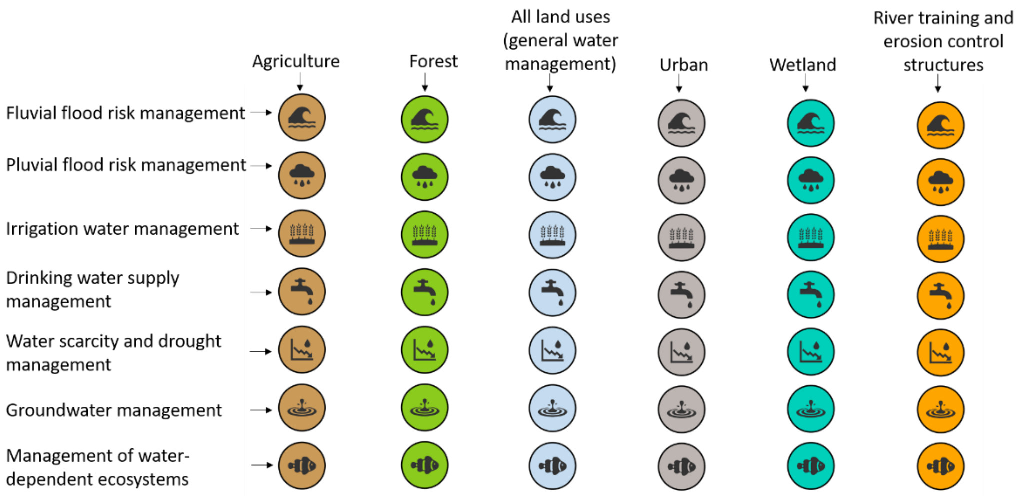


Figure 7: Icons representing identified issues according to the relevant Field of Action and Category

najti..

1. Fluvial flood risk management

Fluvial (river) floods occur when a natural or artificial drainage system, such as a river, stream or drainage channel, exceeds its capacity (European Court of Auditors: Special Report Floods Directive, no 25/2018). Management of flood risks (prevention, protection, preparedness) is aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods (EU Flood Directive (2007/60/EC)).

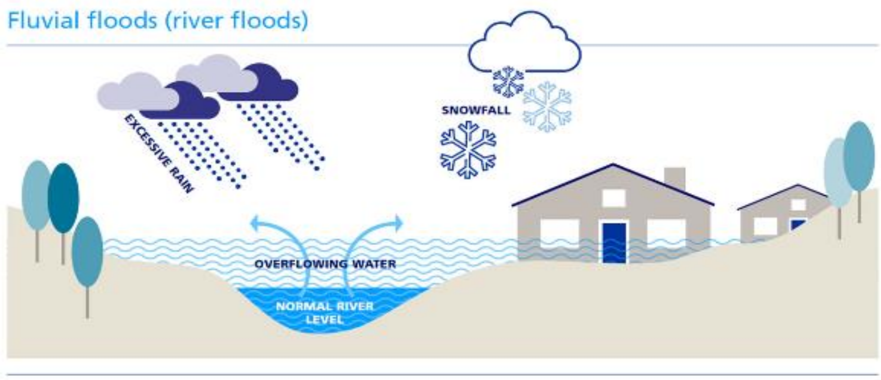


Figure 8: Fluvial floods (source: www.zurich.com)

2. Pluvial flood risk management

Pluvial flooding is “direct runoff over land causing local flooding in areas not previously associated with natural or manmade water courses”. Two key aspects of the definition are “the lack of proper drainage network in the area impacted by the flood" (Monacelli and Bussettini, 2011) and a lack of retention of surface water before it enters (urban) areas (RAINMAN Policy Brief, June 2020).

Flash flood is a flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area (Glossary of the American Meteorological Society, 2000). Key aspect of the definition is the time scale: sudden hydrological response to the causative event. Flash floods occur when heavy rainfall (and/or rapid snowmelt) exceeds the ability of the ground to absorb water and/or the ability to drain the water and the water level rises and falls quite rapidly. Flash Floods can occur also due to Dam or Levee Breaks, and they can be associated to hyper-concentrated flows (Monacelli and Bussettini, 2011).

Sustainable Drainage Systems (SuDS) measures are part of pluvial flood risk management because they are important in urban areas, i.e. the ability to infiltrate water into the ground. (Donatello, 2021).

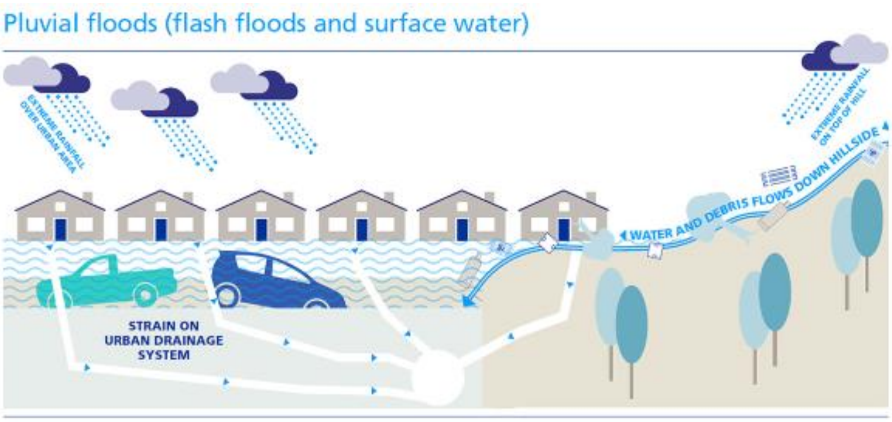


Figure 9: Pluvial floods (source: www.zurich.com)

3. **Water Scarcity and Drought management**

Water scarcity represents a condition of long-term water shortage preventing to satisfy long-term average requirements; it refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system (Water Exploitation Index) (EU Action on Water Scarcity and Drought - Policy Review 2012).

Drought (meteorological, hydrological, agricultural) is a temporary decrease of the average water availability due to e.g. rainfall deficiency or significant evaporative demand; imbalances between water demands and the supply capacity of the natural system. Recent documents added the expression socio-economic drought, which is associated with an imbalance between water demand and water supply and having an impact on society and the economy (GWP CEE 2015).

4. **Groundwater management**

Groundwater management refers to the groundwater quality management (pollution prevention & groundwater protection) and the groundwater quantity management (recharge and water use/demand); also risk and uncertainty.

Measures for the achievement of good quantitative and chemical status of groundwater are presented in EU WFD (Directive 2000/60/EC). Specific measures to prevent and control groundwater pollution are described in the EU Groundwater Directive (Directive 2006/118/EC).

5. **Drinking water supply management**

Drinking water sources protection demands establishing water protection zones for bodies of water used for the abstraction of water intended for human consumption - EU WFD (Directive 2000/60/EC).

Quality of and access to water intended for human consumption are specified in the EU Drinking Water Directive (98/83/EC).

REMARK: in TEACHER-CE we are addressing only protection and management of drinking water sources (recharge area) and we are not addressing the entire chain of drinking water supply elements (raw water treatment and drinking water distribution system).

6. **Management of water-dependent ecosystems**

The chemical composition of the groundwater body is such that the concentrations of pollutants would not result in any significant damage to terrestrial ecosystems which depend directly on the groundwater body (GDE - groundwater-dependent-ecosystems) (EU WFD (Directive 2000/60/EC)).

Groundwater should be protected from deterioration and chemical pollution, which is particularly important for groundwater-dependent ecosystems (EU DWD (98/83/EC)).

Water dependent ecosystems (WDE) are parts of the environment in which the composition of species and natural ecological processes are determined by the permanent or temporary presence of flowing or standing surface water or groundwater. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries, karst systems and groundwater-dependent terrestrial vegetation are all WDEs (Gov. Western Australia, Guidance note 7: Managing the hydrology and hydrogeology of water dependent ecosystems).

7. **Irrigation (water) management**

Irrigation is water management primarily for agriculture: irrigation is the provision of water to support the growth of crops when rainfall is insufficient. There are also irrigated parks, sports fields, golf courses, and other green spaces.

2.3. Map of Climate Indicators

The Toolbox CC-ARP-CE provides information about expected variations in climate indicators potentially due to climate change. Climate indicators are used as proxies for impacts which could affect water management in Central Europe. Fifty-three indicators have been selected accounting for Project Partners and stakeholders' requirements collected by using a web-survey or during the stakeholder workshops held in Autumn 2020.

The indicators are computed exploiting 19 climate simulation chains included in EURO-CORDEX multi-model ensemble where dynamical downscaling by using Regional Climate Models (RCM) is carried out at a horizontal resolution of about 12 km (0.11°). The list of considered modelling chains is reported in deliverable D.T2.1.1, which is attached to this document as an Appendix 1.

For each climate indicator, two Representative Concentration Pathway RCPs (the midway RCP4.5 and the more extreme RCP8.5; more details in Appendix 1)) and time horizon (2021-2050 vs 1971-2000 or 2071-2100 vs 1971-2000) are provided. The values can be visualized in terms of median value of the anomalies aggregated at NUTS level (level 3 for all the countries except Germany for which level 2 is used). For more expert users, beyond median values, data corresponding to the first and third quartiles are also provided at NUTS level and grid point level (exploiting the grid points as provided by EURO-CORDEX simulations).

The List of the selected Climate Indicators:

SU	Number of summer days: Annual count of days when TX (daily maximum temperature) > 25°C
FD	Number of frost days: Annual count of days when TN (daily minimum temperature) < 0°C
PRCPTOT	Annual total precipitation in wet days

R20mm	Annual count of days when PRCP≥ 20mm
R95pTOT	Annual total PRCP when RR > 95p
Rx5day	Monthly maximum consecutive 5-day precipitation
SPI3	Standardized Precipitation Index (3 months)
CDD	Maximum length of dry spell: maximum number of consecutive days with RR < 1mm
CWD	Maximum length of wet spell: maximum number of consecutive days with RR ≥ 1mm
GSL	Growing season length: Annual count between first span of at least 6 days with daily mean temperature T>5°C and first span with T<5°C
HCB	Hydro-Climatic Budget
PR95prctile	95th percentile of daily precipitation
PrRP	Variations in expected precipitation for fixed return period (5,10,25,50,100)
TR	Number of tropical nights: Annual count of days when TN (daily minimum temperature) > 20°C
HD	Number of hot days: Annual count of days when TX (daily maximum temperature) > 30°C
R30mm	Annual count of days when PRCP≥ 30mm
CFD	Consecutive Frost Days - maximum number of consecutive days with Tmin < 0°C
CHD	Heat spell - annual number of days with at least 3 consecutive days when TX> 30°C
DHD	Degree of heating days per year
Bio1	Annual mean temperature
Bio2	Annual mean diurnal range
Bio3	Isothermality
Bio4	Temperature Seasonality
Bio5	Max Temperature of Warmest Month
Bio6	Min Temperature of Coldest Month
Bio7	Annual Temperature Range
Bio8	Mean Temperature of Wettest Quarter
Bio9	Mean Temperature of Driest Quarter
Bio10	Mean Temperature of Warmest Quarter
Bio11	Mean Temperature of Coldest Quarter
Bio12	Annual Precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality
Bio16	Precipitation of Wettest Quarter
Bio17	Precipitation of Driest Quarter
Bio18	Precipitation of Warmest Quarter
Bio19	Precipitation of Coldest Quarter
SSA	Mean of daily surface snow amount (mm)

EWS	98th percentile of daily maximum wind speed (m/s)
SCD=SSA 30	Snow Cover Duration (number of days with surface snow amount >= 30 mm)

To display the desired values of indicators for a specific area use the navigation window in the upper right corner:

1. Select the climate indicator (Figure 10)
2. Select the period (Figure 10)
3. Select the RCP scenario (Figure 10)
4. Click on the area (NUTS) of interest

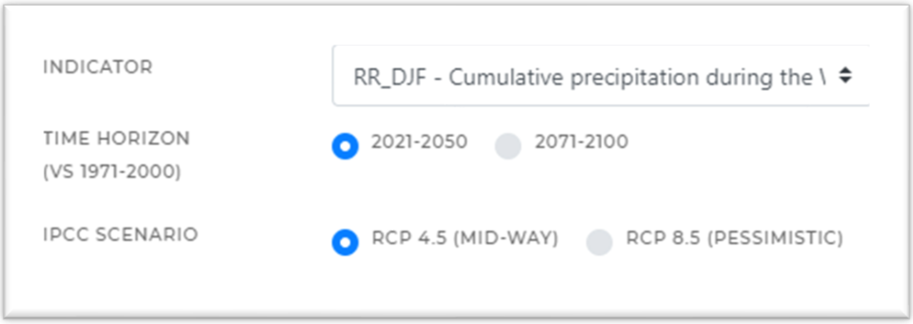


Figure 10: Climate indicator selection panel

Climate indicators relate to measures through Fields of actions.

The map shows the climate indicators at NUTS level, but for the advanced users the download of the EUROCORDEX grid point level of the indicators will be optional upon request to the administrator.

2.4. Other Project Tools

The Toolbox focuses on the integration of the results and tools developed in the selected Interreg Central Europe (CE) projects and other EU projects, reviewed in D.T1.1.1, in D.T1.1.5 and D.T2.1.5.

The selected results of each project integrated into the TEACHER-CE toolbox are shortly presented below.

The core of the catalogue of measures is formed by the specific outcomes of four projects (FRAMWAT, PROLINE-CE, RAINMAN and SUSTREE) which results are directly exploited.

The focus of the TEACHER-CE Toolbox is set on the climate-proof management of water related issues, recognizing common achievements of the four transnational cooperation projects in the programme area of Central Europe. They are sharing several focus points:

- floods/heavy rain/drought risk prevention (FRAMWAT, PROLINE-CE, RAINMAN),
- small water retention measures (FRAMWAT, PROLINE-CE, RAINMAN),
- protection of (drinking) water sources through sustainable land-use management (PROLINE-CE),
- forest adaptation process (SUSTREE).

In addition to the four selected main projects, the toolbox CC -ARP- CE and its catalogue of measures integrates the catalogues of measures and the tools from other EU projects analysed in D.T1.1.1 as listed below: Direct exploitation of results - Other European projects (LUMAT, LIFE LocalAdapt, LIFE+ KAMPINOS, H2020 Fairway, DTP DRIDANUBE, DTP JOINTISZA, Sectoral Information System on Disaster Risk Reduction Contract in Copernicus Climate Change Service (C3S), Demo Case“Soil Erosion” in Copernicus Climate Change Service (C3S)).

The analysis also included the other EU projects to create synergies that are not directly exploited in the TEACHER-CE toolbox. Only selected measures were included in the catalogue of measures. Indirect exploitation of results - Other European projects (CE boDEREC, DTP CAMARO-D, DTP Danube Floodplain, DTP DAREFFORT, DTP REFOCuS, CEF Telecom HIGHLANDER, H2020 Shui, LIFE+ ReQpro, V-A DE-Saxony/CZ; STRIMA II, V-A Saxony/PL TRANSGEA, V-A Saxony/PL NEYMO-NW).

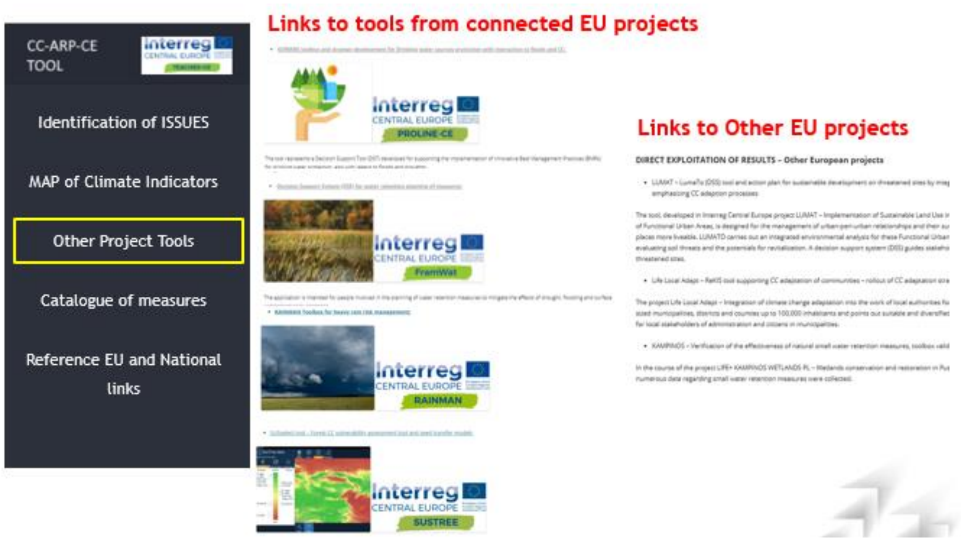


Figure 11: Other Project Tools panel with information about relevant projects and links to tools

Not all projects from the list of exploited projects produced catalogues of measures, some of them produced modelling tools instead. These projects are integrated into our toolbox in two possible ways: as links to the tools or within the catalogue as a measure.

Table 1: Overview of the key features of the tools integrated in the TEACHER- CE project

FRAMWAT:	Development of the two-stage system of sub-basin status identification, static tool assessment (simplified modelling), dynamic tool assessment (modelling), development of concept plan and action plan for the implementation of mitigation measures based upon the non-structural small water retention measures. Use of the GIS DSS tools on different level of this process. Focus on floods, droughts and water quality. Climate change impact and adaptation process is not addressed.
PROLINE-CE:	Focused on the groundwater protection zones for drinking water supply, interaction with floods and forest management. Development of a complex catalogue of measures related to drinking water protection, including CC and nonstructural flood measures, which are related to the pilot actions. The AHP decision support tool uses this catalogue of measures as a core DSS component of the project.
RAINMAN:	Catalogue of measures to mitigate heavy rain risks. The RAINMAN toolbox informs about risk mitigation measures and does not depend on climate related changes (whereas the

	implementation of some of the measures by the user would depend on it). The RAINMAN-Toolbox guides the adaptation process of municipalities and regions related to heavy rain risks with the assumption that heavy rain events will increase in the future.
SUSTREE:	Identification of vulnerability of forest species/structure to climate change. The toolbox is a delineation model for forest seed transfer and genetic conservation.

2.5. Ranking and catalogue of measures

2.5.1. AHP Method - short introduction

The AHP method (Analytic Hierarchy Process) is a Multi-Criteria Decision Analysis (MCDA) tool for the analysis of complex decision-making processes and for supporting decision makers in the selection of the most suitable decisions among a number of alternative solutions. Rather than prescribing a "correct" decision, the AHP helps decision makers to find one that best suits their goals and their understanding of the issue. It does this by using a set of evaluation criteria that can be analysed independently. The process ends with the attribution of a weight to each of the available solutions which leads to the identification of the most suitable measures (PROLINE, 2019).

The AHP method can be summarized by the following operative steps:

1- formulate the hierarchic tree,

2- create a pairwise comparison matrix,

3- check the consistency of the assigned values,

4- calculate the weights,

5- evaluate the final ranking of the alternative and take the final decision.

A detailed description of the AHP method, can be found in Appendix 2, attached to this document.

2.5.2. Ranking of Measures using AHP Criteria

The core of the TEACHER-CE Toolbox CC-ARP-CE is an integrated comprehensive catalogue of measures, gathered from all directly exploited projects and some from other connected EU projects (described in Chapter 2.4).

The results of selected projects were reviewed and harmonized by our expert group to create synergies and include measures that meet the objectives of TEACHER-CE. The result of this approach is the harmonised catalogue of measures which was evaluated according to the ranking of selected criteria. The measures can be filtered by categories (fields of action, land use, type of measures) and assessed with the Analytical Hierarchical Process for selecting measures according to criteria with pairwise comparison (see chapter 2.5.1). The selected criterias are listed below and described in subchapters 2.5.2.1 – 2.5.2.4:

1. cost
2. multi-functionality
3. robustness
4. duration & complexity of implementation

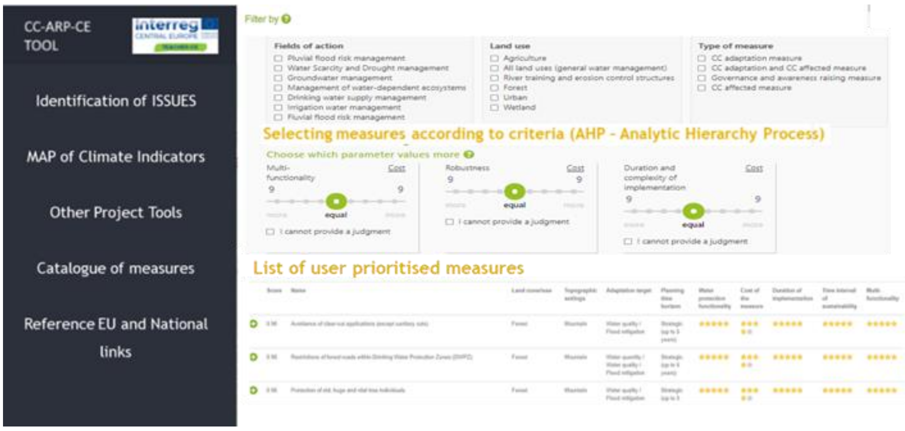


Figure 12: Ranking of measures using AHP criteria

An additional filtering category was added according to CC adaptation measure, CC affected measure, CC adaptation and CC affected measure, Governance and awareness raising measure:

- CC adaptation measures are measures to prepare and adapt to both the current impacts of climate change and the projected impacts in the future.
- CC affected measures are measures whose effectiveness could be limited by the climate change.
- Governance and awareness raising measures are general measures important to the water management sector connected to governance and for raising awareness.

2.5.2.1. Cost

Cost is defined in terms of the relevance of economic constraints to the selection of measures. All aspects "from cradle to grave" should be considered.

Including:

- cost-efficiency: e.g., in terms of quantity (m3) rather than general cause.

- Land requirements: usually an investment (e.g. storage area) or measure (e.g. temporary inundation) needs a specific piece of land that is not obviously owned by the investor (state, municipality, etc.). A sub-criterion (land requirement) can be defined for more detailed evaluation of the cost of the selected measure.

Rating: the cheaper the BMP, the higher the associated rate.

2.5.2.2. Multi-functionality

Multifunctionality, meaning the ability to provide other functions for which the BMP is not specifically designed. It includes additional functions, for example hydrological regulating functions (objective status of the waterbodies) as additional services (e.g., supporting, provisioning, regulating, cultural).

Rating: the larger/higher the suite of services provided, the higher the associated rate.

2.5.2.3. Robustness (Sustainability with Climate Robustness)

This refers to the ability of BMPs to cope with external constraints that were not planned for or were subject to uncertainty during the design phase (e.g., climate change or land use change in surrounding areas). Under such constraints, robust BMPs should be able to maintain sufficient effectiveness despite limited adjustments (e.g., in the form of additional maintenance).

Rating: the more robust the BMPs, the higher the associated rate

2.5.2.4. Duration & Complexity of Implementation

The duration of implementation is very complex and can be seen as a barrier to realisation. Duration is the time it takes to implement BMPs and until a measure is effective. It should include all aspects: e.g., securing social acceptance, eminent domain, administrative issues, actual realization until sufficient BMP effectiveness is achieved. The implementation time criterion is focused mainly on the implementation itself and generally does not address the ever-repeating necessary maintenance of a specific measures. The "duration" criterion therefore refers only to the first implementation.

The issue of maintenance should properly be addressed in the "cost" criterion, where also the maintenance costs should be assessed.

The main problem with nature and climate-oriented rehabilitation of water bodies is the realisation and duration of land acquisition, in some countries it is not a question of available budgets or costs. It is simply a matter of land availability and willingness to sell and the complex land acquisition procedures for public (environmental) needs. Thus, based on reality, the most multifunctional and robust measure may make the smallest contribution to actual adaptation.

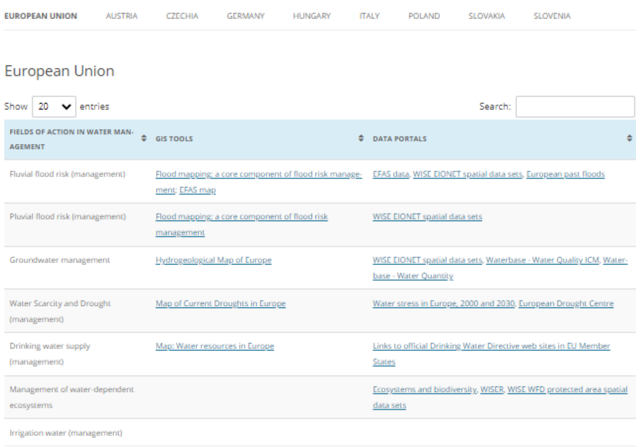
Rating: The shorter and simpler the implementation process, the higher the rate.

2.6. Reference EU and National links

Navigating the universe of pre-existing tools in the field of water management is challenging. Therefore, we have collected the existing national links to different tools (data portals, reports, legislation, etc.) that are closely related to the implementation of EU legislation:

- Water Framework Directive (WFD),
- Floods Directive (FD),
- Urban Waste-water Treatment Directive (UWWTD),
- Nitrate Directive (ND),
- Drinking Water Directive (DWD),
- Bathing Water Directive (BWT),
- Industrial Emissions Directive (IED, ex. IPPC),
- Priority Substances Directive (PSD).

The Water navigation node provides a transparent overview of the existing national and EU tools accessible through the CC-ARP-CE. The links are categorized by its content and structured into Fields of actions.


EUROPEAN UNION AUSTRIA CZECHIA GERMANY HUNGARY ITALY POLAND SLOVAKIA SLOVENIA

European Union

Show 20 entries Search:

FIELDS OF ACTION IN WATER MANAGEMENT	GIS TOOLS	DATA PORTALS
Fluvial flood risk (management)	Flood mapping: a core component of flood risk management; EFAS map	EFAS data, WISE EIONET spatial data sets, European past floods
Pluvial flood risk (management)	Flood mapping: a core component of flood risk management	WISE EIONET spatial data sets
Groundwater management	Hydrogeological Map of Europe	WISE EIONET spatial data sets, Waterbase - Water Quality ICM, Waterbase - Water Quantity
Water Scarcity and Drought (management)	Map of Current Droughts in Europe	Water stress in Europe, 2000 and 2030, European Drought Centre
Drinking water supply (management)	Map: Water resources in Europe	Links to official Drinking Water Directive web sites in EU Member States
Management of water-dependent ecosystems		Ecosystems and biodiversity, WISER, WISE WFD protected area spatial data sets
Irrigation water (management)		

Figure 13: Water Navigation Node

3. Conclusions

The CC-ARP-CE tool is the TEACHER-CE project's main output and is designed to support the needs of the users in the water management sector. The tool is developed for an online platform and validated in pilot activities with the aim to support stakeholders of water management in integrated strategies and actions for climate change adaptation and prevention/reduction of associated risks. This manual was written in order to help the users to understand the structure of the CC-ARP-CE toolbox and its contents. The toolbox includes a web map service which provides spatial orientation that provides a spatial orientation among all identified issues in water management, provides information on climate change scenarios with key indicators, provides navigation through EU and national data portals, links to the tools developed in the past EU projects and provides an integrated comprehensive catalogue of measures. The tool is designed with simple to use options for basic use and broader audience. However, it also includes advanced features for expert use which elevate the complexity of the tool and require background data.

4. References

GWP-CEE 2015. Guidelines for the preparation of drought management plans. Development and implementation in the context of the EU Water Framework Directive. Global Water Partnership Central and Eastern Europe, GWP, Stockholm, Sweden.

IDMP CEE 2019: How to communicate drought - A guide by the Integrated Drought Management Programme in Central and Eastern Europe. Global Water Partnership Central and Eastern Europe (GWP CEE), World Meteorological organization (WMO), Integrated Drought Management Programme for Central and Eastern Europe (IDMP CEE).

RAINMAN Policy Brief, June 2020

American Meteorological Society, 2000: Flash flood. Glossary of Meteorology, http://glossary.ametsoc.org/wiki/flashflood.

Guidelines for the preparation of drought management plans. Development and implementation in the context of the EU Water Framework Directive. GWPCEE, 2015.

EU Flood Directive (2007/60/EC): Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks

European Court of Auditors: Special Report Floods Directive, no 25/2018

EU Action on Water Scarcity and Drought - Policy Review 2012 & Addressing the challenge of water scarcity and droughts in the European Union, COM (2007)414

EU WFD (Directive 2000/60/EC) measures for the achievement of good quantitative and chemical status of groundwater & EU Groundwater Directive (Directive 2006/118/EC)

EU Drinking Water Directive (Directive 98/83/EC): Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption

European Communities (2003), COMMON IMPLEMENTATION STRATEGY FOR THE WATER FRAMEWORK DIRECTIVE (2000/60/EC) Guidance Document No 8 Public Participation in Relation to the Water Framework Directive Produced by Working Group 2.9 – Public Participation - Office for Official Publications of the European Communities

Monacelli G., Bussettini M. (2011): Common Implementation Strategy Working Group F on Floods – Thematic Workshop on Flash Floods and Pluvial Floods. 26 -28 May 2010. Cagliari. URL: https://bit.ly/2CGAeN4

PROLINE, 2019: development of a transnational adaptation plan for integrated land-use management (available as an Appendix 1 and at: https://www.interreg-central.eu/Content.Node/PROLINE-CE/CE110-PROLINE-CE-T3-O.T3.1-GOWARE-CE-Transnational-guide-tow.pdf)

TEACHER, 2020: Climate Change Impacts on Water Management in CE and TEACHER Pilot Actions, available at: https://www.interreg-central.eu/Content.Node/TEACHER-CE/D.T1.1.3-Impacts-of-CC-on-water-management.pdf

APPENDIX 1

CE1670_TEACHER_D.T2.1.1 Climate data, expected variations in climate proxies, impact indicators for application in toolbox

CLIMATE DATA, EXPECTED VARIATIONS IN CLIMATE PROXIES, IMPACT INDICATORS FOR APPLICATION IN TOOLBOX

WORK PACKAGE T2 - INTEGRATION: CC-ARP-CE TOOLBOX FOR CLIMATE CHANGE ADAPTATION AND RISK PREVENTION IN CE

ACTIVITY T2.1- INTEGRATED TOOLBOX FOR CLIMATE CHANGE ADAPTATION AND RISK PREVENTION -VERSIONS FOR TESTING

DELIVERABLE D.T2.1.1

- Euro-Mediterranean Center on Climate Change Foundation - CMCC (PP5):
    - Guido Rianna
    - Giuliana Barbato
    - Sergio Noce
    - Roberta Padulano
    - Veronica Villani

Table of Contents

List of abbreviations

CC-ARP-CE	Integrated toolbox for Climate Change Adaptation and Risk Prevention in Central Europe
CC	Climate change
CE	Central Europe
CORDEX	Coordinated Regional Downscaling Experiment
GHG	greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathways
WRCP	World Climate Research Program

6. Introduction

The Deliverable D.T2.1.1 is aimed at supporting the development of the Toolbox CC-ARP-CE by assessing the variations, potentially due to climate change, between future time spans and the reference one in climate indicators assumed as proxies for several impacts that could affect the water management in Central Europe. Fifty-three indicators have been selected accounting for Project Partners and stakeholders' requirements collected by using a web-survey (see D.T1.1.3) or during the stakeholder workshops held in Autumn 2020. Furthermore, a sub-sample of indicators has been first computed within PROLINE-CE INTERREG Project.

The indicators have been assessed by exploiting the modeling chains included in EURO-CORDEX initiative (Jacob et al., 2014). It represents the European branch of "the international [Coordinated Regional Downscaling Experiment] CORDEX initiative, which is a program sponsored by the World Climate Research Program (WRCP) to organize an internationally coordinated framework to produce improved regional climate change projections for all land regions world-wide". Specifically, the outputs are provided by nineteen modeling chains where the dynamical downscaling of Global Climate Models has been carried out at a horizontal resolution of about 12 km (0.11°). Moreover, two scenarios for the future concentrations of climate-altering gases: the Representative Concentration Pathway (RCP) 4.5 considered as "mid-way scenario" and RCP8.5 assumed as the most pessimistic one. The variations under the two RCPs are computed for two future time spans: 2021-2050 and 2071-2100 while 1971-2000 is considered as the reference thirty years.

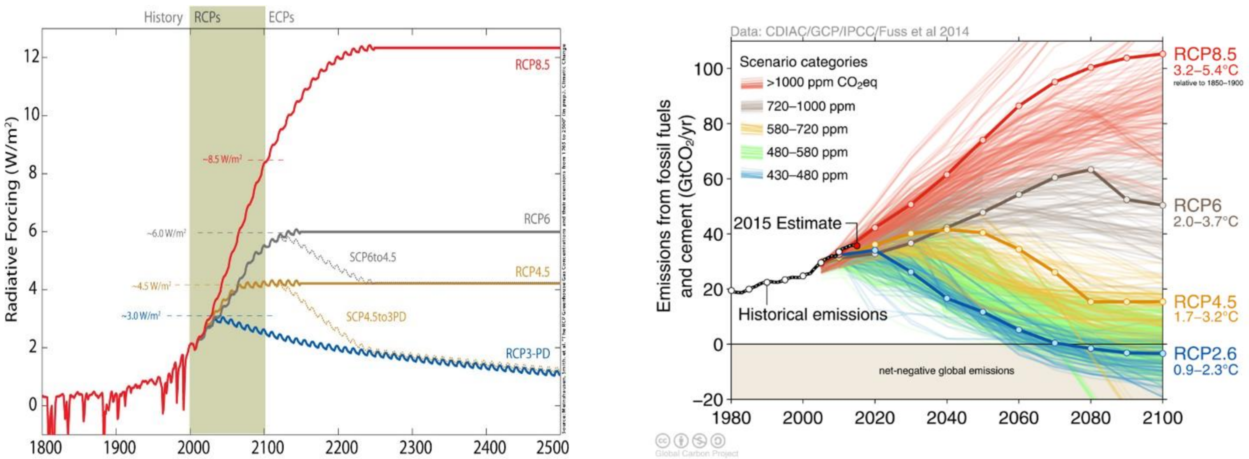
In this regard, such Deliverable should be viewed as a sort of an Engineering Guide supporting the informed adoption of the information provided by the indicators. To this aim, the section 1 provides details about the modeling chains adopted to derive the weather forcing required for the computation of the indicators. Section 2 reports the table where all the indicators are recalled and described. Finally, Section 3 reports brief insights for a proper interpretation of the results and their use from the practitioners.

7. Description of the modeling chains

The climate indicators are computed by exploiting a widely consolidated simulation chain according to which:

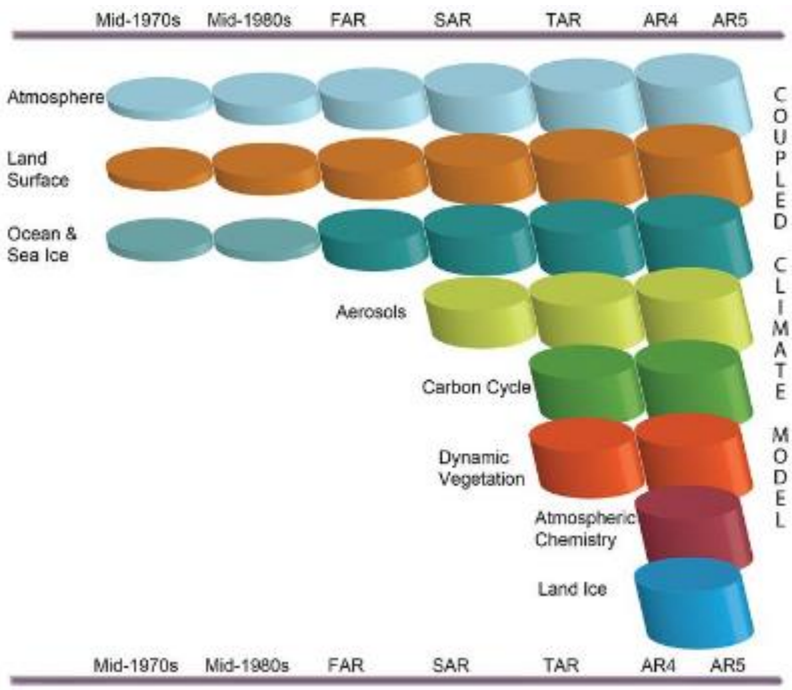
Based on assumptions about future evolutions of economic development/growth and demographic changes at global and regional scale, Integrated Assessment Models (IAM) provide evaluations for future concentrations of greenhouse gases (GHG), aerosols, chemically active gases (climate-altering gases) and changes in land use over the next centuries. In this regard, Intergovernmental Panel on Climate Change (IPCC) has selected four reference standard pathways (commonly known as RCP Representative Concentration Pathways) allowing subsequent analysis by means of Climate models (CMs) following reference assumptions about baselines and starting points and permitting the comparisons among climate projections. The four pathways respectively estimate an increase in radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m^2, by the end of the century compared to pre-industrial era (1750). Of course, the first one is recognized as more pessimistic under which no or very limited mitigation measures are implemented and the last one more optimistic and feasible only assuming high mitigation measurements (Figure 8). More specifically, RCP2.6 should be the only one permitting to achieve the Paris Agreement targets.

Figure 14: left) expected trends in radiative forcing following the different RCPs [Meinshausen et al.,2011]; right) assessed increases in global temperature and emissions under the different concentration scenarios



Such assessments are used as forcing for Global Climate Models (GCMs). They are numerical and physically-based representation of the atmospheric processes aimed to assess the impacts on the climate system of variations of greenhouse gases. Nevertheless, due to their coarse horizontal resolution (at the moment, hardly exceeding 70-80km) they are able to simulate only large-scale atmospheric state (IPCC, 2014). Numerous studies (IPCC, 2014) show that they are able to reproduce the climate and the global response to the changes of climate-altering gases with higher reliability for some variables (temperature) and lower for others (precipitation). However, despite significant developments in recent years (Figure 2) permitting to account for also biogeochemical processes in the last generation of Earth System Models, because of the horizontal resolutions today permitted, these models are inadequate for estimates of trends and impacts at the local/regional level for which the features of the area (distance from the sea, topography) are crucial (even with respect of large-scale atmospheric circulation). GCMs used for the assessments of the indicators have been produced in the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) initiative exploiting as forcing RCPs. Within the sixth phase (CMIP6), CMIP6 will consist of the “runs” from around 100 distinct GCMs from 49 different modelling groups are expected to be run to produce updated climate projections exploiting also information from Shared Socioeconomic Pathways (SSPs)

Figure 2: The evolution of Global models in terms of considered physical dynamics (from Wilby, 2017)



To improve the assessments at regional scale, several techniques were developed in last years; they largely differ for computational costs, prerequisites, and limitations; they are classifiable as "statistical" and "dynamical" downscaling approaches. The first ones adopt frameworks based on empirical statistical relationships between "predictors" large-scale and “predictand” local climate variables, calibrated and validated on observed data and then applied to GCMs variables. They require limited computational burden and also allow analysis at station scale but need long series of observed data for the definition of the statistical relationships. The latter ones involve the use of climate models at limited area and highest resolution (RCM Regional Climate Model) nested for the area of interest on the global model from which they draw the boundary conditions. Currently adopted resolutions, in the order of 10 km, on the one hand, allow a better resolution of the orography and, on the other one, solve a substantial fraction of the local atmospheric phenomena. Moreover, different experiments have proven their good capability in reproducing regional climate variability and changes.

Even if this refinement makes it possible to accurately evaluate a remarkable fraction of weather patterns, dynamical approaches may misrepresent orography, land surface feedbacks and sub-grid processes, thus inducing biases preventing their direct use for impact analysis (Maraun, 2016). To overcome this issue, different approaches, known as Bias Correction (BC) methods, have been proposed in recent years (Maraun & Widmann, 2017). They can be defined as statistical regression models calibrated for current periods in order to detect and correct biases, which are assumed to systematically affect the climate simulations. Although the advantages, limitations and warnings regarding their adoption are widely debated in recent literature (Maraun & Widmann, 2017), they are currently recognized as a necessary stage in producing weather variables to use as inputs for impact-predictive tools. Otherwise, under the assumption that climate modeling chains could be affected by similar errors in current and future time spans, considering the anomalies between time spans is expected limiting the influence of errors potentially affecting the modeling chains.

Moreover, as well-known different sources of uncertainties deeply affect the robustness and reliability of climate projections (e.g. due to natural variability, model limitations, future development of non-climatic forcing; Hawkins & Sutton, 2009); in last years, several consortiums have promoted “ensemble” initiatives to evaluate uncertainties associated to different realizations of climate experiments and favor the comparison among the simulations. Among these ones, in more recent years, the WCRP Coordinated Regional Downscaling Experiment (CORDEX) project (Giorgi et al. 2009) has been established; it provides a global coordination for Regional Climate Downscaling experiments over fixed domains and agreed horizontal resolution. The included climate projections form a multi-model ensemble where different GCMs and RCMs (or statistical approaches) concur to provide assessments for the area of interest.

As reported above, the indicators are computed exploiting 19 climate simulation chains included in EURO-CORDEX multi-model ensemble where dynamical downscaling by using RCMs is carried out at a horizontal resolution of about 12 km (0.11°). The list of considered modeling chains is reported in Table 1.

Table 1:Adopted EURO-CORDEX simulations at a 0.11º resolution (~12km) over Europe (EURO-CORDEX ensemble); they are identified reporting providing institution, driving model and adopted RCMs

Code	Institution	Driving model	RCM
1	CLMcom	CNRM-CM5_r1i1p1	CCLM4-8-17_v1
2	CNRM	CNRM-CM5_r1i1p1	Aladin53
3	RMIB-Ugent	CNRM-CM5_r1i1p1	Alaro
4	SMHI	CNRM-CM5_r1i1p1	RCA4_v1
5	KNMI	EC-EARTH	RACMO22E_v1
6	DMI	EC-EARTH	HIRHAM5_v1
7	CLMcom	EC-EARTH	CCLM4-8-17_v1
8	KNMI	EC-EARTH	RACMO22E_v1
9	SMHI	EC-EARTH	RCA4_v1
10	IPSL-INERIS	IPSL-CM5A-MR_r1i1p1	WRF331F_v1
11	SMHI	IPSL-CM5A-MR_r1i1p1	RCA4_v1
12	CLMcom	HadGEM2-ES	CCLM4-8-17_v1
13	KNMI	HadGEM2-ES	RACMO22E_v1
14	SMHI	HadGEM2-ES	RCA4_v1
15	CLMcom	MPI-ESM-LR_r1i1p1	CCLM4-8-17_v1
16	MPI-CSC	MPI-ESM-LR_r1i1p1	REMO2009
17	SMHI	MPI-ESM-LR_r1i1p1	RCA4_v1
18	MPI-CSC	MPI-ESM-LR_r1i1p1	REMO2009
19	DMI	NorESM1-M	HIRHAM5

The modeling chains are forced by two RCPs: RCP4.5 and RCP8.5. Furthermore, the climate indicators are given as anomalies between the future 30 years periods (2021-2050 and 2071-2100) and the reference time span 1971-2000.

8. Definition of the indicators

Table 2: Lists of the computed indicators

	Acronym	Description	Required variables	Anomaly expressed as
1	RR_DJF	Cumulative precipitation during the Winter season (December-January-February)averaged over 30 years	P	Relative anomaly (%): $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
2	RR_MAM	Cumulative precipitation during the Spring season (March-April-May)averaged over 30 years	P	Relative anomaly (%): $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
3	RR_JJA	Cumulative precipitation during the Summer season (June-July-August)averaged over 30 years	P	Relative anomaly (%): $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
4	RR_SON	Cumulative precipitation during the Autumn season (September-October-November) averaged over 30 years	P	Relative anomaly (%): $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
5	PRCPTOT	Annual total precipitation in wet days	P	Absolute anomaly (mm): $X_{fut} - X_{pres}$
6	Rx_1D	Yearly maximum 1-day precipitation averaged over 30 years	P	Relative anomaly (%): $\frac{X_{fut} - X_{pres}}{X_{pres}}$
7	R20mm	Annual count of days when daily precipitation ≥ 20mm averaged over 30 years	P	Absolute anomaly (days): $X_{fut} - X_{pres}$
8	R30mm	Annual count of days when daily precipitation ≥ 20mm averaged over 30 years	P	Absolute anomaly (days): $X_{fut} - X_{pres}$
9	Rx5day	Yearly maximum value of cumulative precipitation over 5 days averaged over 30 years	P	Absolute anomaly (mm): $X_{fut} - X_{pres}$
10	R95pTOT	Precipitation fraction in very wet days (%).Precipitation fraction due	P	Absolute anomaly (%):

		to precipitation greater than 95th percentile over the annual cumulative value averaged over the thirty years.		$X_{fut} - X_{pres}$
11	PR95prctile	95th percentile of daily precipitation (mm) computed over thirty years	P	Absolute anomaly (mm) : $X_{fut} - X_{pres}$
12	PrRP_5	Daily precipitation expected for a return period of 5 years computed by using Generalized Extreme Value approach	P	Absolute anomaly (mm) : $X_{fut} - X_{pres}$
13	PrRP_10	Daily precipitation expected for a return period of 10 years computed by using Generalized Extreme Value approach	P	Absolute anomaly (mm) : $X_{fut} - X_{pres}$
14	PrRP_50	Daily precipitation expected for a return period of 50 years computed by using Generalized Extreme Value approach	P	Absolute anomaly (mm) : $X_{fut} - X_{pres}$
15	PrRP_100	Daily precipitation expected for a return period of 100 years computed by using Generalized Extreme Value approach	P	Absolute anomaly (mm) : $X_{fut} - X_{pres}$
16	CWD	Consecutive Wet Days- Maximum yearly length of wet spell (maximum number of consecutive days with RR ≥ 1mm) averaged over 30 years	P	Absolute anomaly (days): $X_{fut} - X_{pres}$
17	CDD	Consecutive Dry Days- Maximum yearly length of dry spell (maximum number of consecutive days with RR < 1mm) averaged over 30 years	P	Absolute anomaly (days): $X_{fut} - X_{pres}$
18	SPI3_SD	Standardized Precipitation Index- (cumulative value of precipitation over three months). Over the reference period, for each month, the 30 cumulated values are fitted to a gamma probability distribution which is then transformed into a normal distribution. SPI3value represents units of standard deviation from the long-term reference mean. The indicator represents the percentage of	P	Absolute anomaly (%): $X_{fut} - X_{pres}$

		months in “severe dry” conditions (-1.5>x>-2) over the total number of months over the 30 years		
19	SPI3_ED	Standardized Precipitation Index-(cumulative value of precipitation over three months). Over the reference period, for each month, the 30 cumulated values are fitted to a gamma probability distribution which is then transformed into a normal distribution. SPI3value represents units of standard deviation from the long-term reference mean. The indicator represents the percentage of months in “extremely dry” conditions (x<-2) over the total number of months over the 30 years	P	Absolute anomaly (%): $X_{fut} - X_{pres}$
20	TG_DJF	Mean temperature during the Winter season (December-January-February)averaged over 30 years	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
21	TG_MAM	Average temperature during the Spring season (March-April-May)averaged over 30 years	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
22	TG_JJA	Average temperature during the Summer season (June-July-August)averaged over 30 years	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
23	TG_SON	Average temperature during the Autumn season (September-October-November)averaged over 30 years	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
24	FD	Annual count of days when daily minimum temperature <0°Caveraged over 30 years	T_{min}	Absolute anomaly (days): $X_{fut} - X_{pres}$
25	SD	Annual count of days when daily maximum temperature > 25°C averaged over 30 years	T_{max}	Absolute anomaly (days): $X_{fut} - X_{pres}$
26	TR	Tropical Nights- Annual count of days when daily minimum temperature > 20°C averaged over 30 years	T_{min}	Absolute anomaly (days): $X_{fut} - X_{pres}$

27	HD	Hot days- Annual count of days when daily maximum temperature >30°C averaged over 30 years	T_{max}	Absolute anomaly (days): $X_{fut} - X_{pres}$
28	CFD	Consecutive Frost Days-Maximum yearly length of days when daily minimum temperature < 0°C averaged over 30 years	T_{min}	Absolute anomaly (days): $X_{fut} - X_{pres}$
29	CHD	Annual count of days with at least 3 consecutive days withmaximum temperature>30°C averaged over 30 years	T_{max}	Absolute anomaly (days): $X_{fut} - X_{pres}$
30	HDDs	Heating Degree Days (DD): yearly sum of difference between the reference temperature of 18°C and daily mean temperature when it falls below 15°C	T_{mean}	Absolute anomaly (degree days): $X_{fut} - X_{pres}$
31	GSL	Growing Season Length-1st Jan to 31st Dec in Northern Hemisphere. Annual count between first span of at least 6 days with daily mean temperature >5°C and first span after July 1st of 6 days with mean temperature <5°C	T_{mean}	Absolute anomaly (days): $X_{fut} - X_{pres}$
32	HCB	Hydroclimatic Budget- Annual difference between Cumulative Precipitation and Potential Evapotranspiration computed by using the formula suggested by Hargreaves et al. (1985)	P, T_{mean}, T_{max}, T_{min}	Absolute anomaly (mm): $X_{fut} - X_{pres}$
33	SFX1DAY	Maximum value of daily snowfall flux averaged over 30 years	Sf	Relative anomaly: $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
34	EWS	98th percentile of daily maximum wind speed (m/s) computed over thirty years	ws_max	Relative anomaly: $\frac{X_{fut} - X_{pres}}{X_{pres}}\%$
35	SCD	Snow Cover Duration (days): number of days with surface snow amount >= 30 cm (yearly computed over the period from 1st November to 31th March of the following year)	sc	Absolute anomaly (days) : $X_{fut} - X_{pres}$
36	BIO1	Annual mean temperature	T_{mean}	Absolute anomaly (°C):

				$X_{fut} - X_{pres}$
37	BIO2	Mean diurnal range. It is calculated by averaging, within the thirty years, the daily differences between the maximumand minimum temperature	T_{max},T_{min}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
38	BIO3	Isothermality- It is the ratio, expressed in %, of BIO2/BIO7 (see belowfor BIO7).	T_{max},T_{min}	Absolute anomaly (%): $X_{fut} - X_{pres}$
39	BIO4	Temperature seasonality- the average of daily mean temperature is calculated for each calendar month in the selected period, and then the Standard Deviation is computed among the 12 monthly values obtained and expressed in percentage.	T_{mean}	Absolute anomaly $\%X_{fut} - X_{pres}$
40	BIO5	Maximum temperature of warmest month computed for each year and averaged over the thirty years	T_{max}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
41	BIO6	Minimum temperature of coldest monthcomputed for each year and averaged over the thirty years	T_{min}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
42	BIO7	Temperature annual range. It is the difference between Bio5 and Bio6	T_{min}, T_{max}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
43	BIO8	Mean temperature of the wettest quarter. After computing the wettest quarter of each year in the 30 years, the mean temperature among all wettest quarters is calculated	P, T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
44	BIO9	Mean temperature of the driest quarter. After computing the driest quarter of each year in the 30 years, the mean temperature among all the driest quarters is calculated	P, T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
45	BIO10	Mean temperature of warmest quarter. After computing the warmest quarter of each year in the 30 years, the mean	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$

		temperature among all the warmest quarters is calculated		
46	BIO11	Mean temperature of coldest quarter. After computing the coldest quarter of each year in the 30 years, the mean temperature among all the coldest quarters is calculated	T_{mean}	Absolute anomaly (°C): $X_{fut} - X_{pres}$
47	BIO12	Annual precipitation	P	Absolute anomaly (mm): $X_{fut} - X_{pres}$
48	BIO13	Precipitation of wettest month. After computing the wettestmonth of each year in the 30 years, the average cumulative precipitation among all the wettest months is calculated	P	Absolute anomaly (mm/month): $X_{fut} - X_{pres}$
49	BIO14	Precipitation of driest month. After computing the driest month of each year in the 30 years, the average cumulative precipitation among all the driest months is calculated	P	Absolute anomaly (mm/month): $X_{fut} - X_{pres}$
50	BIO15	Precipitationseasonality-It is the ratio between the standard deviation and the mean of 12 values representing the monthly average precipitation over the considered period. To avoiddivision by 0, the denominator is increased by 1	P	Absolute anomaly (%): $X_{fut} - X_{pres}$
51	BIO16	Precipitation of wettest quarter. After computing the wettest quarter of each year in the 30 years, the mean cumulative precipitation value among all wettest quarters is calculated	P	Absolute anomaly (mm/3months): $X_{fut} - X_{pres}$
52	BIO17	Precipitation of driest quarter. After computing the driest quarter of each year in the 30 years, the mean cumulative precipitation value among all driest quarters is calculated	P	Absolute anomaly (mm/3months): $X_{fut} - X_{pres}$
53	BIO18	Precipitation of warmest quarter. After computing the warmest quarter of each year in the 30	P	Absolute anomaly (mm/3months):

		years, the mean cumulative precipitation value among all warmest quarters is calculated		$X_{fut} - X_{pres}$
54	BIO19	Precipitation of coldest quarter. After computing the coldest quarter of each year in the 30 years, the mean cumulative precipitation value among all coldest quarters is calculated	P	Absolute anomaly (mm/3months): $X_{fut} - X_{pres}$

9. Brief insights

For each climate indicator, RCP and period (2021-2050 vs 1971-2000 or 2071-2100 vs 1971-2000), the values can be visualized in terms of median value of the anomalies aggregated at NUTS level (level 3 for all the Countries except Germany for which level 2 is used). For more Expert Users, beyond median values, data corresponding to the first and third quartiles are also provided at NUTS level and grid point level (exploiting the gridpoints as provided by EURO-CORDEX simulations).

When these data are used, it worths to consider several aspects:

- CMIP5 and, in cascade, Euro-CORDEX represent multi-model “ensemble of opportunity” (Tebaldi and Knutti, 2007) where the participant research centers are on a voluntary basis. So, the ensemble cannot have the ambition to explore, in a systematic way, all the sources of uncertainties associated to the modelling systems. In this regard, it is well known how participant global modelling often share assumptions, parametrizations making not suitable the assumption of independence among the models. For these reasons, the spread among the findings could be viewed as a “lower bound” for the characterization of uncertainties associated to the assessments. On the other side, several investigations carried out for Global Climate Models proved how the assumption of exchangeable or statistically indistinguishable ensemble (Annan & Hargreavas, 2010) according to which the “true” climate status is drawn from the same distribution as the ensemble members could work for characterizing the distribution of climate models better than the hypothesis of distribution centered around the truth (‘truth plus error’; Tebaldi et al., 2005). The assumption of indistinguishable ensemble could result particularly adequate for the analysis of future projections (Sanderson & Knutti, 2012) or patterns at more detailed spatial and temporal scale. In this respect, the adoption of central value or relevant percentiles should be carefully used and accounting for the potential limitations.

- Climate indicators are expected acting as proxies for associated impacts. They can have only a limited information content compared to more complex (time and resource consuming) approaches as, for example, physically based modelling but they represent a consolidated and expeditious way to return information about the frequency and severity of weather-induced hazards. Indicators for extreme events are usually able to return information for «moderately rare» events while for rarer events, more complex statistical approaches are required (e.g. Extreme Value Analysis).The selection for the indicator has to represent a «trade-off» for maximizing the information content; e.g. the reference time span for cumulated precipitation in flooding events (concentration time) is dependent on the geomorphological features of the basin (size, sealed surfaces, orography); then, the related indicator can be proper for detecting some events but it fails for others.

- The values for the indicators are provided in terms of anomalies between future and current time spans in an attempt to minimize the influence of the potential biases affecting climate modelling and under the assumption that the performances of the models can be comparable over the entire period of analysis.

10. Aknowledgments

We acknowledge the World Climate Research Programme's Working Group on Regional Climate, and the Working Group on Coupled Modelling, former coordinating body of CORDEX and responsible panel for CMIP5. We also thank the climate modelling groups (listed in Table 1 of this Deliverable) for producing and making available their model output. We also acknowledge the Earth System Grid Federation infrastructure an international effort led by the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison, the European Network for Earth System Modelling and other partners in the Global Organisation for Earth System Science Portals (GO-ESSP).

11. References

Annan,J. D., and J. C. Hargreaves (2010), Reliability of the CMIP3 ensemble, Geophys. Res. Lett., 37, L02703, doi:10.1029/ 2009GL041994.

Donatello, S., Dodd, N., Cordella, M. (2021), Level(s) indicator 5.3: Sustainable drainage; user manual: Introductory briefing, instructions and guidance (Publication version 1.1) (available at: https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_indicator_5.3_v1.1_19pp.pdf)

Giorgi, F., C. Jones, and G. R. Asrar (2009), Addressing climate information needs at the regional level: the CORDEX framework, WMO Bulletin, 58(3), 175-183.

Hargreaves, G. L., Hargreaves, G. H., and Riley, J. P.: Irrigation water requirements for Senegal river basin, J. Irrig. Drain. Eng.,111, 265–275, 1985.

Intergovernmental Panel on Climate Change. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, 2014; (151 pp.).

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O.B., Bouwer, L.M., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B., Yiou, P. EURO-CORDEX: New high-resolution climate change projections for European impact research (2014) Regional Environmental Change, 14 (2), pp. 563-578

Hawkins, E., & Sutton, R. (2009). The Potential to Narrow Uncertainty in Regional Climate Predictions, Bulletin of the American Meteorological Society, 90(8), 1095-1108

Maraun, D., & Widmann, M. (2018). Statistical Downscaling and Bias Correction for Climate Research. Cambridge: Cambridge University Press. doi:10.1017/9781107588783

Maraun, D. (2016) Bias Correcting Climate Change Simulations - a Critical Review. Curr Clim Chang Reports, doi:10.1007/s40641-016-0050-x.

Meinshausen, M., S. J. Smith, K. V. Calvin, J. S. Daniel, M. L. T. Kainuma, J.-F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. M. Thomson, G. J. M. Velders and D. van Vuuren (2011). "The RCP Greenhouse Gas Concentrations and their Extension from 1765 to 2300." Climatic Change (Special Issue), DOI: 10.1007/s10584-011-0156-z

Sanderson, B. M., and R. Knutti (2012), On the interpretation of constrained climate model ensembles, Geophys. Res. Lett., 39, L16708, doi:10.1029/2012GL052665.

Tebaldi, C., R.W. Smith, D. Nychka, and L.O. Mearns, 2005: Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multi-model ensembles. J. Clim. , 18, 1524-1540.

Tebaldi, C., and R. Knutti (2007), The use of the multi-model ensemble in probabilistic climate projections, Philos. Trans. R. Soc. A, 365, 2053–2075, doi:10.1098/rsta.2007.2076.

Wilby R. (2017) Climate change in practice Cambridge Press

APPENDIX 2

CE110_PROLINE-CE_O.T3.1 GOWARE-CE transnational guide towards an optimal water regime; Chapter 3.3 - Analytic Hierarchy Process (AHP), pg.: 12 - 17

(the entire document is available online at: https://www.interreg-central.eu/Content.Node/PROLINE-CE/CE110-PROLINE-CE-T3-O.T3.1-GOWARE-CE-Transnational-guide-tow.pdf)

PROLINE-CE

WORKPACKAGE T3

DEVELOPMENT OF A TRANSNATIONAL ADAPTATION PLAN FOR INTEGRATED LAND-USE MANAGEMENT

O.T3.1 GOWARE - CE TRANSNATIONAL GUIDE TOWARDS AN OPTIMAL WATER REGIME

June, 2019

Lead Institution	PP13 - CMCC Foundation
Lead Author/s	Guido Rianna, Angela Rizzo
Contributor/s	See page 1
Date last release	June, 2019

Contributors, name and surname	Institution
Guido Rianna	CMCC Foundation
Angela Rizzo	CMCC Foundation
Monia Santini	CMCC Foundation
Anna Sperotto	CMCC Foundation
Primož Banovec	University of Ljubljana
Ajda Cilenšek	University of Ljubljana
Špela Železnikar	University of Ljubljana
Daniel Bittner	Technical University of Munich
Matko Patekar	Croatian Geological Survey, Department of Hydrogeology and Engineering Geology
István Waltner	Herman Ottó Institute Nonprofit Ltd.
Norbert Csatari	OVF General Directorate of Water Management
Giuseppe Ricciardi	ARPAE
Roland Koeck	University of Natural Resources and Life Sciences, Vienna, Department of Forest- and Soil Sciences, Institute of Silviculture
Joanna Czekaj	Silesian Waterworks PLC

Table of Contents

3.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Analysis (MCDA) tool introduced and developed by Thomas Saaty (1980) for the analysis of complex decision-making processes andfor supporting decision makers in the selection of the most suitable decisions among a number ofalternative solutions. It, therefore, considers a set of options among which the best decision is tobe made based on a number of evaluation criteria. In recent years, such approach has been widelyadopted for water management issues and for the implementation of operative actions, proving to be an effective tool for dealing with complex decision-making processes.

The AHP allows structuring a decision-making problem by dividing it in a finite number of stages and of elements and evaluating and ranking the alternative solutions. It allows assigning a priorityto a series of decision-making alternatives and identifying the one(s) that achieves the most suitable trade-off among all the available solutions, accounting for the specific context of the decision-making problem. It is based on the pair comparison between alternatives (or between the criteria that characterize the alternatives) in order to give to each of them a score of relativeimportance and to finally rank the available alternatives.

The process starts with dividing the decision-making problem into elements in order to form a hierarchical order that simplifies the decision analysis. Once the hierarchy is built, the Users systematically evaluate the various elements by comparing them to each other (considering the criteria two-by-two) and giving them a score with respect to their relative impact on an elementabove in the hierarchy. In making the comparisons, the Users typically use judgments about the elements' relative meaning and importance. The judgement values are then transferred to a pairwise comparison matrix (Siddayao et al., 2014). The process ends with the attribution of a weight to each of the available alternatives that allows, after, identifying the most suitable solutions.

The AHP method can be summarized by the following operative

steps:1- Formulate the hierarchic tree;

2- Create a pairwise comparison matrix;

3- Check the consistency of the assigned values;

4- Calculate the weights;

5- Evaluate the final ranking of the alternative and take the final decision.

The available alternatives (A_i; i = 1, …. j) represent the criteria that can be selected in the decision-making process. In general terms, A_i is defined as the i-alternative and a_{ij} is the numericalvalue resulting from the comparison between A_i and A_j. If the number of alternatives is **n**, the number of total comparisons is **n(n-1)/2**. These comparisons will generate the comparison matrixA_{nxn} that will be used to calculate the weight values of each single alternative (Fig. 7). In creatingthe comparison matrix, an evaluation process is required in order to indicate how much one alternative is more important than another one.

The diagonal elements of the matrix are always equal to 1 because of the comparison is made between the same alternatives, while the non-diagonal elements show the relative importance of the alternatives taken into account in the comparison. If the elements of the pairwise comparisonmatrix are shown with $\mathbf{a}_{ij}$, which indicates the importance of alternative "**i**th" over "**j**th", then $\mathbf{a}_{ji}$ could be calculated as $\mathbf{1/a}_{ij}$ (Boroushaki and Malczewski 2008). In Fig. 7, an example of a pairwisecomparison matrix is shown.

	A1	A2	A3	Aj
A1	**1**	a_{12}	a_{13}	a_{1j}
A2	**1 / a_{12}**	**1**	a_{23}	a_{2j}
A3	**1 / a_{13}**	**1 / a_{23}**	**1**	a_{3j}
Aj	**1 / a_{1j}**	**1 / a_{2j}**	**1 / a_{3j}**	**1**

Figure 7 - A generic comparison matrix.

From Fig. 7, it is clear that the comparisons are made between the elements of the upper regionof the matrix (blue cells) and that the score values in the lower part (yellow cells) are equal to the reciprocal values assigned in the blue cells. In this specific case, the number of comparisons is equal to 6, being the number of alternatives (n) equal to 4.

In Table 1 are shown the scores that are commonly assigned in the evaluation of the relative importance of each alternative (adapted from Saaty, 1980) and the related verbal interpretations(judgements).

Table 1 - Scores and judgements generally used in the comparison between the alternatives availablein a decision-making process.

Score (a_{ij} values)	Judgement
1	Ai is equal important to Aj
3	Ai is moderately more important than Aj
5	Ai is more important than Aj
7	Ai is strongly more important than Aj
9	Ai is absolutely more important than Aj
2, 4, 6, 8	Intermediate values between adjacent values

Once the weight comparison matrix is obtained, the AHP method employs different techniques todetermine the final weights of each alternative: one of the most used technique is the **"eigenvector approach"** (lambda max technique - λ_{max}), in which a vector of weights is defined as the normalized eigenvector corresponding to the largest eigenvalue λ_{max}. Nevertheless, this method requires hard efforts and for this reason, simplified methods, which provides a good approximation of the lambda max method and easily enforceable in programming codes, have been proposed (Malczewski, 1999; Kordi, 2008).
Among the others, **mean of normalized values** is a method that allows calculating an approximation of the eigenvector associated with the maximum eigenvalue through a simple arithmetic procedure. In this case, first the sum of the scores in each column of the pairwise comparison matrix is calculated (see row in orange in Fig. 8). Then, each element in the column

is divided by the calculated sum in order to obtain normalized values and the corresponding normalized pairwise comparison matrix $\mathbf{A}_{norm}$ (see Fig. 9).

	A	B	C	D	E
A	1.00	7.00	7.00	5.00	3.00
B	0.14	1.00	1.00	0.33	0.20
C	0.14	1.00	1.00	1.00	1.00
D	0.20	3.00	1.00	1.00	1.00
E	0.33	5.00	1.00	1.00	1.00
SUM	1.82	17.00	11.00	8.33	6.20

Figure 8 - An example of a pairwise comparison matrix. A, B, C, D, E refer to the available alternatives proposed in the decision-making process. Note that white cells are reciprocal of the blue cells with respect to the green diagonal.

Last, the arithmetic average of the entries on each row of $\mathbf{A}_{norm}$ is calculated to build the PriorityWeight Vector "**w**" that is an m-dimensional column vector (see column "Weights" in Fig. 9). Based on the results of this analysis, it is possible to state how important each alternative is in the decision-making process (accounting for the percentage of weight values).

	A	B	C	D	E	Weights
A	0.55	0.41	0.64	0.60	0.48	0.54
B	0.08	0.06	0.09	0.04	0.03	0.06
C	0.08	0.06	0.09	0.12	0.16	0.10
D	0.11	0.18	0.09	0.12	0.16	0.13
E	0.18	0.29	0.09	0.12	0.16	0.17

Figure 9 - A typical normalized pairwise comparison matrix ($\mathbf{A}_{norm}$). The weight values, calculated as arithmetic mean, are shown in the orange column. These values are used for the final ranking of the criteria.

Then, the values provided by AHP according to specific User's requirements are used to return the weighted sum related to each BMP:

$$R = \sum_{i=1}^{5} w_i J_i$$

They can be ranked according the values R so obtained returning the most suitable options tailoredaccording to User's preferences.

3.3.1 Consistency evaluation

It is good practice that AHP analysis incorporate an analytical technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process and therefore avoid rank reversal issue (see for example Fig. 10).

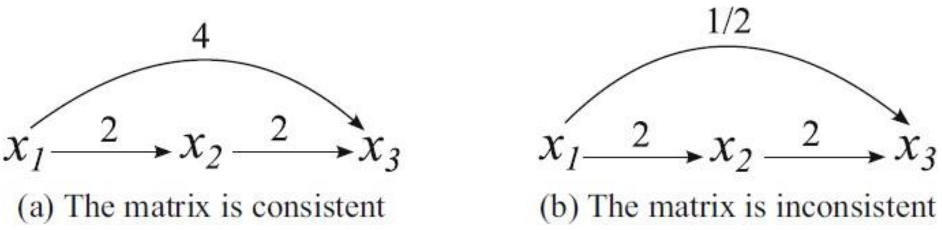


Figure 10 – Examples of consistent and inconsistent transitivities (Brunelli, 2015).

In order to fulfil this purpose, the accuracy of the matrix, which is referred to the consistency ofthe pairwise preferences, is evaluated by means of the **Consistency Ratio** using the following formula (Malczewski, 1999):

$$CR = CI / RI \quad (4)$$

where **CI** represents the Consistency Index and **RI** is the so-called Random Index.The Consistency Index CI is expressed as:

$$CI = (\lambda_{max} - n) / (n - 1) \quad (5)$$

where λ_{max} is the principal eigenvalue of the matrix (it is a scalar) and **n** is the order of the matrix.

Operatively, CI can be calculated by the matrix product of the pairwise comparison matrix and the weight vector (*multiplying each score in each column of pairwise comparison matrix by its weight*) and then calculating the weighted mean of each row of the new matrix.

RI depends on the number of elements that are compared (n). RI values, referred to different values of **n,** are shown in Table 2 while in Table 3 illustrative examples of Principal Eigenvalues, CI, RI and CR values are shown.

Table 2 – Random Index values (adapted from Saaty, 1980).

n	1	2	3	4	5	6	7	8
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

According to Saaty (1980), in a 5 by 5 matrix, a threshold equal to 10% (5% and 8% for the 3 by 3 and 4 by 4 matrices, respectively) has to be adopted for considering the matrix as consistent andtherefore for accepting the estimation of the Priority Vector **w**. Nevertheless, first testing carriedout also for GOWARE-DST highlighted how such limit could be strict.

Specifically, the value of CR = 0.1 indicates that the judgments are 10% inconsistent (Brunelli, 2015). In the example shown in Table 3, the comparisons can be considered consistent since the CR value is equal to 0.06 against a limit of 0.1.

Table 3 - Example of Principal Eigenvalues, CI, RI and CR values.

Weights	Principal Eigenvalue	Consistency Index (CI)	Random Index (RI)	Consistency Ratio (CR)	Threshold
0.54	5.29	0.07	1.12	0.06	0.1
0.06	5.27				
0.10	5.30				
0.13	5.25				
0.17	5.20				

Within the activities carried out for development of the PROLINE-CE DST, desk review concerningseveral approaches proposed in the scientific literature for the evaluation of weights provided bypairwise comparison analysis and their consistency has been performing (Brunelli, 2015). The finalchoice of the implemented methods is therefore in line with the State-of-the-art, aiming at minimizing some drawbacks recognized in the AHP approach (e.g. rank reversal issue).

3.3.2 Missing comparisons

In complex decision-making processes, it can happen that end-User may not (does not want to) provide a score for the evaluation of the relative importance between two criteria. This could lead to an incomplete pairwise comparison matrix in which some entries are missing. In this case,the AHP model requires setting its parameters to avoid overestimating weights to be assigned to the accounted criteria. Several methods have been proposed for solving this issue, mainly based on the following two approaches: 1) the comparison matrix is completed by means of an expert

based judgment and then the priority vector is calculated; 2) the priority vector is directly calculated by means of modified algorithms.

When the “the eigenvector approach” or “the mean of normalized values” procedure are applied,the missing comparisons issue is generally faced by applying the method proposed by Harker (1987), in which the priority vector is estimated without completing the comparison matrix but considering only the available comparison values for creating a supporting matrix. In details, the supporting matrix is constructed by setting “zero value” to the cells referring to the missing comparisons and increasing the score value in the diagonal by adding the number of missing comparisons present in the accounted row (1+m_i, where “m” refers to the number of missing values in the “i^{th}” row). By applying the proposed algorithm, the estimation of the priority vectoris not affected by the presence of missing values.

3.3.3 Group decisions

Generally, in real context of analysis, decisions are made by groups of decision makers such as stakeholders, boards or teams of experts. In this case, it is opportune accounting for all the provided opinions and aggregating them in order to provide a synthetic weight priority vector. According to Forman and Peniwati (1998), there are two methods to derive a priority vector froma set of pairwise comparison matrices:

1) **Aggregation of individual judgments (AIJ)**, in which the comparison matrices are aggregated into a single comparison matrix from which the priority vector is calculated. Inthis case, the priority vector estimation takes place after the aggregation of all the singlejudgments from a single pairwise comparison matrix.
2) **Aggregation of individual priorities (AIP),** in which a set of priority vectors is calculated from all the available pairwise matrices and then they are aggregated to obtain the representative priority vector. In this case, the priority vector estimation takes place afterthe derivation of all the priority vectors derivation.

In this second case, the aggregation of all the priority vectors derived from each single comparison matrix can be performed by calculating the weighted geometric mean or the weighted arithmeticmean. These two formulas clearly lead to different priority vectors, but they are both accepted in the literature (Brunelli, 2015). In GOWARE DST (attached Excel file in Toolkit), the first approach is implemented.