Cross-sectoral planning decision-making platform to foster climate change

Rethink Action

D 6.1 | Climate change impacts, risks and vulnerabilities in each case study

WP6 – Case studies-local evaluation

Version 1.1 | February 2025

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List of Organizations

	Participant Name	Short Name	Country	Logo
1	Fundación CARTIF	CARTIF	Spain	
2	University of Valladolid	UVa	Spain	
3	IVL Swedish Environmental Research Institute	IVL	Sweden	
4	RINA Consulting	RINA-C	Italy	
5	Euro-Mediterranean Center of Climate Change	CMCC	Italy	
6	Climate Media Factory	CMF	Germany	
7	National Observatory of Athens	NOA	Greece	
8	GMV Aerospace and Defence SAU	GMV	Spain	
9	FCiências.ID - Associação para a Investigação e Desenvolvimento de Ciências	FC.ID	Portugal	
10	ICLEI - Local Governments for Sustainability e.V. (World Secretariat) 10 A | ICLEI European Secretariat GmbH	ICLEI	Germany	
11	United Nations University - Institute for Environment and Human Security	UNU-EHS	Japan	
12	Geonardo Environmental Technologies Ltd.	GEO	Hungary	
13	Institut National de la Recherche pour l'Agriculture, l'Alimentation et l'Environnement	INRAE	France	

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Abbreviations and Acronyms

Acronym	Description
AWY	(InVEST) Annual Water Yield (model)
CERRA	Copernicus regional reanalysis for Europe
CMIP6	Coupled Model Intercomparison Project 6
CRVA	Climate Risk Vulnerability Assessment (CRVA)
CS	Case Study
CSX	Case Study number X
ECV	Essential Climate Variable
EUC	End-Users Community
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
IC	Impact Chain
ICXY	Impact Chain number Y of Case Study X
ISWC	Initial Soil Water Content
LAMS	Land use-based Adaptation and Mitigation Solutions
MCA	Multi-Criteria Analysis
MCIRVA	Multi-Criteria Impact, Risk and Vulnerabilities Assessment
RCP	Representative Concentration Pathways
RES	Renewable Energy Sources
SD	Systems Dynamics
SSP	Shared Socio-economic Pathway
STO	Scientific and technological objectives
TAW	Total Available Water
TD	Technical Deviation
USDA	United States Department of Agriculture

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Executive Summary

This document is Deliverable 6.1 “Climate change impacts, risks and vulnerabilities in each case study”, due in M30 (March 2024) but delayed to M32 (May 2024), which reports the results of Task 6.1 “Analysis of climate change impacts, risks and vulnerabilities at local scale.”. The six analysed case studies were: Gotland (Sweden) - Northern case study (CS1), Tarn-et-Garonne (France) - Atlantic case study (CS2), Southern Great Plain (Hungary) - East of EU case study (CS3), Valle D’Aosta (Italy) - Alpine - Mountain (CS4), Almeria (Spain): Mediterranean case study (CS5) and Azores Archipelago (Portugal) - Small Islands case study (CS6).

Due to a terminology adjustment this deliverable produces an “Analysis of climate change risks at the local scale”. This is in accordance with the used terminology of the Intergovernmental Panel on Climate Change (IPCC). This technical deviation was communicated in the Official progress report M1-M18, which identifies a technical deviation referred as “Change in climate risk terminology” (TD13).

As such, this report summarizes the climate risk analysis made in six case studies. Each risk analysis report is put in Annex (I to VI), the workshop manual (Annex I of D6.2) used in the 3rd EUC local workshops, and the ECVs tables (Annex VII) which used data from WP3.

The six case studies proceeded with their analysis according to methods initially defined in D5.2 (Methods for impact assessment and land allocation considering LAMS deployment) and adjusted as necessary. Additional methods were used to analyze the risks. The stakeholders and the case study leaders co-selected the most vulnerable sectors and defined the problem statement of each case study. Impact Chains were developed about the risks which affect the most vulnerable sectors of the problem statement. These impact chains identify the risk factors within each risk component (hazard, exposure, and vulnerability) and their dynamics. They also allow for synthetization of the risk analysis and the quantification of the risk components.

The Impact Chains developed by each case study leader will inform the local Systems Dynamics model development (T6.4) and the quantification will be made available in the platform (WP7) for stakeholder informed decision.

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1 Introduction

This Deliverable 6.1, Climate change impacts, risks and vulnerabilities in each case study, reports the work developed in Task 6.1: Analysis of climate change impacts, risks and vulnerabilities at local scale. The six analysed case studies were: Gotland (Sweden) - Northern case study (CS1), Tarn-et-Garonne (France) - Atlantic case study (CS2), Southern Great Plain (Hungary) - East of EU case study (CS3), Valle D'Aosta (Italy) - Alpine - Mountain (CS4), Almeria (Spain): Mediterranean case study (CS5) and Azores Archipelago (Portugal) - Small Islands case study (CS6).

According to the Official progress report M1-M18, Technical Deviation 13 (TD13) this task focussed on climate risks and its three components: hazard, exposure, and vulnerability (which includes sensitivity and adaptation capacity). This definition was updated because it uses the propellor risk framework used by the Intergovernmental Pannel for Climate Change (IPCC), as discussed in this deliverable and in D5.2 (Methods for impact assessment and land allocation considering LAMS deployment). Deliverable 5.2 defined the methods to be used in Task 6.1, which were adapted as discussed in the section 2.

Each case study made a Risk Analysis that led to the development of impact chains, which was used as an analysis tool that applies multi-criteria impact, risk, and vulnerabilities assessment. As stated in the Scientific and technological objective 3 (STO3) of the Official progress report M1-M18, case study leaders centered their analysis in a problem statement. This statement defined the scope of the risk analysis and gave it more focus. The problem statement was co-developed with stakeholders as to define the problem to be studied by project RethinkAction, framing the most vulnerable sectors and the main risks that affect them. The problem statement was first used in D5.1 (Design of scenarios consistent across scales) and refined in different End user Community (EUC) Workshops (see section 2.2), leading to its current form (see section 3.5).

The risk analysis which was developed, evaluates, and delivers in a structured way, the climate change risks of each case study by means of literature review and sectoral impact models results: InVEST Annual Water Yield Model and AquaCrop water crop model (see section 2.5). Information delivered by WP3 included Essential Climate Variables (ECVs) both basic and derived were produced in D3.4 (Results of the downscaling of essential climate variables at EU). These were statistically downscaled to the local level from Coupled Model Intercomparison Project Phase 6 (CMIP6) global models using several Shared Socio-economic Pathways (SSP) (see section 2.1). Land use maps and spatial information developed in D3.3 (Land use maps and suitability factors for the allocation of land uses) were also provided.

The most vulnerable sectors in each case study were co-selected by a participatory process coordinated by WP2 (T2.4), which facilitated dialogue with stakeholders to understand the local context. The

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following sectors were selected as most vulnerable: agriculture, water resources, tourism, forestry, energy, tourism, and society, specifically focused on migration. Impact Chains were co-developed with stakeholders to capture and synthesize the complex connections of the different risk components (see section 3.6). They serve the needs of local System Dynamics model development (T6.4) and summarize the analysis in a structed way. The impact chains were quantified in section 4 as to produce risk maps which will be used by the platform (WP7), improving decision-making at local level by offering a high-resolution climate diagnosis to cover the requirements of stakeholders for detailed assessments.

The structure of this main report includes:

- Section 1: Introduce the purpose of the document and its structure.
- Section 2 - Methods: Highlights the methods stated in D5.2 and identifies the necessary adaptations and additions to develop the task.
- Section 3 - Results : Summarizes the Risk Analysis made by the Case Study leaders in their D6.1-CSX annex reports.
- Section 4: Quantifies the Impact Chains developed in the risk analysis of each Case Study.

The main report is supported by 7 annexes:

- Risk Analysis report of each case study (D6.1-CSX Annexes):
  - D6.1 |Annex I - CS1 Gotland (Sweden)
  - D6.1 | Annex II - CS2 Tarn-et-Garonne (France)
  - D6.1 | Annex III - CS3 Southern Great Plain (Hungary)
  - D6.1 |Annex IV - CS4 Valle D'Aosta (Italy)
  - D6.1 | Annex V - CS5 Almeria (Spain)
  - D6.1 | Annex VI – CS6 Azores Archipelago (PT)
- Other methods and results:
  - D6.1 | Annex VII - ECV Summary tables.
  - D6.1 | Annex VIII – Results of risk quantification.
  - D6.1 | Annex IX – Hazard exceedance probability results and hazards' interactions.

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2 Methods

Task 6.1 applied methods developed by T5.2 (Methodology for climate change impacts and land-based adaptation and mitigation analysis) to conduct a multi-criteria impact, risk and vulnerabilities assessment. The method is described in the D5.2 (Methods for impact assessment and land allocation considering LAMS deployment) main document and in its Annexes structured as:

- Annex I - modelling activities of the surface water model.
- Annex II - modelling activities of the crop model.
- Annex III - Impact Chains Manual.

The D5.2 uses the propeller framework of the IPCC of climate risk and its components of risk: hazard, exposure and vulnerability (sensitivity and adaptive capacity).

Further developments were made with the application of these methods, as well as the inclusion of additional work deemed necessary, namely:

- Refinements in the InVEST model workflow for surface water modelling.
- Restructuring of the AquaCrop crop modelling framework.

Development of a workshop guidance (Annex I of D6.2) which includes the co-development strategies for its implementation.

- Production of Essential Climate Variables (ECVs) anomalies static maps and graphs at case study level to understand the current and future climate.
- Quantification methods for vulnerabilities and risk, translating the impact chains into quantified values.
- Implementation of geolocated analysis to calculate relevant indicators for the impact chains quantification.

2.1 ECVs: anomalies static maps and graphs at case study level

WP3 has developed high-resolution climate data for the RethinkAction case studies. These data are of great interest for the quantification of climate hazards and to offer relevant climate information for the case studies, such as the evolution of the Essential Climate Variables (ECVs) throughout the annual time series or over the months. To exploit the results and offer information of added value to the case studies, maps, graphs and tables have been produced to make the climate information more visual and understandable. The maps will be included in the RethinkAction Zenodo repository

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(https://zenodo.org/communities/rethinkaction/records) under "ECVs anomalies static maps". The graphs and tables are presented are put in Annex VII – D6.1-ECVs | ECV graphs and summary tables.

2.1.1 ECVs anomalies static maps

A total of 63 static maps have been produced at CS level displaying the anomalies derived from three basic-ECVs listed in Table 1, for SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios (under CMIP6 projections). Each map illustrates the downscaled spatial distribution of the 30-year average ECVs anomalies values evolution over near-term (2015-2040), mid-term (2041-2070), and long-term (2071-2100) periods under one of the three CMIP6 climate model scenarios (SSPs). For cartographic production, WP3 used Geographic Information System (GIS) software to process the data produced at the local scale.

Table 1. The CMIP6 Basic-ECVs collected by Task 3.2 and statistically downscaled at the CS level by Task 3.4.

Name [Description]	Units	Temporal aggregation
tasmax [Daily maximum near surface air temperature]	°C	30-year
pr [Precipitation]	mm	30-year
sfcWind [Near surface wind speed]	m/s	30-year

Presented below are the equations applied to calculate the anomalies for the three selected basic-ECVs. For the anomaly calculation, the historical period (1985-2014) layer of each ECV and CS has been assumed as the reference 30-year average values. While the daily maximum near surface air temperature and near surface wind speed variables are represented in °C and m/s, respectively; precipitation is displayed as percentage.

- Daily maximum near surface air temperature anomalies (°C):

tasmax anomaly (ºC) = Future projected tasmax (ºC) - Historical modelled tasmax (ºC)

- Precipitation anomalies (%):

pr anomaly (mm) = Future projected pr (mm) - Historical modelled pr (mm)
pr anomaly (%) = Anomaly pr (mm) * 100 / Historical modelled pr (mm)

- Near surface wind speed anomalies (m/s):

sfcWind anomaly (m/s) = Future projected sfcWind (m/s) - Historical modelled sfcWind (m/s)

The map values are provided in a tabular format in Annex VII and are briefly discussed in section 3.1.

For the cartographic representation of the anomalies, colour scales from official sources, such as the European Environment Agency (EEA), NASA Scientific Visualization Studio, Copernicus Climate Change Service, and the National Centers for Environmental Information (NCEI), have been employed.

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Table 2, Table 3 and Table 4 compile the colour scale applied to each variable and the sources used as references for the cartographic production for each selected ECV. Examples of the resulting maps are given in Figure 1, Figure 2 and Figure 3.

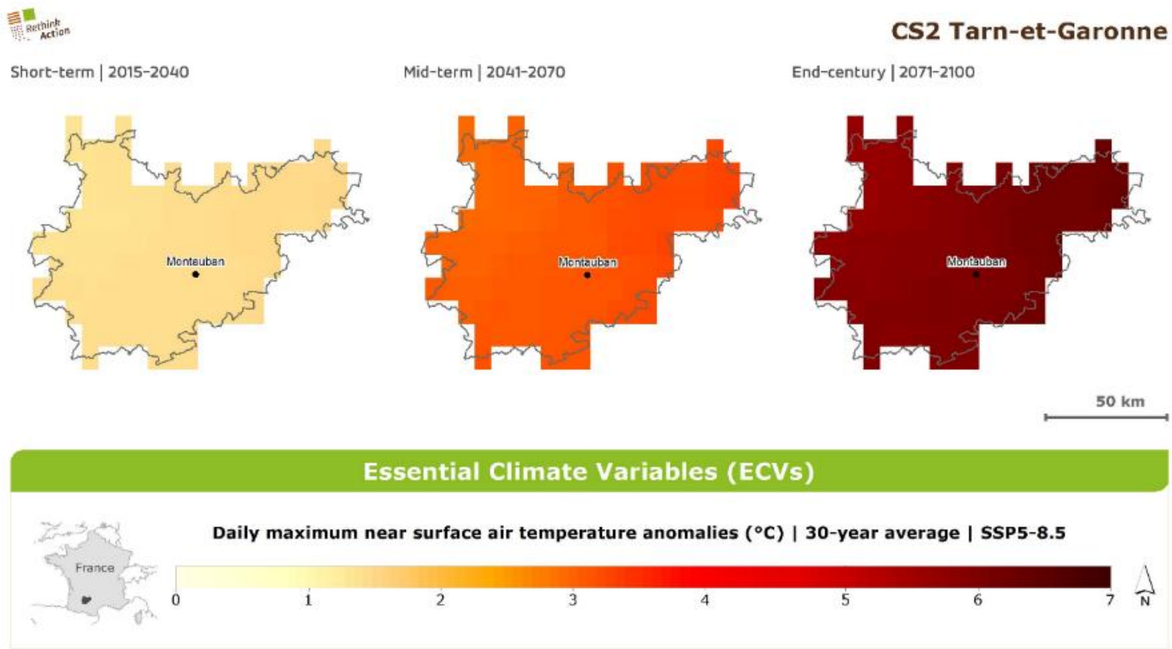

Figure 1: Daily maximum near surface air temperature (tasmax) anomalies (°C) at CS2 Tarn-et-Garonne (France) in 30-year averages (short-term, mid-century and end-century) using an Ensemble Model with an SSP5-8.5 scenario.

Table 2: Colour scale image, description and references used for the tasmax anomaly static maps.

Daily maximum near surface air temperature anomalies (°C)
Colour scale legend:
Description: Sequential continuous colour scale ranging from 0 (light yellow) to the maximum value (dark red).
Sources of reference colour scales: • European Environment Agency (2017). *Climate change, impacts and vulnerability in Europe 2016 – An indicator-based report*. Publications Office. https://data.europa.eu/doi/10.2800/534806. • NASA Scientific Visualization Studio. (2024). Global Temperature Anomalies from 1880 to 2023 [Webpage]. Retrieved from https://svs.gsfc.nasa.gov/5207/. • Copernicus Climate Change Service (2024). Surface Air Temperature Maps [Webpage]. Retrieved from https://climate.copernicus.eu/surface-air-temperature-maps.

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Table 3: Colour scale image, description and references used for the precipitation anomaly static maps.

Precipitation anomalies (%)
Colour scale legend:
Description: Diverging discrete colour scale, featuring 5 categories for negative values (yellow to red) and 5 for positive values (light blue to dark blue). The grey colour category represents values close to 0.
Sources of reference colour scales: • European Environment Agency (2017). *Climate change, impacts and vulnerability in Europe 2016 – An indicator-based report*. Publications Office. https://data.europa.eu/doi/10.2800/534806. • European Environment Agency (2022). Projected change in annual and summer precipitation, 2071-2100 [Webpage]. Retrieved from https://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-annual-and-6.

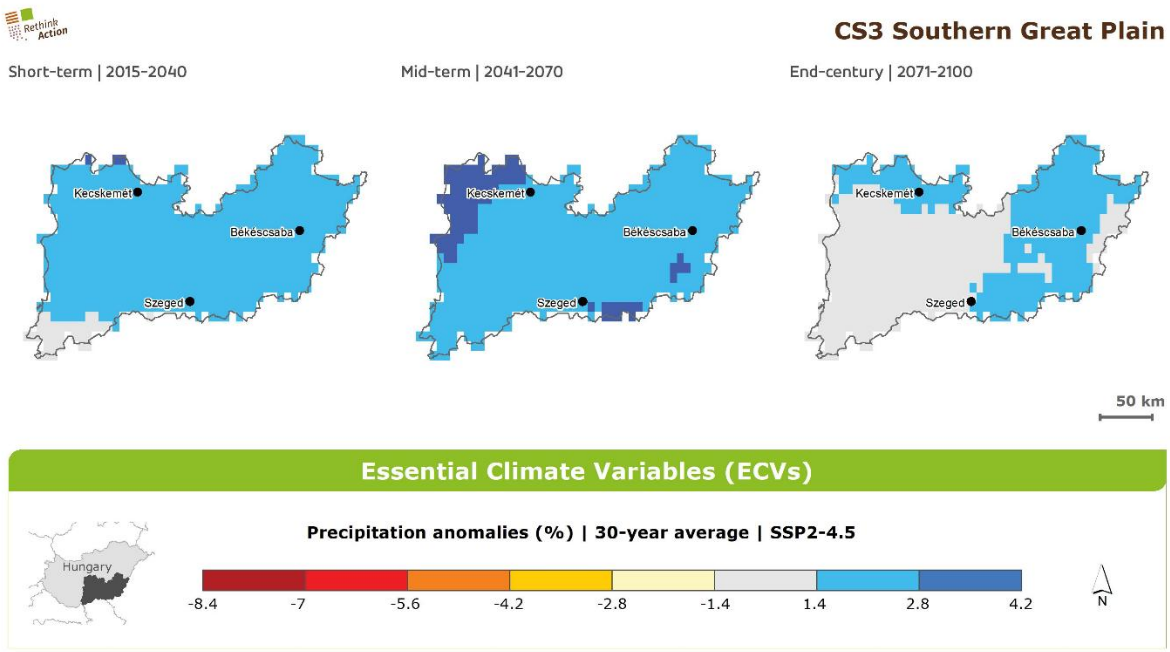

Figure 2: Precipitation (pr) anomalies (mm) at CS3 Southern Great Plains (Hungary) in 30-year averages (short-term, mid-century and end-century) using an Ensemble Model with an SSP2-4.5 scenario.

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Table 4. Colour scale image, description and references used for the sfcWind anomaly static maps~.

Near surface wind speed anomalies (m/s)
Colour scale legend:
Description: Diverging discrete colour scale, featuring 5 categories for negative values (light blue to dark blue) and 5 for positive values (yellow to red). The grey colour category represents values close to 0.
Sources of reference colour scales: • European Environment Agency (2017). *Climate change, impacts and vulnerability in Europe 2016 – An indicator-based report*. Publications Office. https://data.europa.eu/doi/10.2800/534806. • National Centers for Environmental Information (2024). U.S. Wind Climatology [Webpage]. Retrieved from https://www.ncei.noaa.gov/access/monitoring/wind/.

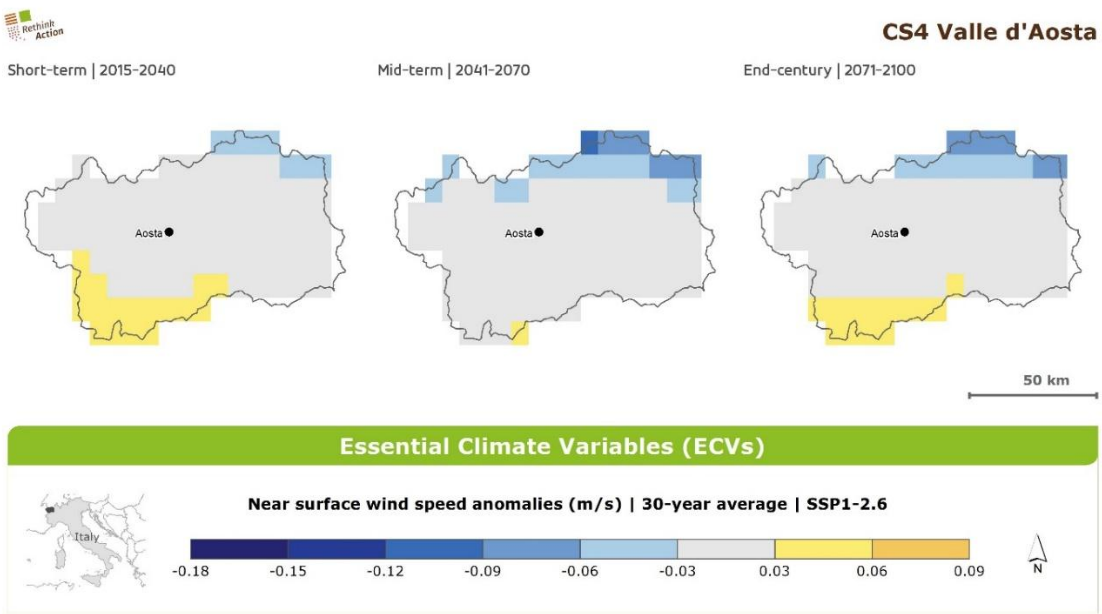

Figure 3: Near surface wind speed (sfcWind) anomalies (m/s) at CS4 Valle d'Aosta (Italy) in 30-year averages (short-term, mid-century and end-century) using an Ensemble Model with an SSP1-2.6 scenario.

2.1.2 Charts

Using the WP3 results, graphical representations of the climate variables were developed to provide climate information for the case study reports. According to the different climate scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) and periods (short, medium and long-term), the following variables were used for the representation:

- Anomalies in temperature at monthly level and for each climate scenario and period.

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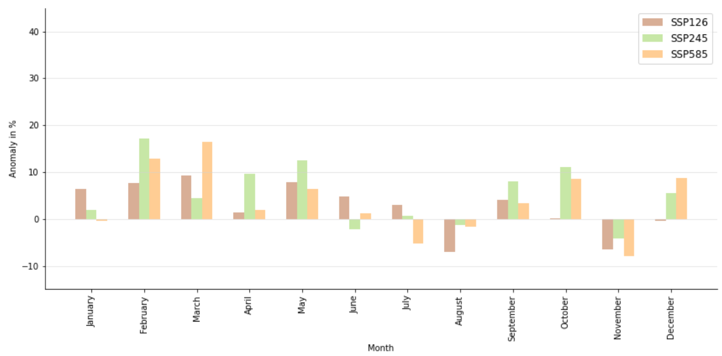
- Anomalies in precipitation at monthly level and for each climate scenario and period.
- Anomalies in the number of days with daily precipitation exceeding the 99th percentile of wet days in a monthly based for period and scenario.
- CDD, representing annual time series and monthly values by period and scenario.
- HDD, representing annual time series and monthly values by period and scenario.
- Annual time series for evapotranspiration.
- Hot days: annual time series and monthly values by period and scenario.
- Hot nights: annual time series and monthly values by period and scenario.
- Annual time series for the accumulated annual precipitation.
- Standard Precipitation Index (SPI) covering monthly values by period and scenario with a number of standard deviations that observed cumulative precipitation over 6 months.
- Annual time series of average temperature.
- Annual time series of average maximum temperature.
- Annual time series of average wind speed.

Figure 4 includes two examples of the maps developed that are included in each case study report.

a)



b)

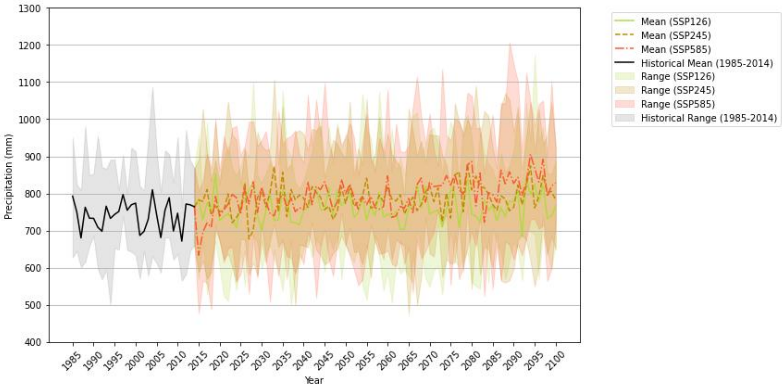


Figure 4: Anomalies in the precipitation monthly (a) and evolution of the accumulated precipitation (b) for Gotland case study (CS1), considering the historical period (1985 - 2014) and the future (2015 - 2100) under three different socioeconomic scenarios: SSP1-2.6, SSP2-4.5 and SSP5-8.5.

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2.2 Participatory process

The engagement strategy has been coordinated under WP2 (T2.4) with consistent interactions with the End-User Community (EUC) planned throughout the duration of the project (see D2.4 | Report on the Activities with the End-User Community I). Three main stakeholder interactions (workshops) were delivered since the start of the project:

- EUC Workshop I, which was held virtually with all EUC members on 1 July 2022, where stakeholders responded to different themes of local risks, local challenges, Regional and International factors, and local solutions. This led to an initial problem statement which was developed for D5.1 (Design of scenarios consistent across scales).
- EUC Workshop II, which was held virtually with all EUC members on 29 November 2022 focused on the co-creation of Land use-based Adaptation and Mitigation Solutions and collecting initial feedback for digital mock-ups of the platform in terms of design, functionality, and content. This led to more insights into the needs of stakeholders, problem statement and the start of the definition of the most vulnerable sectors.
- EUC Workshop III, which was held in person in each of the six case study areas of the project in the local language (Figure 5) and on different dates according to stakeholder availability(see Table 5). These workshops focussed on presenting the risks of the most vulnerable sectors, developing the associated Impact Chains (i.e. a visual mapping activity to explore how a specific climate stimulus causes a chain of effects through a system affecting both nature and society) interactively with the stakeholders and evaluating and prioritizing a set of LAMS according to the local context. This led to the co-development of the local risk analysis (T6.1) and adaptation and mitigation capacities analysis (T6.2).


Figure 5: In-person EUC Workshop III: CS3 Great Southern Plains (left) and CS1 Gotland (right).

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Table 5. End user Community (EUC) Workshop III in-person events at different Case Studies (CS).

Case Study	Location	Date	Participants
CS1 Gotland (Sweden)	Visby, Gotland, Sweden	07/11/2023	18
CS2 Tarn-et-Garonne (France)	Montauban, France	23/01/2024	11
CS3 Southern Great Plain (Hungary)	Szeged, Southern Great Plain, Hungary	25/01/2024	16
CS4 Valle D'Aosta (Italy)	Aosta, Valle d'Aosta, Italy	20/05/2024	10
CS5 Almeria (Spain)	Almeria, Almeria, Spain	25/01/2024	13
CS6 Azores Archipelago (Portugal)	Ponta Delgada, Azores, Portugal	23/01/2024	16

For T6.1 the EUC Workshop III events were important to co-develop impact chains to address the needs of the local models (T6.4). They were also co-developed in order to incorporate the insights of local stakeholders to capture and synthesize complex connections of risk components including hazards, exposure, and vulnerability (adaptive capacity and sensitivity). The same workshop content and agenda were delivered by the case study leaders in each of the six case study regions, ensuring a consistent approach to engagement and data collection.

Each EUC Workshop improved the identification of the problem statement and the most vulnerable sectors in each case study (see section 3.5). Parallel to the process coordinated under WP2, additional meetings and communications in each case study were useful to expedite this identification process.

This process through which stakeholders and case study leaders engaged in dialogue to understand the local context led to the co-selection of the most vulnerable sectors and the effects of climate change in different sectors.

2.3 Impact Chains

An impact chain can be defined as an analytical tool that helps to understand, systematize, and prioritize the factors that lead to risk and vulnerability in each system or sector, establishing cause and effect relationships between these factors.

The use of Impact Chains aims to synthesize the risk analysis as to inform the local Systems Dynamics (SD) model development (T6.4). They capture and synthesize the complex connections between the different risk components which are also quantified. This synthetization and quantification will improve decision-making at local level by offering a high-resolution climate diagnosis which will be made available in the platform (WP7).

Impact Chains's methods were described in D.5.2 (Methods for impact assessment and land allocation considering LAMS deployment) within the framework of Climate Risk Vulnerability Assessment (CRVA) (Birkmann, J., 2006). It was explained that CRVAs framework has been used in Assessment Reports (AR)

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of the IPCC, first with AR4, and then with AR5 (IPCC, 2014) but this time using the risk propeller framework which was kept in AR6 (IPCC, 2023). The transition of the climate risk framework from AR4 to AR5, something which is relevant for Task 6.1. Because of this a taxonomy change was made as explained in the Official progress report M1-M18, Technical Deviation 13 (TD13). The local analysis is now about the climate risks and its components of hazard, exposure, and vulnerability (adaptive capacity and sensitivity). Hagenlocher, M. et. al (2018) CRVAs framework iteration was used as the main reference for impact chain development. This main reference that was used for was which was used to create Annex III of D5.2 designated as the Impact chains manual.

Using this manual case study leaders developed several Impact Chains which were based on the risk analysis of their case studies. Subsequently, using the Workshop Guide (Annex I of D6.2), case study leaders co-developed impact chains with the stakeholders. The impact chains were represented in diagrams showing the direct and indirect connections between the different elements. Having these impact chains developed the quantification process was pursued to find indicators for hazards, exposure, and vulnerability factors. The identification of indicators and data collection was co-developed with the stakeholders. The developed Impact Chains and the quantification indicators are described in each of one the D6.1-CS Risk Analysis Annexes (Annexes I to VI).

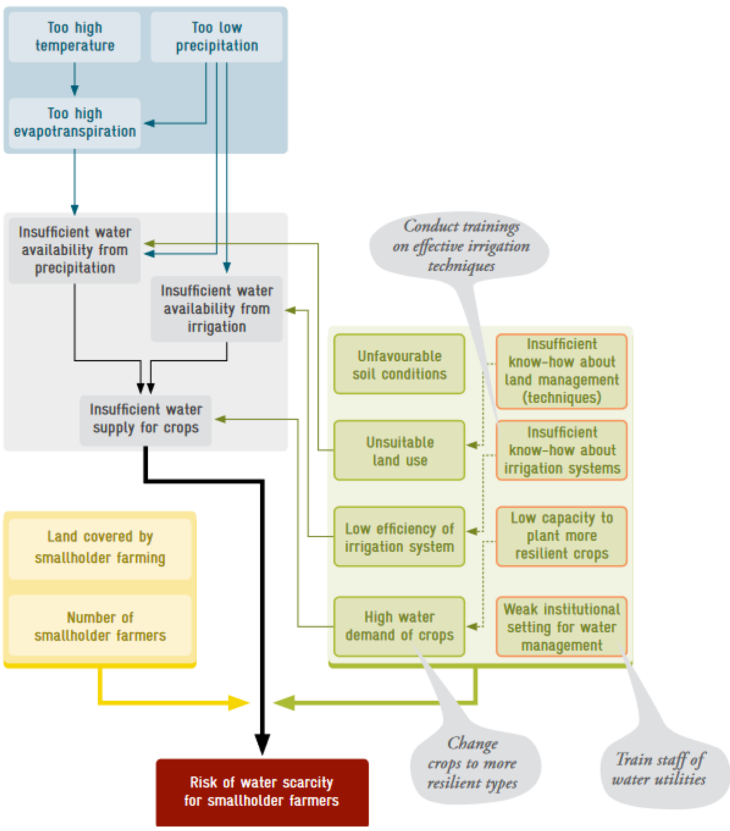

Figure 6: Example of an impact chain for water scarcity. Source: GIZ and EURAC (2017).

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For quick context about what an Impact Chain is a conceptual example taken from GIZ and EURAC (2017), a previous CRVA iteration to Hagenlocher, M. et. al (2018), is presented in Figure 6. The different boxes with different colors are factors of the different risk components. The hazards are identified in the blue boxes, the intermediate impacts are in the grey boxes and the vulnerability is represented in the green ones. The green boxes with an orange outline are related with the capacity factors of the vulnerability component, and with a green outline represent sensitivity. The exposure is covered in the yellow boxes while the adaptation options are shown in the grey ballons. The used methods did not explicitly consider integration of adaptation options in impact chains. However, this figure illustrates how such integration could be achieved, considering the affected factors within the CRVA framework. Finally, the diagram is connected with different arrows representing the interlinkages between the different variables and factors.

2.4 Risk identification and characterization

This section delineates the steps undertaken to quantify Hazard, Exposure, Vulnerability and Risk, considering the Vulnerability as the combination of Sensitivity and Adaptive capacity. Figure 7. displays the workflow and briefly describes the processes in each step.

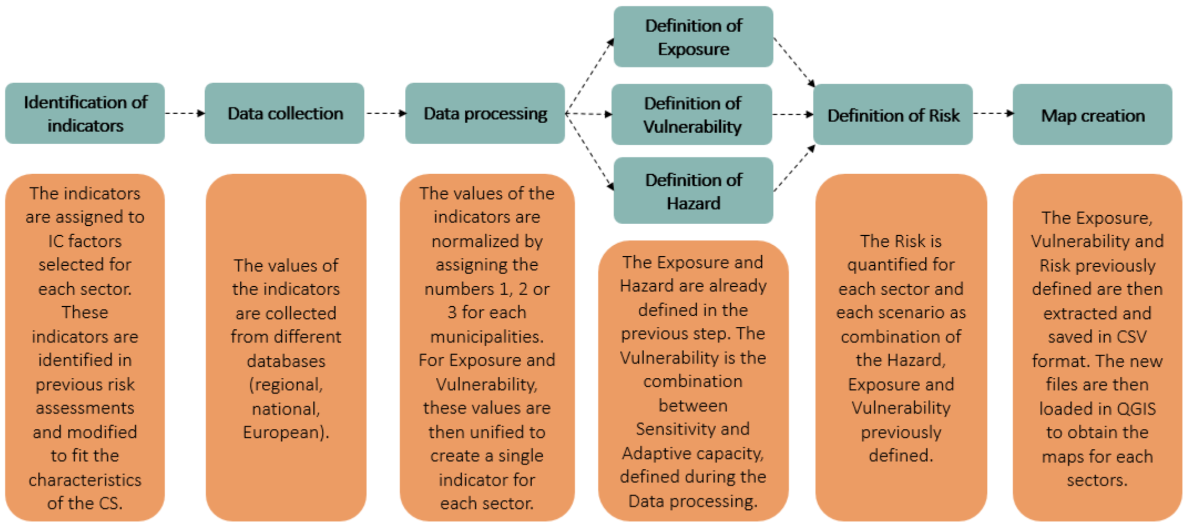

Figure 7. Workflow of the quantification and mapping of Exposure and Vulnerability.

2.4.1 Identification of the most relevant indicators for each sector

The initial phase of the quantification process involves identifying indicators of hazard, exposure, sensitivity, and adaptive capacity. The steps followed in the analysis are shown in Figure 7.. After the creation of Impact Chains (IC) (explained in section 2.3), some of the factors identified as representatives

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of hazard, exposure and vulnerability are selected to be quantified. This selection is based on data availability for the Case Study (CS).

Then, indicators are assigned to the selected factors of hazard, exposure, sensitivity, and adaptive capacity. These indicators are extracted from previous studies and modified to fit the characteristics of the CS and ensure the representation of its key sectors (e.g. agriculture, energy, biodiversity, etc.). The factors selected for exposure, sensitivity and adaptive capacity can be characterized by more than one indicator as shown in the example displayed in Table 6. The full list of indicators used for risk quantification in the six case studies is included in Annex VIII. The indicators differ from the ones included in the Impact Chains due to data availability at case study level.

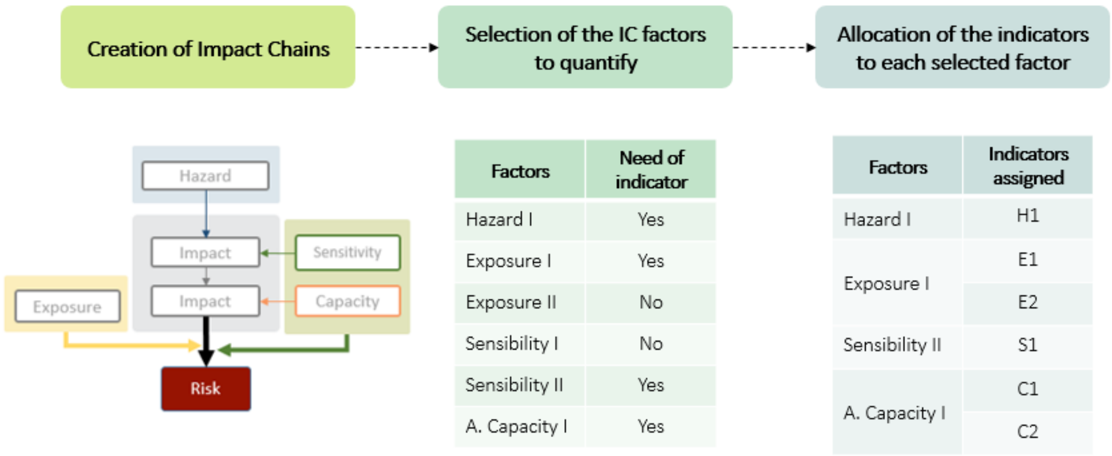

Figure 8. Workflow of the identification of indicators for the quantification.

Table 6. Example extracted from the full table of alignment between factors from IC52 and quantification indicators

Components	IC Factors	Indicators	Units
Exposure	Agriculture (area/workers)	Agricultural areas exposed	km^2
		People working in agricultural sector	Nº of workers in agricultural sector
Vulnerability - Sensitivity	High sensitivity to fire	Municipal degree of fire danger in forest combined with the tourist accommodation	Nº of accommodation (related to High risk of fire areas)
		Propensity to fire	Nº of fires
		Municipal degree of fire danger of in forest combined with the km of road network that passes through the municipality	Nº of accommodations (related to High risk of fire areas)
		Average gross income per person per municipality (INE)	€

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Components	IC Factors	Indicators	Units
Vulnerability - Adaptive capacity	High number of dependent citizens	Dependency index	%

2.4.2 Data collection

Once a set of indicators for exposure, sensitivity and adaptive capacity is defined and explained through a brief description, the values of these factors are downloaded from regional, national, and European databases for each municipality. The format of the data is an Excel file or a layer (vector or raster), which are modified through QGIS tools to obtain values of indicators that are saved in excel format.

The hazard characterization includes not only the description of the hazard indicator, but also thresholds extracted from literature for each indicator. These thresholds (e.g. temperature higher than 25°C), together with climate variables (e.g. temperature) collected in WP3 for the historical period and each scenario (SSP1-2.6, SSP2-4.5, SSP5-8.5) are used to define hazard probabilities (e.g. probability of hot days) in each municipality.

2.4.3 Data processing

As anticipated in the previous section, hazard probabilities are determined by processing variables with thresholds to obtain probability values of hazard for the historical period and each scenario in each municipality. The three scenarios considered in the project include an additional division based on three periods of the future: 2015-2040, 2041-2070, 2071-2100. Consequently, one hazard indicator is defined by ten probability values for each municipality.

Then, the values collected for exposure, sensitivity and adaptive capacity, and the hazard probabilities are normalized by assigning the numbers 1, 2 or 3 to each indicator and municipality. These numbers are set based on the 25th and 75th percentiles of all the values in the municipalities. The highest risk is defined by 3 and the lowest by 1, which is valid for hazard, exposure and sensitivity values. For example, if the surface of protected area overcomes the 75th percentile, the value assigned will be 3 because a big area increases the risk. On the other hand, the value 3 in adaptive capacity represents the highest ability to cope with the effects of climate change. Therefore, if the amount of accessible water is bigger than the 75th percentile, the value assigned is 3 because improves the level of adaptive capacity.

After the normalization, the indicators of exposure, sensitivity and adaptive capacity are combined for each sector to obtain a unique value assigned to each municipality. In this process, the arithmetic mean (μ), the standard deviation (σ) and the coefficient of variation (σ/ μ) are computed for all indicators

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comprised in the same sector. Then, the single value (N) for each sector (*i*) and municipality (*m*) is defined as:

$$N_{i,m} = \mu_{i,m} - \frac{\sigma_{i,m}}{\mu_{i,m}}$$

Moreover, a mean (weighted or arithmetic based on the CS) of the normalized values are calculated to combine the values of all the sectors in a single general indicator. In case of a weighted mean, the weights are assigned to each sector of the CS based on economic and environmental criteria.

These procedures are followed for exposure, sensitivity and adaptive capacity.

2.4.4 Exposure quantification

The exposure is represented by the assets that are affected by climate change. The single values for the indicator representing the exposure calculated in the previous step, are again transformed with the percentiles in 1, 2 or 3. After this procedure, the final indicators of the exposure are obtained. These outcomes are used to produce maps and for the calculation of risk.

2.4.5 Vulnerability quantification

Vulnerability (*V*) is calculated as the combination of sensitivity (*S*) and adaptive capacity (*A*) for each sector (*i*) and municipality (*m*):

$$V_{i,m} = S_{i,m} - A_{i,m}$$

The values computed are again normalized by assigning the numbers 1, 2 or 3 to each sector and municipality, with 3 representing the most vulnerable conditions. These numbers are assigned based on the 25th and 75th percentile exactly like the procedure followed in Data processing. With the values computed, it is possible to create radar graphs and maps of the vulnerability for each sector (section 4).

2.4.6 Hazard quantification

The normalized probabilities of the hazards, which are quantified in the Data processing step, correspond to the final values. These probabilities are used for the quantification of the risk for the historical period and in each hazard scenario.

2.4.7 Risk quantification

The risk is determined through the combination of hazard probability (*H*), exposure (*E*) and vulnerability (*V*). This is obtained by performing the mean of the indicators for each sector (*i*), each hazard scenario (*j*) and for each municipality (*m*):

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$$R_{i,j,m} = \frac{H_{j,m} + E_{i,m} + V_{i,m}}{3}$$

The outcomes of the above equation are normalized with the 25th and 75th percentiles. The final values of risk are then used for the creation of heatmaps to represent the results per municipality (section 0).

2.4.8 Mapping of Exposure, Vulnerability and Risk

The single normalized values for each sector and the general values are then extracted and transformed in CSV format. The files of exposure, vulnerability and risk are loaded in QGIS and the maps of these two components of risk are created for each sector over the municipalities of the Case Study regions. These maps will be included as part of the RethinkAction platform to provide an idea of the most vulnerable sector before simulating the effects of policy implementation.

2.5 Sectoral impact models

Sectoral impact models are meant to use as risk assessment tools in T6.1 and for the parameterization of variables namely in damage functions, in the local SD model development in T6.4 (see D5.3 | Design of scenarios consistent across scales). In this section we discuss the use of the InVEST Annual Water Yield (AWY) and AquaCrop models in the context of the risk analysis. This work is expected to continue and evolve under T6.4.

2.5.1 InVEST model

The InVEST modelling have been conducted in accordance with the methodology and objectives outlined in the D5.2 | Annex I - modelling activities report, for the surface water model and is briefly described in this section. Only the AWY model has been implemented, and the proposed extended AWY modules that would additionally quantify water scarcity and/or water resources in economic terms has been left out for now.

The InVEST Annual Water Yield model (AWY) was adopted and executed for each case study with ECV-data provided by WP3. This data was derived from the ensemble model socioeconomic pathway scenarios, downscaled, and averaged over the three different time periods (historical, 1985-2014; mid, 2040:2070; end, 2071-2100). The current model state (described in more detail in the D5.2 | Annex I report) is in line with the original objective to develop a baseline model for each CS. A baseline model sets a benchmark for further modelling but does not necessarily constitute an appropriate final version to be implemented. The following constraints/simplifications are imposed on the baseline models:

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- To fully promote homogenous and comparable results between case studies, European open-source data sources have been used regardless of other available case study specific data, or higher resolution data. The only exception from this is the referred ECV data.
- Input parameters (such as land use class properties and seasonality coefficients) were held constant between case studies to the model defaults suggested by the user guide.
- In terms of output format, results are aggregated to each period and to the whole case study region. The first is due to limitations in computational capacity, and the second due to varying quality of elevation data and watershed delineation between case studies, as well as the aforementioned inconsistent adaptation of data to local conditions.

2.5.2 AquaCrop model

Under the RethinkAction project, to get the simulated yield of a selection of crops, the simulation was carried out in the Python implementation of the FAO AquaCrop model: AquaCrop-OSPy (Kelly, T.D. and Foster, 2021). This model has widely been used to simulate the yield in water-constrained situations as well as its applicability for climate change risk assessment on crops (Steduto et al., 2012). As described in D5.2, the parameters that were used were: planting date, initial water content expressed in Total Available Water (TAW), crop (USDA texture) and soil. The inputs were CO_2 atmospheric concentration, and the climate of the case study area, both for historical and future modeled data.

The available Python version of the model (v3.0.1) has a significant limitation of not linking the simulation between the years concerning the soil water balance. Consequently, the TAW goes back to the initial soil water (and salinity content) value for the subsequent simulation. To deal with this issue a procedure to find the initial water content parameter was developed which departed from what was established in D5.2. The model was run for a range of 0 to 100 % TAW to observe the best possible fit between the historical yield data (ton/ha) and the simulation results in the historical period. This work was developed in the scope of a master thesis (Saretto, 2024) and led to the publication of a scientific paper, Saretto et al., (2024).

Planting date interval information was provided by the case study partners. Afterward, using the best-fitted TAW, a suitable planting date for the respective crop was chosen by comparing the simulated yield obtained with different planting dates, with the historical yield data.

After having obtained the TAW and the Planting date, the crop yield was computed for different SSPs scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the baseline (1985-2014), mid (2041-2070) and end-century (2071-2100) periods.

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3 Results

This section includes a systematic reporting and summary of the results of the six local risk analysis, which were focussed on six RethinkAction case studies (see Figure 9):

- CS1 - Gotland (Sweden): Northern case study.
- CS2 - Tarn-et-Garonne (France): Atlantic case study.
- CS3 - Southern Great Plain (Hungary): East of EU case study.
- CS4 - Valle D'Aosta (Italy): Alpine – Mountain.
- CS5 - Almeria (Spain): Mediterranean case study.
- CS6 - Azores Archipelago (Portugal): Small Islands case study.

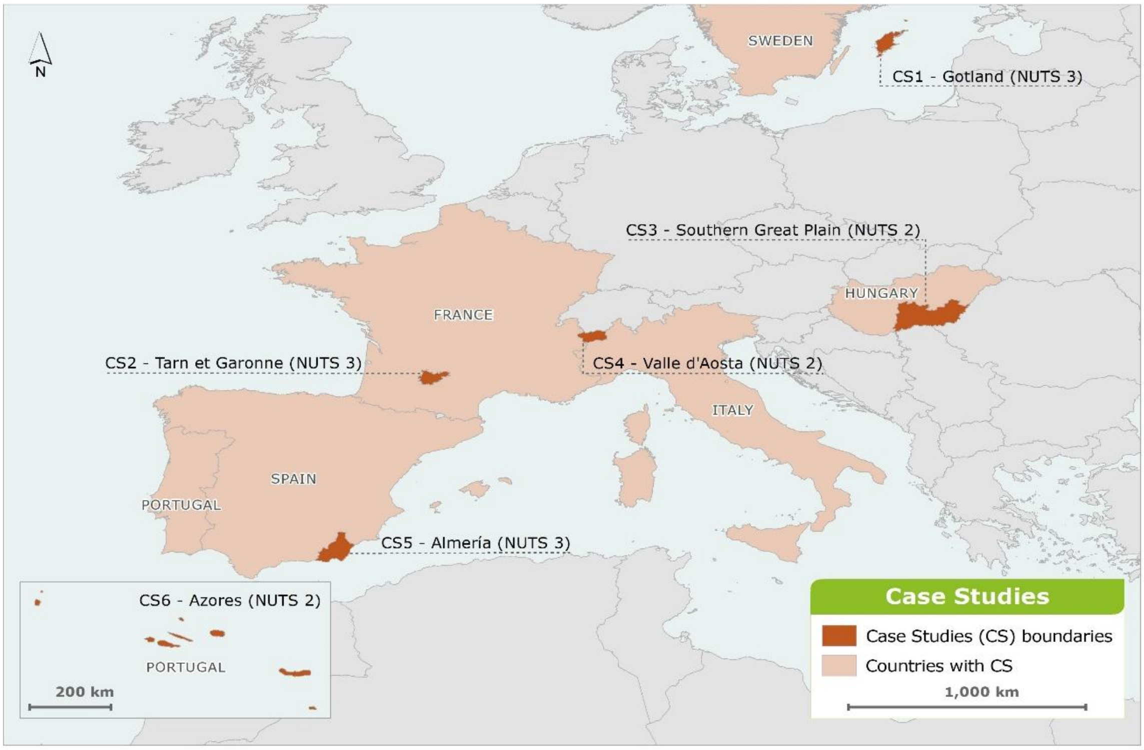

Figure 9: Area of Interest of RethinkAction Case Studies.

These case studies comprise relevant and representative examples in EU based on (a) the variety of climate change impacts and land system pressures, including hot-spots such as small islands in outermost regions, boreal forests, Mediterranean and Alpine region, and (b) less-represented areas in terms of climate services developed and also abandoned territories such as specific rural areas underutilized or mismanaged.

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Each case study conducted a risk analysis which is presented in this section in a short and systematic way, extracted from the case studies Risk analysis reports (D6.1-CSX) included as Annexes of this deliverable (Annex I to Annex VI).

3.1 Summary of ECV anomalies

The ECV static anomaly maps presented in section 2.1.1 are summarized in tabular form which presented in Annex VII – D6.1-ECVs. Here are highlighted two table examples that show the similarities and the differences of the Case Studies in regard to the project ECV anomalies. These anomalies are further explored in each one of the D6.1-CSX Risk Analysis Annex reports (Annex I to VI).

In Table 7 it can be observed that already for SSP1-2.6 there are noticeable temperature anomalies across the different Case Studies (CS) which show a general increase in temperature, ranging from 0.29˚C to 2.82˚C. The CS1 (Gotland) shows the maximum projected temperature anomaly for the end of the century. The CS6 (Azores) shows the lowest anomaly projected values across the different timeframes and models. This is likely to be related to the importance of seawater temperature in the local climate, which will increase less than the maximum air temperature anomaly which can be observed in the IPCC Interactive Atlas (Gutiérrez et. al, 2021). In SSP2-4.5 and SSP5-8.5, the anomalies increase with a range of 0.48˚C to 4.26˚C and 0.36˚C to 7.77˚C respectfully. Across scenarios CS1 (Gotland) has the largest temperature anomaly and CS6 (Azores) the lowest.

Table 7: Daily maximum near surface air temperature anomalies (˚C) values for the SSP1-2.6 scenario for the 6 CSs for the three periods of reference.

ECVs - Daily maximum near surface air temperature anomalies (ºC) | 30-year average | SSP1-2.6						
Case Studies	Anomalies range	Future Projected Periods			CS Range	Total Range
		2015-2040	2041-2070	2071-2100		
		˚C	˚C	˚C	˚C	˚C
CS1	Min.	1.07	1.80	2.08	From 1.07 to 2.82	From 0.29 to 2.82
	Max.	1.44	2.45	2.82		
CS2	Min.	1.10	1.84	2.09	From 1.10 to 2.37	
	Max.	1.26	2.11	2.37		
CS3	Min.	1.30	2.24	2.39	From 1.3 to 2.54	
	Max.	1.39	2.41	2.54		
CS4	Min.	0.94	1.54	1.70	From 0.94 to 2.33	
	Max.	1.29	2.09	2.33		
CS5	Min.	0.76	1.23	1.46	From 0.76 to 2.57	
	Max.	1.36	2.19	2.57		
CS6	Min.	0.29	0.48	0.52	From 0.29 to 1.6	
	Max.	0.93	1.39	1.60		

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In Table 8 we can observe the range of precipitation anomalies (%) of the different climate models for the six case studies in the three future periods considering SSP1-2.6 scenario. Case Study 1(Gotland) shows a clear trend for precipitation increase across the timescales. CS3 (Southern Great Plain) and 4 (Valle d'Aosta) and 6 (Azores), show a variation range which is more positive than negative. CS2 (Tarn-et-Garonne) and CS5 (Almería) show a trend for a precipitation decrease. This is in line to what is expected distribution projected change in annual precipitation (European Environment Agency, 2017). Scenario SSP2-4.5 changes these trends slightly except for CS5 (Almeria) which sufferers even more from projected precipitation loss. In SSP5-8.5, all climates show a decrease in projected precipitation for almost all models and time frames, having CS5 (Almeria) a significant decrease (from -42% to -35%) and being CS1 (Gotland) the exception with an increase from 10% to 16%.

Table 8: ECVs - Precipitation anomalies (%) values for the SSP1-2.6 scenario for the 6 CSs for the three periods of reference

ECVs - Precipitation anomalies (%) | 30-year average | SSP1-2.6						
Case Studies	Anomalies range	Future Projected Periods			CS Range	Total Range
		2015-2040	2041-2070	2071-2100		
		%	%	%	%	%
CS1	Min.	1.46	2.82	2.29	From 1.46 to 4.57	From -14.89 to 8.32
	Max.	2.49	4.57	4.49		
CS2	Min.	-2.90	-6.75	-8.14	From -8.14 to -0.88	
	Max.	-0.88	-5.32	-6.38		
CS3	Min.	2.92	-1.63	-0.69	From -1.63 to 4.13	
	Max.	4.13	0.46	0.99		
CS4	Min.	-1.86	-2.13	-2.84	From -2.84 to 5.86	
	Max.	1.82	3.52	5.86		
CS5	Min.	-0.18	-12.09	-14.89	From -14.89 to 8.32	
	Max.	8.32	-6.96	-9.44		
CS6	Min.	-1.81	-1.52	-1.75	From -1.81 to 5.96	
	Max.	3.99	1.65	5.96		

3.2 Summary of case study characterization

3.2.1 CS1 – Gotland (Sweden)

Gotland is an island (approx. 3.140 km²) situated in the middle of the Baltic Sea and is one of the less populated regions of Sweden. However, the island is a popular summer destination for tourists and therefore the population increases vastly during summer months. The island is originally a coral reef, based on limestone and large parts of the island has thin soil layers which limits the volumes of

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groundwater and the possibility to store water for long periods of dry weather (summer season). The region is covered by 31% arable land, mainly growing crops for cattle and pastureland, 40% of the island consists of forests, mainly smaller independent patches.

Gotland is one of the smallest regions in Sweden, it consists of only one municipality with approximately 60 000 residents. The largest town on the island is the medieval town of Visby with 24 000 residents, other urban areas are Slite (approx. 1500 residents) and Hemse (approx. 1600 residents). The island has a low population density of approx. 18,5 residents per km², with the highest density around the county town Visby (Region Gotland, 2017).

The two largest economic sectors and employment sectors in Gotland is agriculture and tourism, when we remove the public employed, that work at the military, hospital, schools and similar. The third largest areal industry is forestry. Many people on Gotland are active and has their income from more than one of these sectors. 24 % of the employment places at Gotland is in areal industries (Agriculture/forestry) and approx. 13 % in sectors connected to tourism. The island's main land use on the island is arable land 31%, mainly growing crops for cattle and pastureland, and forest 40%, mainly smaller independent patches.

Water shortage and drought in southern Sweden, changes in precipitation as well as increased temperature (Figure 10) and evaporation can lead to increased summer drought in southern Sweden. At the same time, the number of downpours is expected to increase and intensify even in southern Sweden. Temperature zones move north. The length of the growing season is expected to increase by several weeks or up to several months (Naturvårdsverket, 2024).

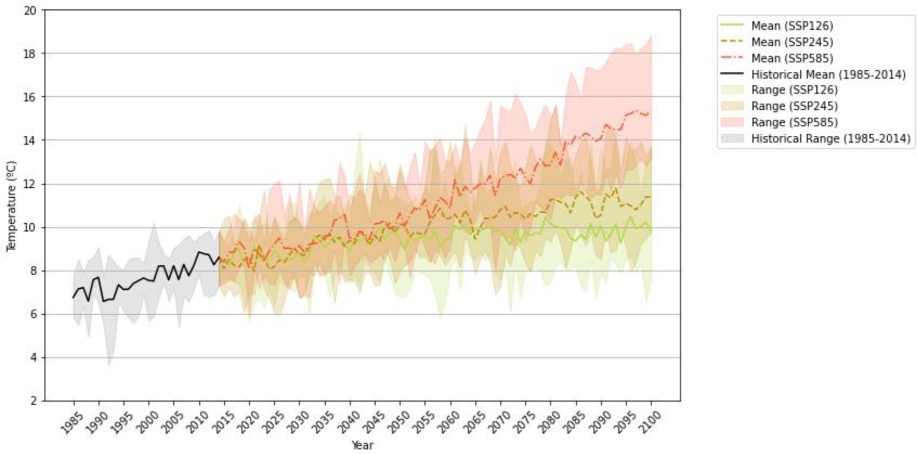

Figure 10. Evolution of the mean temperature in the CS1, considering the historical values (1985 - 2014) and the scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5 for the future (2015 - 2100).

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3.2.2 CS2 – Tarn-et-Garonne (France)

The department of Tarn-et-Garonne is in the South-West of France, in the Occitanie Region and covers an area of 3,717 km² with a population of 262,316 inhabitants (INSEE, 2020). The Tarn-et-Garonne has a diversity of landscapes: plains, located between the main rivers: the Tarn, the Garonne and the Aveyron, and hills in the North and in the South-West of the department, with a peak at 510 meters.

Agriculture is a very important sector for the case study: it represents 5% of the employment in 2021 and covers about 72% of the area of the department (RethinkAction Consortium, 2023). 3,684 farms are recorded in Tarn-et-Garonne in 2020 and the average area per farm is 54 ha (Chambre d'Agriculture d'Occitanie, 2022). Cereals, fodder/grasslands, and oil crops are mainly cultivated and cover 33%, 31%, and 20% of the agricultural areas, respectively. Fruit, vegetables, and horticulture are also very important in this region and cover 7.8% of the total agricultural area (Chambre d'Agriculture Occitanie, 2022). The turnover in agriculture reached 585M€ in 2020: fruit, vegetables, and horticulture represented 276M€, cereals and oil crops 102M€ and fodder 39M€ (Chambre d'Agriculture Occitanie, 2022).

Due to its natural position at the junction of the three rivers, the case study benefits from water resources. Irrigation infrastructures have been created to match the irrigation demand, essential for the growth of fruit, vegetables, seeds, cereals, as well as fodder. Irrigation concerns more than a quarter of the departmental utilised agricultural land and half of the farms (Chambre d'Agriculture Occitanie, 2022). 25,4% of the water consumedin 2020 in Tarn-et-Garonne was for irrigation (BNPE, 2020).

The Tarn-et-Garonne has a warm temperate climate. Rainfalls occur throughout the year and even in the driest months (from July to September and from February to March), the rainfall remains quite high. The average annual temperature in Montauban is 13.8 °C and rainfall reaches 749 mm per year (Climate Data, 2023). Located halfway between the Atlantic and the Mediterranean, this area is swept by two dominant winds: the "Autan" from the south-east which usually dries out the crops and the

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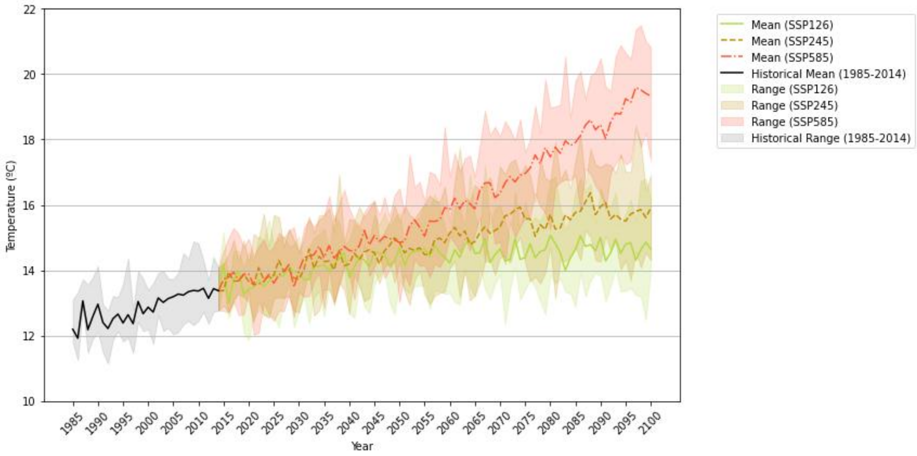
"Tramontane", the north-west wind, which normally brings rain (Chambre d'Agriculture Occitanie,



2021).

Figure 11 shows the projections of the mean temperature in Tarn-et-Garonne by the end of the century considering the historical values and the 3 different scenarios. The historical period shows an increasing tendency: the temperature rises by around 1.5°C between 1985 and 2014. Until mid-century all the scenarios are similar, and the temperature rises by around 1.5ºC from 2015 to 2050. The temperature in the scenario SSP5-8.5 increases then more significantly than the others and shows an increase of almost 6°C from 2015 by the end of the century.

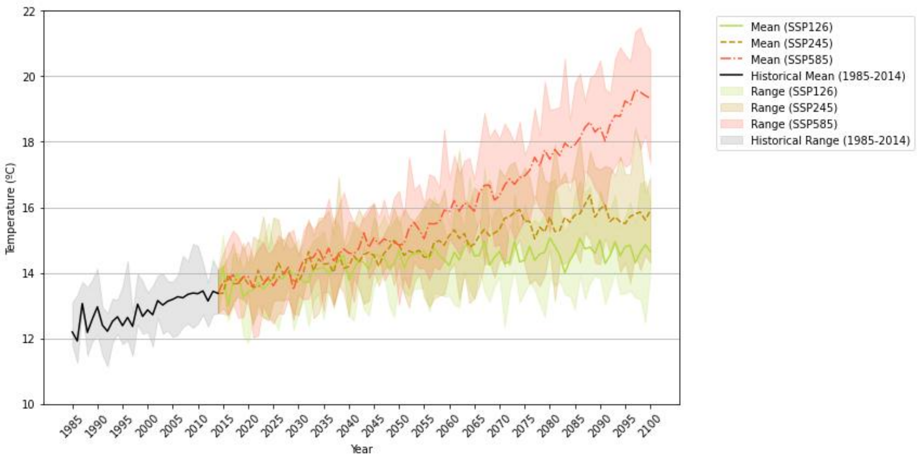


Figure 11: Evolution of the mean temperature in the CS2, considering the historical values (1985 - 2014) and the scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5 for the future (2015 - 2100).

Figure 12 shows the projections of the precipitation by the end of the century in the case study n°2 considering the historical values and the 3 different scenarios. The precipitation during the historical period varies from 700mm/year to 850 mm/year. The three scenarios SSP1-2.6, SSP2-4.5, SSP5-8.5 show a decrease in the precipitation and vary from 650 to 750 mm/year by the end of the century.

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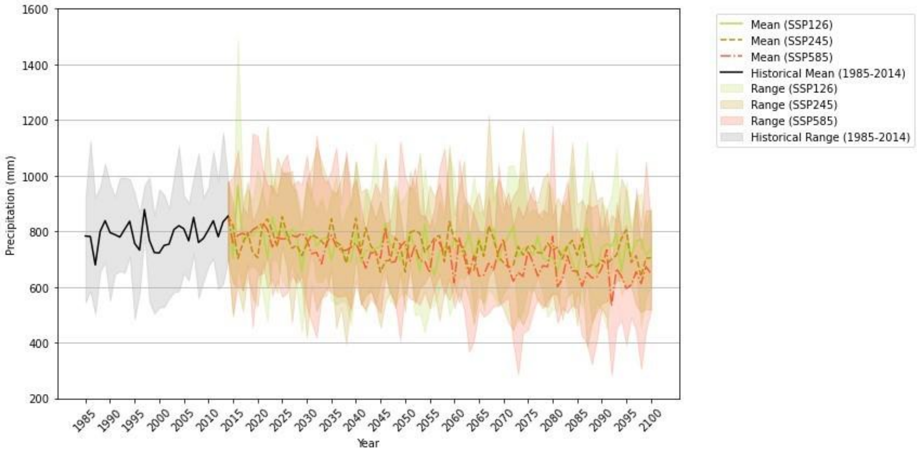

Figure 12: Evolution of the precipitation in the CS2, considering the historical values (1985 - 2014) and the scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5 for the future (2015 - 2100).

3.2.3 CS3 – Southern Great Plain (Hungary)

The region of the Southern Great Plain lies in the south, south-east of Hungary, being particularly low, ca. 70-80m above sea level, and part of the Tisza River Basin, where the river has an alluvial character. The main soil types include sandy soils, chernozems and meadow soils, generally fertile with good humus contents, which gave the base for extended agriculture and cultivation. As of 2022, housed a population of 1,213,595 individuals, boasting an average density of 65 people/km2 (KSH, 2022). The employment landscape is diverse, with agriculture, industry, and services accounting for 9%, 30.2%, and 60.8% of the workforce, respectively.

The regions' climate can be characterised as humid continental. Summer is warm, even hot, and tends to stretch over to the first autumn months. The average temperature is about 23 Celsius, with maximums ca. 40 Celsius, and number of hot days (T>30 C) fluctuated around 40-45 days/y, within the 2000s. Precipitation on average is ca. 550-650 mm/y, which is delivered in a typically non-consistent manner: May, June and July deliver the highest amounts, while autumn-winter months provide less amounts.

The Southern Great Plain of Hungary is experiencing a trend in slowly decreasing annual rainfall, its increasingly uneven nature combined with drought in the critical growing season (i.e. Spring). More risks come along with a trend of rising average temperatures (all seasons, see Figure 13) and extreme hot days (and nights) adding more stress to ecosystems.

Agriculture, forestry and its supply chains are dominant in the region thus numerous vulnerabilities have been associated to them and identified as most impactful due to its economic significance. Not only employment-economics are affected but people's health and wellbeing. Climate change greatly affects

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the water systems, consequently the water sector is vulnerable too, as water management and infrastructures tend to be low level and underdeveloped.

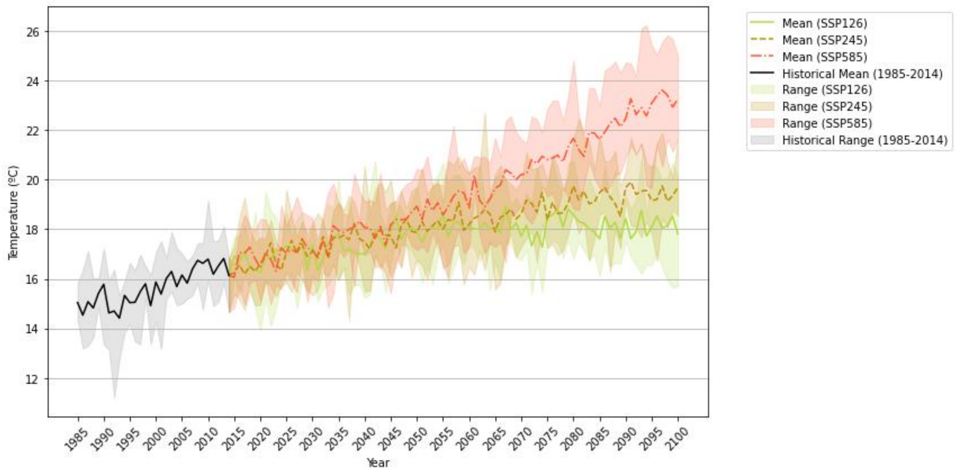

Figure 13: Evolution of the mean temperature in the CS3, considering the historical values (1985 - 2014) and the scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5 for the future (2015 - 2100).

Surface and groundwaters, soils, land use, cultivation patters and ecosystems are affected quantitatively and qualitatively, therefore agricultural activities is at risk and being exposed, cumulatively. Reflect to climate change, sectoral strategies and strategic documents have been produced at local (SECAPs) and at national levels along with state supported studies. Nonetheless we hear that an integrated and multi-stakeholder approach has not yet been worked out to date, that has consensus with industry (farmers), citizens and researchers. Adaptation practices, including land use based, have been started to spread among stakeholders e.g. farmers switch crops or efforts to build capacity to supply water, but coordinated efforts at various spatial scales and multi-disciplinary approach is yet to emerge.

3.2.4 CS4 – Valle d’Aosta (Italy)

Located in the heart of the Alps and nestled between the Mont Blanc (4810 m), the Matterhorn (4634 m), Monte Rosa (4634 m) and Gran Paradiso (4061 m), the Aosta Valley is the smallest of the regions of Italy in terms of surface. It borders France to the west, Switzerland to the north, and Piedmont to the east and south. In mountain areas, in the Alps and therefore also in Valle d'Aosta, warming is greater than in other parts of the planet (IPCC 2019). Since the pre-industrial period in the Alps, average annual temperatures have increased by around 2°C, more than double what was measured globally (1.1 ± 0.1°C). The average temperature historic and projections up to 2100 for Valle D’Aosta for the SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios are reported in Figure 14.

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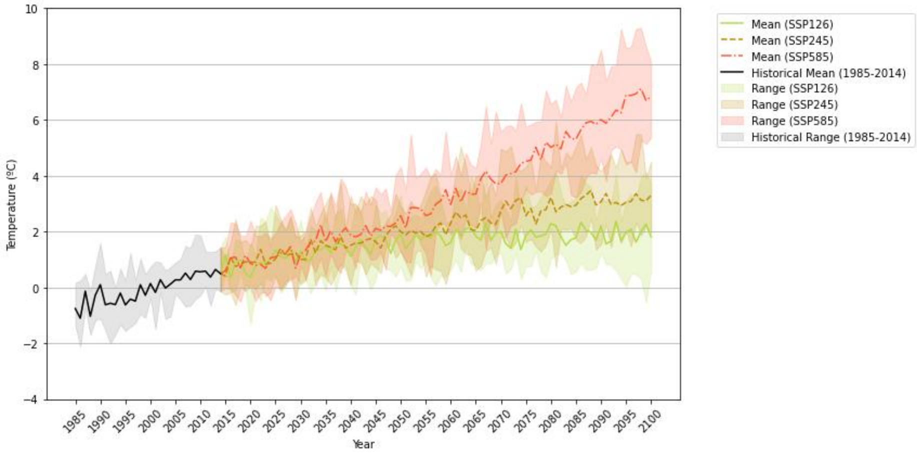

Figure 14: Evolution of the average temperature in the CS4, for the historical period (1985-2014) and the future scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the period 2015-2100.

Regarding precipitation (Figure 15), it is expected that annual precipitation will not change compared to the period 1980-2010, while a change in the seasonal distribution of rainfall is expected. By 2050, a significant increase in winter precipitation is expected (approximately 20%), a moderate increase in autumn and spring precipitation (approximately 8%) and a slight reduction in summer precipitation (-3%).

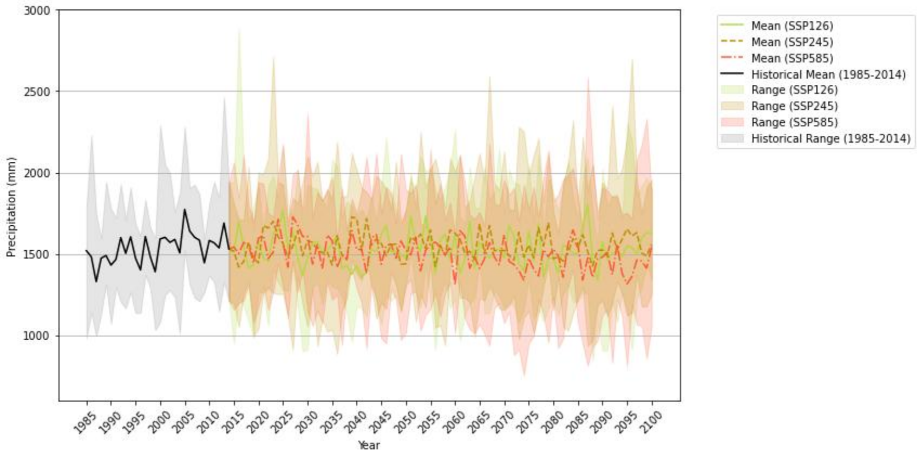

Figure 15: Evolution of the precipitation in the CS4, for the historical period (1985-2014) and the future scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the period 2015-2100.

3.2.5 CS5 – Almería (Spain)

Almería is located in eastern Andalusia, Spain and is noted for its arid climate and extensive agricultural activities, especially greenhouse horticulture. The population of the Almeria province is 753,920 according to the Spanish National Census data, with a density of 85 inhabitants per square kilometre. The economy is heavily reliant on horticulture, with greenhouse crops playing a significant role in its

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GDP and employment. The demographic structure is diverse, with a significant number of migrant workers from North and West Africa, primarily employed in the agricultural sector, which underscores the social and economic dynamics of the region.

The province experiences one of the driest climates within the European Union, receiving annual rainfall between 200-300 mm and average temperatures ranging from 13°C in January to 24°C in July. Future climate scenarios predict an increase in temperature and a decrease in precipitation (Figure 16), exacerbating the existing challenges such as water scarcity and changes in agricultural productivity due to the lack of water and the effects of CO_2 fertilization. The analysis of different climate models provides significant warming effect and drying trends by 2100 as it is presented in the figures, influencing both natural and agricultural systems.

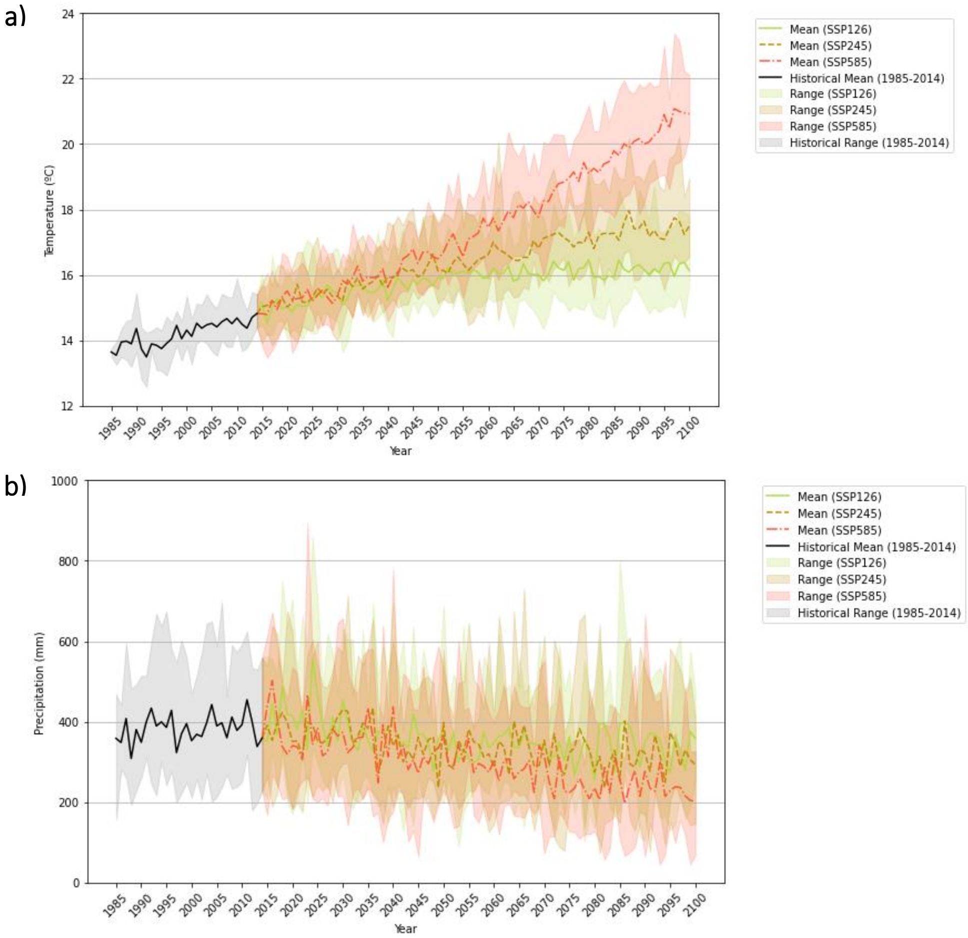

Figure 16: Evolution of the temperature (a) and precipitation (b) in the province of Almeria, considering the historical period (1985 - 2014) and the future (2015 - 2100) under three different socioeconomic scenarios: SSP1-2.6, SSP2-4.5 and SSP5-8.5.

Almería's economy is driven by its agricultural sector, particularly through intensive greenhouse farming, which contributes to the majority of the region's economic output. The GDP per capita for

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Almería province was 21,091€ in 2021. The agricultural sector not only drives economic growth but also presents challenges related to sustainability and labour conditions. The dependency on migrants for the agricultural production highlights critical social issues, including the integration and living conditions of these workers, which are often precarious.

Land use in Almería is heavily influenced by agricultural demands, particularly the extensive areas covered by greenhouses and dry areas. Greenhouses are crucial for the production of fruits and vegetables, primarily for export. Aside from agriculture, the land is characterized by shrubland (46%), cropland (19%), and forests (10%), with the remaining areas classified as other types of land. This distribution highlights the significant role of agriculture on land use follow by vegetated areas with shrublands and trees.

It is necessary to highlight the necessity of adaptive strategies to fight against the impacts of climate change, with a strong focus on sustainable water management and agricultural practices. Overexploitation of aquifers and reliance on water-intensive agriculture underpin many of the sustainability challenges faced by the province. The implementation of green infrastructure and the use of more sustainable agricultural practices are key to mitigate adverse environmental impacts and promote a balanced and sustainable regional development.

3.2.6 CS6 – Azores (Portugal)

The Azores, a 9-island archipelago in the North Atlantic Ocean, is a Portuguese Autonomous Region and one of the EU outermost regions. Influenced by the Atlantic Subtropical Anticyclone, known as the Azores High, and by the surrounding oceanic climate, the Azores has a temperate moist climate, with temperate summers and no marked dry season and a wet winter, with precipitation distributed across all months of the year (Carvalho et. al, 2022), but presenting a maximum in the winter (656 mm). The yearly precipitation average is high, 1875 mm, with summer being the season with lower values (236 mm). Projections anticipate a small decrease in precipitation, but with higher variability (Figure 18).

Two of the main economic drivers of Azores are Agriculture and Tourism, each employing 8% of the active population respectfully (SREA, 2023). The main land use is Agriculture with 48.9% (1134 km^2) of the total land use attributed area (2320 km^2 in total), 39.7% are pastures (920 km^2), followed by forests with 40.1% (930 km^2) (DRA, 2018). These land uses benefit from favorable morphological and climate conditions with a yearly average temperature of 15.8 ˚C. Altitudes higher than 330 meters represent 70% of the territory (1634 km^2), and higher than 660 meters represent 33%, influencing precipitation and temperature. Future scenarios indicate an increase of temperature (Figure 18).

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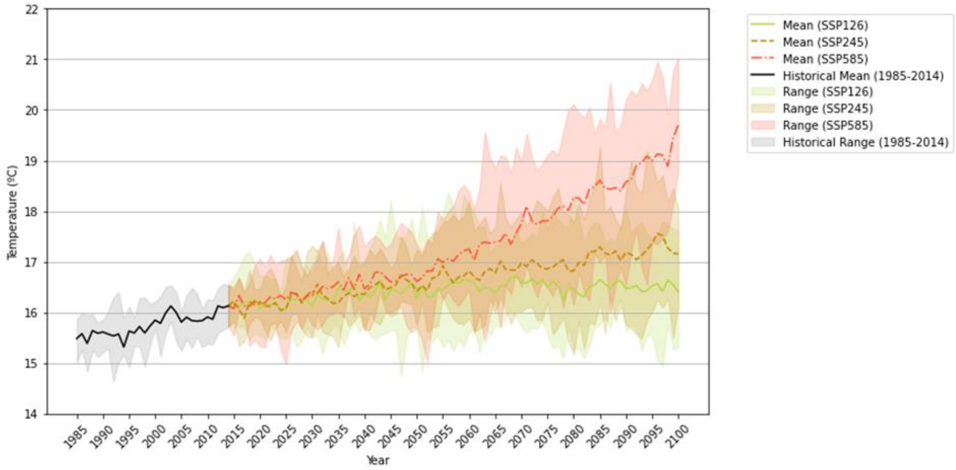

Figure 17: Evolution of the average temperature in the CS6, for the historical period (1985-2014) and the future scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the period 2015-2100.

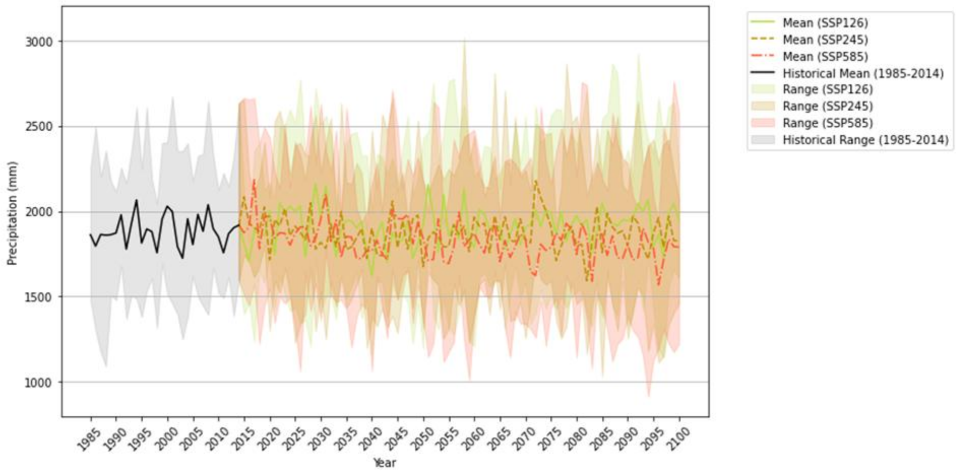

Figure 18: Evolution of the precipitation in the CS6, for the historical period (1985-2014) and the future scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the period 2015-2100.

Local stakeholders have signalled concerns that the climate may become drier, hotter, and more variable in the future. Climate risks may include localised water scarcity and groundwater salinisation, with impacts on Agriculture and Tourism. Additionally, warmer temperatures and extremes, may affect human thermal comfort levels, tourism attractiveness and the efficiency of energy production.

Despite the challenges associated with its geographical context, the Azores region has achieved significant decarbonization levels, decreasing net emissions by 10% between 2014 and 2019 (REAA 2017-2019) and is the first archipelago region in the world certified in 2017 as a Sustainable Tourist Destination (EarthCheck). The region aims for a safe, clean environment, with a net-zero carbon balance and high socio-economic cohesion levels across its islands. Azores ultimate goal as a region is to combine economic development with the preservation of natural capital and ecosystems for future generation.

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3.3 Results from InVEST AWY model

The results of the modelling exercise in each case study using the InVEST model are presented in Table 3 and Figure 18. In order to evaluate the impact of climate change, different SSP scenarios were used in 30-year future time periods to evaluate the water availability under warming conditions.

Table 3: Results of AWY for all scenarios, time periods, and case studies. The actual water yield in absolute numbers (Billions of Cubic meters) is presented alongside the percentual change as compared to the historical scenario.

Scenario	Time Period	Water Yield CS1		Water Yield CS2		Water Yield CS3		Water Yield CS4		Water Yield CS5		Water Yield CS6	
		Gm^3	% change of hist	Gm^3	% change of hist	Gm^3	% change of hist	Gm^3	% change of hist	Gm^3	% change of hist	Gm^3	% change of hist
	Historical (1985-2014)	9.43		3.65		16.28		27.45		5.50		2.14	
SSP1-2.6	2041-2070	9.07	-3.8	2.39	-34.6	12.93	-20.6	26.14	-4.8	4.17	-24.2	2.13	-0.4
SSP2-4.5	2041-2070	9.35	-0.8	2.36	-35.5	13.89	-14.7	26.59	-3.1	3.71	-32.5	2.10	-1.7
SSP5-8.5	2041-2070	9.18	-2.6	1.91	-47.6	11.54	-29.1	25.15	-8.4	3.05	-44.6	2.05	-4.3
SSP1-2.6	2071-2100	8.95	-5.1	2.28	-37.6	12.62	-22.5	25.90	-5.7	3.84	-30.2	2.19	2.2
SSP2-4.5	2071-2100	9.43	0.0	1.95	-46.6	12.28	-24.5	25.75	-6.2	3.22	-41.4	2.11	-1.7
SSP5-8.5	2071-2100	8.98	-4.7	1.06	-71.0	7.63	-53.1	21.84	-20.5	1.83	-66.7	2.00	-6.6

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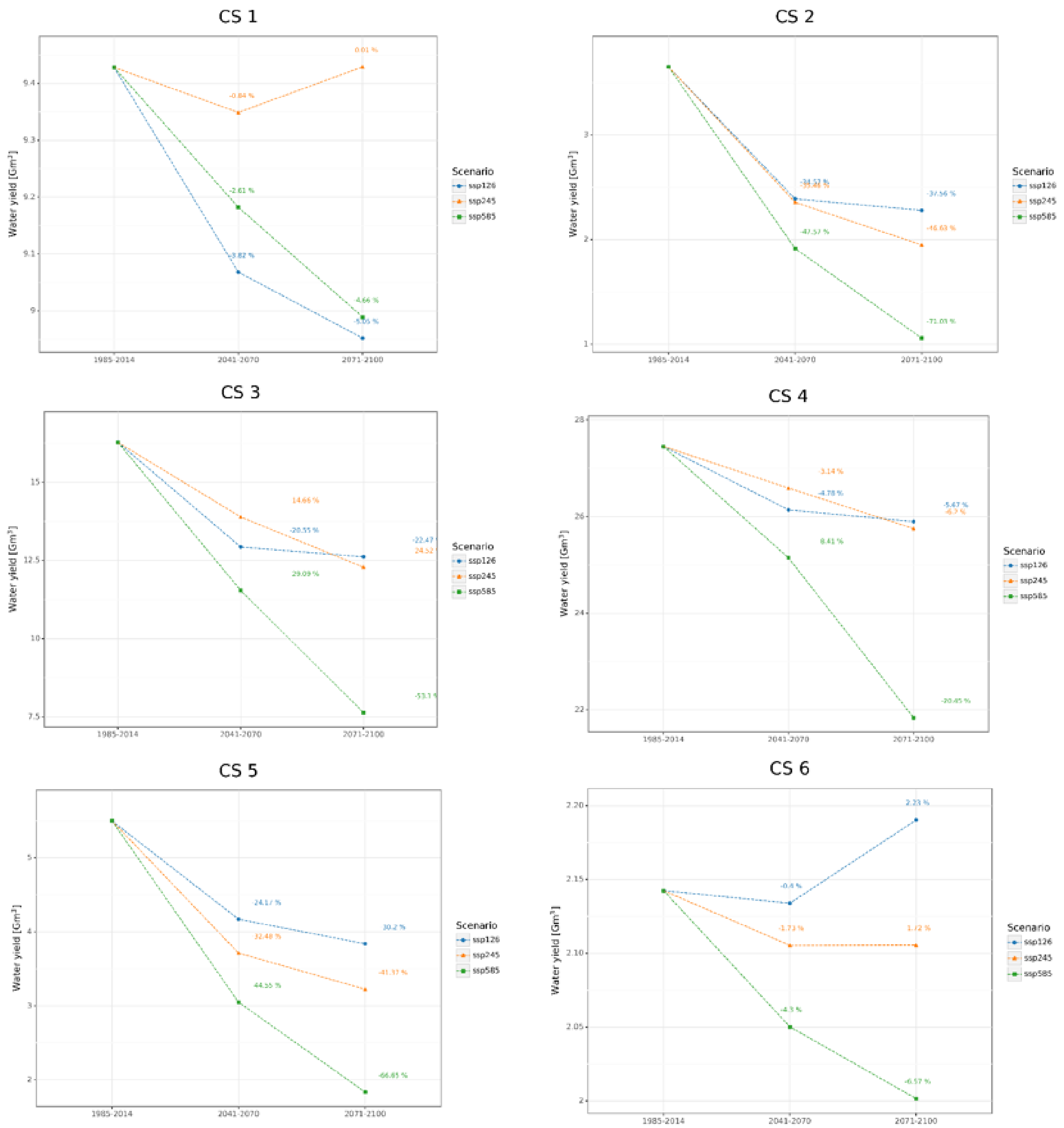

Figure 19: Results of InVEST model per case study and socioeconomic scenario.

3.3.1 CS1 – Gotland (Sweden)

The results of AWY, as shown in table 3 and figure 18, indicate relatively small changes in water availability on Gotland based on different scenarios into the middle and end of the century compared to historical data. The trend is overall downward water availability with increasingly future time periods, and upward in relation to SSP scenarios predicting larger increases in GHG emissions. The largest decrease is with the SSP1-2.6 scenarios in the respective time periods (-3.8% for 2041-2070, -5.1% for

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2071-2100), followed by the SSP5-8.5 scenarios (-2.6% for 2041-2070, -4.7% for 2071-2100). Meanwhile, the SSP2-4.5 for 2071-2100 predicts essentially no change in water availability compared to the historical period (-0.8% for 2041-2070, 0% for 2071-2100). The lack of any distinct direction of change in water availability can mainly be attributed to the interplay between rising temperatures (which drive evapotranspiration) and concurrent increases in precipitation. The 30-year averages smooth out the increasingly fluctuating climate, where events such as drought and flooding take place on a much smaller temporal scale. Consequently, on a yearly or monthly resolution, the picture could be significantly different for the future pessimistic scenarios, with alternating droughts and flooding events.

With the current aggregate results, the conclusion to be drawn is instead that overall water availability in Gotland will likely decrease in the future. The decrease is on the order of a few percent according to the model results, but probably obscures problems related to a more fluctuating climate. Since seasonal water scarcity is already a problem on Gotland, this is an undesirable trajectory that could exacerbate some of the risk factors described in D6.1 Annex Report CS1 sections 4.4.3 – 4.4.4. Even though the overall trend is negative in terms of water availability, it is still important to consider the risks of e.g., flooding as well (see D6.1 Annex Report CS1 section 4.4.1), since occurrence of extreme events are unrelated to the overall trend. To capture this with InVEST, it is possible to either adopt the seasonal water yield model, or improve the temporal and spatial resolution of AWY, with yearly catchment-level outputs instead of 30-year averages for the whole case study region.

3.3.2 CS2 – Tarn-et-Garonne (France)

The projections of the InVEST AWY model, for the Tarn-et-Garonne, show a downward trend for the three scenarios (Table 3 and Figure 18) and for both period 2041-2070 and 2071-2100.

For the SSP1-2.6, SSP2-4.5 it is expected a water yield significant decrease (- 34.4% and –35.5% respectively), for 2041-2070. The SSP5-8.5 shows an even more significant decrease which reach -47.6% for the same period. For the period 2071-2100, the projections show a decrease as well but less important than in the 2041-2070 period. Indeed, the SSP1-2.6 and SSP2-4.5 show a decrease in the water yield compared to the historical data of –37.6% (-3.2% compared to 2041-2070 period) and –46.6% (-11.1% compared to 2041-2070 period). The SSP5-8.5 shows a decrease of –71% compared to the historical data and –23.4% compared to the 2041-2070 period.

The decrease in water availability in the case study will be a challenge to use water in a sustainable way as the case study is already facing water availability and water quality issues that affect livelihoods and in particular the agricultural sector.

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3.3.3 CS3 – Southern Great Plain (Hungary)

The InVEST model projections for the region of the Southern Great Plain found patterns and trends related to both temperature and precipitation that holds significant potentials for increasing drought. In all the three SSP scenarios considered, the AWY found steady increase in average temperature, by ca. 5%, 18% and 35%; found increases in temperature for all months but more significantly in the summer term; and foreseen increase in the number of hot days.

In case of precipitation the model predicts a slight decreasing trend, with a ca. 10% decrease till 2100. On a monthly bases, the anomalies show more significant changes for the coming decades, 8-10% increase in the February-March and average 7% decrease in the summer months by 2040, a 7-15% increase and 12-18% decrease by 2070, and 15-22% increase and 20-25% decrease by 2100, respectively.

Modelled values by the AWY for regional evapotranspiration also show increasing trend, by 5% till 2050 and ca. 10-20% till 2100. Though this parameter, along with precipitation and temperature, shows strong seasonal patterns, indicating that summer evapotranspiration can be more significant. Based on the AWY results it can be foreseen that summer periods holds significant risk of drought and related effects in the Southern Great Plain region. The combined effects of increasing tendency of hot periods, decreasing precipitation values and its increasingly uneven pattern are likely to increase further evapotranspiration that will be increasingly challenging to balance with the decreasing water stocks. The risk of decreasing ecosystem services is expected to increase, which will affect the agricultural sector sensitively in the coming decades.

3.3.4 CS4 – Valle d'Aosta (Italy)

The AWY in Valle D'Aosta was found to decrease under SSPs 1-2.6, 2-4.5, and 5-8.5 into both the middle and end of the century according to the results in table 3 and figure 18. However, by the end of the century, SSP1-2.6 shows a less significant decrease compared to the other scenarios.

Given that the regional territory is particularly vulnerable to natural dangers linked to the intensification of the water cycle and changes in the cryosphere (snow, glaciers, permafrost), it shall be considered that despite the expected constant precipitation, the increasing evapotranspiration is exposing Valle D'Aosta to severe water shortages.

3.3.5 CS5 – Almería (Spain)

Based on Almería's AWY projections displayed in both table 3 as well as figure 18, we predict that the province will experience a decreased water yield during both the middle and end of the century. This

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further points to the downward trend of water resources, thereby highlighting the need for adequate water and resource management. Almería's case is somewhat pronounced, as in comparison to the other CSs, Almería is already predicted to experience a decrease in AWY towards the middle of the century) by at least 24% (SSP 1). The least projected loss towards the end of the century is also significant, as the AWY is predicted to be at least 30%.

The extent of the Almería's aridity poses not only a current challenge in sustainable water use and management (given the widespread reliance on Agricultural productivity in the province) but also a future challenge by way of the increase in climatic processes that result in evapotranspiration. A detailed IC on precisely these processes can be found in section 5.5.5., however suffice it to say that the combination of the projections from the InVEST model alongside the AquaCrop model in section 5.3.3. point to increased risks to water security in the CS, which has a knock-on effect to the livelihoods of the local population as well as impacts to other non-agricultural local industries. Additionally, the continental impacts regarding food security must also be considered, given the extent to which Almería is a food basket for the rest of Europe.

3.3.6 CS6 – Azores (Portugal)

The projections of the InVEST AWY model, for Azores, anticipate three distinct paths, depending on the scenarios (Table 3 and Figure 18). For the SSP1-2.6, it is expected an initial minor water yield decrease (- 0.4%), for 2041-2070, followed by an increase for the end century, up to 2.2%. In the middle term, the SSP2-4.5 indicates small decreases, -1.7% when comparing with the historical data, for both periods. The most extreme scenario reveals a decrease of water yield in the future, that can reach -6.6 %, in the end of century, and less impressive in the mid-century, -1.7%.

Giving the hydrography and soil type of Azores, future changes in water yields will impact the water streams and agriculture. The projected decrease in most of the scenarios and periods can negatively impact the water availability, due to the small river basins, higher periods of drought and higher evaporation. Additionally, the agriculture can be affected by a combination of the previous aspects, together with the type of soil in Azores, that does not support water for long time leading to a rapid loss of humidity. Consequently, longer drought periods will affect agricultural yields. AquaCrop model was also used to assess these impacts. A more detailed description on these hazards and impacts can be found on sectors 4.3.1 and 4.4 of the Annex VI - D6.1-CS6 Azores Archipelago (Portugal): Small Islands case study.

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3.3.7 Limitations and future work

The development of a baseline model for each CS is in line with the original objective. However, there is of course an inherent limitation in applying baseline models to retrieve accurate and trustworthy results. Furthermore, the results have not been calibrated or validated to hydrological measurements, and without a sensitivity analysis of the inputs, we do not know how large errors to be expected from low-quality data, and assignment of generic values to parameters. In other words, the baseline model results involve a high degree of uncertainty.

To remedy the limitations of the baseline models, the next step in the modelling effort should involve the adjustment of model parameters to local conditions through more comprehensive data acquisition and/or consultation with subject matter experts. In that process, sensitivity analysis and/or calibration will come more naturally as they are necessary components in calibrating* the results for the user once the CS-specific objective is clear.

A suggestion for moving forward in this direction is to alter the workflow. The work conducted so far has followed the principle of *"model first, ask later"*, according to this flow-chart:

Data ➡ Model ➡ outputs ➡ User

This was suitable for proceeding with the laborious technical work instead of waiting for bottlenecks to dissolve, as well as generating some early aggregate results. The technical work involved finding potential data sources, learning about how the model works, and performing the model setup. Meanwhile, the coarse initial results allow for an early risk analysis discussion (e.g. see the D6.1 Annex reports), even though further modelling efforts for each individual case study would be required to say something more decisive. To get to that level, one suggestion is to instead follow the flow in completely reversed (and circular) order:

User ➡ Outputs ➡ Model ➡ Data ➡ Model ➡ Outputs ➡ User

Which, made explicit, involves:

- Understanding what type of information (in regard to water resources) the user needs
- Asking ourselves: How can we transform the outputs of our model into that information?
- Constructing a modelling flow with pre-and post-processing for this purpose
- Collecting required data, or purposely retaining "lower quality" data if in accordance with purpose
- Running the case-specific model
- Processing the outputs (*Should involve calibration)

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- Delivering the results to the user

3.4 Results from AquaCrop model

3.4.1 CS1 – Gotland (Sweden)

Gotland's main agricultural production is dominated by winter wheat, followed by barley and vegetable cultivation. Under the scope of the RethinkAction project, Winter wheat was chosen to assess the risk of losing crop yield in future climatic scenarios. The historical yield data available for winter wheat are from 1965 to 2020, according to the information from the case study. The dominant soil textures in this region are sandy loam and have been chosen for subsequent simulation runs. However, loam and clay loam are also available on the island (Eckersten et al., 2010).

Figure 10 shows the average yield of winter wheat under different SSP scenarios for the baseline and the mid and end centuries. The results show that the simulated winter wheat yield during the baseline period is lower than the mid and end-century for all the SSPs. The average yield increases a little from mid to the end century for both SSP1-2.6 and SSP2-4.5, while on the other hand, the average yield remains the same in these two centuries for SSP5-8.5 scenarios.

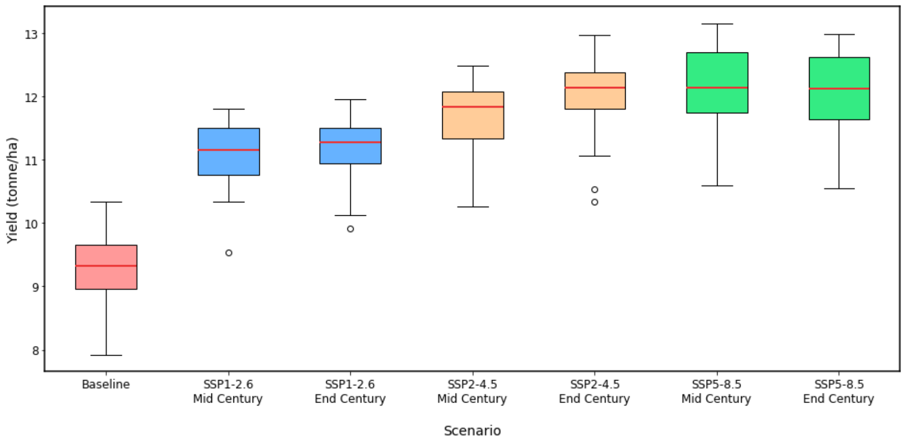

Figure 20: Mean yield of winter wheat, (IWC 10%, PD 10/30) in different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) at three temporal scales (baseline, Mid Century and End Century), in Gotland case study.

The climate data show that there will be an increase in precipitation together with higher temperatures. Our results show a higher yield in the crop during the mid and the end of the centuries under SSP1-2.6 and SSP2-4. For the SSP5-8.5 scenario, the yield is projected to increase until 2040-2070 and stabilize for the rest of the century.

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3.4.2 CS2 – Tarn-et-Garonne (France)

The first results did not consider the AquaCrop water balance problem referred before because they were identified later. Therefore, the results had a consistent error, due to the initial water content. AquaCrop was run again to solve the problem, using the apple crop parameters identified before. However, those parameters were not usable.

Giving these difficulties, the AquaCrop results for CS2 are not presented. Future work will try to solve these issues, in particular using the AquaCrop stand-alone version, which permits to apply more tools and modify parameters.

3.4.3 CS3 – Southern Great Plain (Hungary)

The Southern Great Plains of Hungary is highly vulnerable to climate change and increasing global temperatures, which has resulted in droughts, salinification, and desertification due to the general decrease in groundwater. The agricultural sector is a major contributor to the Hungarian economy. Winter wheat is the most grown crop followed by maize and sunflower in the southeastern region of Hungary, therefore the winter-wheat was chosen for the simulation. The historical yield data available for winter wheat was used from 2000 to 2020 (Kosponti Statisztikai Hivatal, 2023). The dominant soil textures in this region are Loam and Silt Clay Loam, based on case studies area information. Planting date interval information was provided by the case study partners (Geonardo), as from October 15th to October 30th. Afterward, using the best-fitted TAW, a suitable planting date for the respective crop was chosen by comparing the simulated yield obtained with different planting dates, with the historical yield data.

After having obtained the TAW and the Planting date, the crop yield was computed for different SSPs scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5), for the baseline (1985-2014), mid (2041-2070) and end-century (2071-2100) periods, considering Silt Clay Loam texture soil.

Figure 21 shows the average yield of winter wheat under different SSP scenarios for the baseline and the mid and end centuries. The results show that the simulated winter wheat yield during the baseline period is lower than the mid and end-century for all the SSPs. The average yield increases from mid to the end century in both SSP2-4.5 and SSP5-8.5, while on the other hand, the average yield remains same in these two centuries for the SSP1-2.6 scenario.

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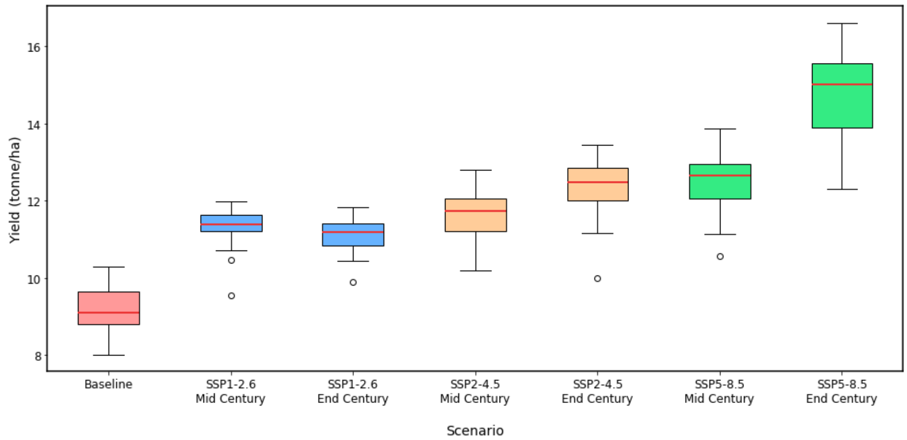

Figure 21: Mean yield of winter wheat, (IWC 10%, PD 10/30) in different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) at three temporal scales (baseline, Mid Century and End Century), in Hungary case study.

3.4.4 CS4 – Valle d'Aosta (Italy)

AquaCrop simulations were not developed for CS4 because risks associated with the agricultural sector were not identified. Future work may include simulations of generic crops for the development of the local SD Model.

3.4.5 CS5 – Almería (Spain)

The proposed analysis focuses on assessing Climate Change Impacts on Rainfed Barley production and evaluating the performances under different adaptation options, in Almeria Province, Spain. Targeting Barley is relevant because it represents one of the most resilient crops available to farmers (Cossani et al., 2007), representing a significant resource for particularly harsh areas.

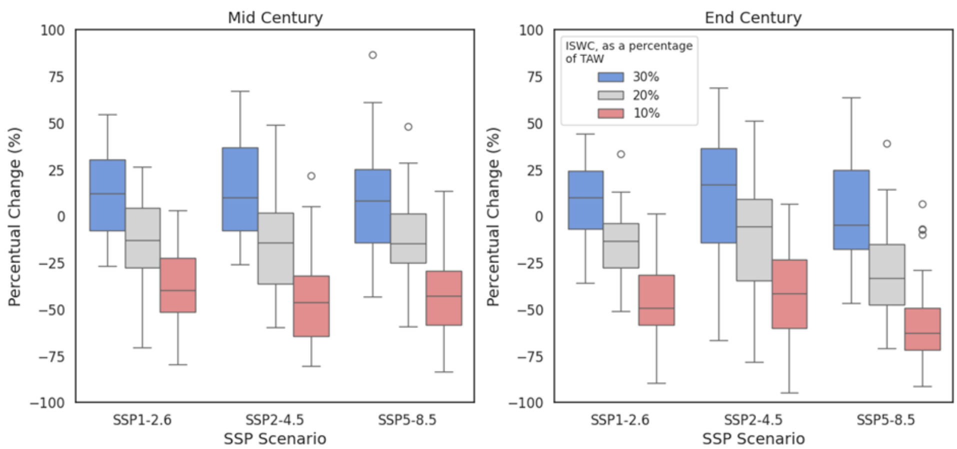

Figure 22: Percentual change in productivity under the different analysed scenarios (Saretto et. al, 2024)

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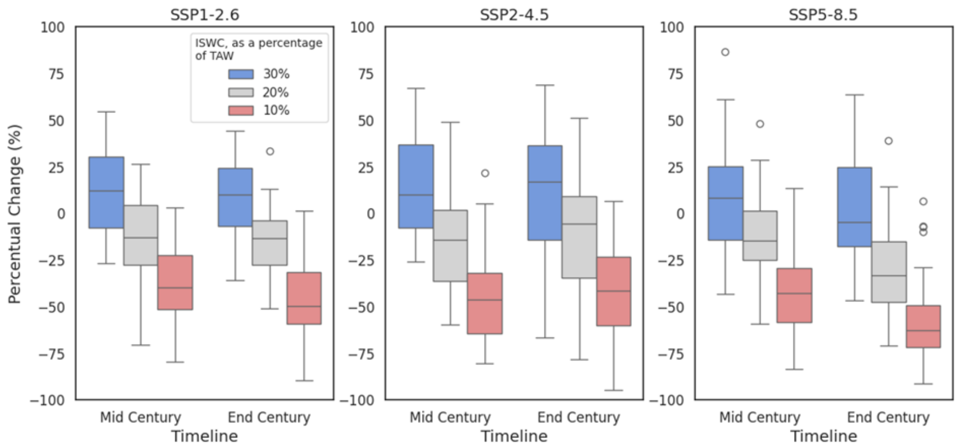

Figure 23: Percentual change in Rainfed Barley Productivity under the different analysed Scenarios, clustered by SSP Scenarios (Saretto, 2024)

The table and graphs reported above summarize the projected impacts of Climate Change on Rainfed Barely production in the Almeria Province, expressed as percentual change from the modelled mean of the baseline period.

From the graphs, it is possible to see how the SSP Scenario that yields the causes the worst losses is SSP5-8.5, thus the one linked to more extreme changes in climate. Concerning the Initial Soil Water Content Scenarios, lower water content leads to lower productivity, with a 10% TAW of Initial Soil Water Content that can cause a loss in average productivity up to -55% (Figure 22). On the other hand, however, an Initial Soil Water content of 30% TAW appears to always lead to increased productivity, reaching values of +14%. This parameter appears to be more important than the SSP scenario or the Timeline in impacting Barley production leading to a variability in results up to almost 65% if only considering the averages, and only the End Century Timeline. With regards to this latter parameter, from Figure 23, it is possible to see how at the End of the Century, all of the productivities are projected to decrease except for SSP2-4.5, where instead a slight increase is projected by the Model. This SSP Scenario is moreover the one that leads to the largest changes in variabilities in results between Mid Century and End Century, while the others lead to stable or decreased variability in Scenarios further away in time.

The results obtained seem to indicate that a decrease in rainfed barley productivity in the future could be linked more strongly to decreased water availability in the soil at sowing, rather than changes in temperature or precipitations during the growing season (Saretto et al., 2024). These latter changes, seem to have a larger impact under SSP5-8.5, particularly at the End of the Century, while in other cases the impact seems to be minimal. Regarding the SSP Scenarios, an interesting behaviour is shown by

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SSP2-4.5, in which an increase in productivity happens at the End of the Century. This might be linked to a trade-off between Climate Change and CO_2 concentration that is optimal for the plants' growth.

3.4.6 CS6 – Azores (Portugal)

The current and the future yields of the agriculture crop (maize) had been simulated for the mid (2040 –2070) and end (2070 – 2100) century taking three different Shared Socio-economic Pathway (SSP) scenarios. This simulation has been carried out for three different islands of Azores archipelago namely Sao Miguel, Pico and Terceira considering different initial soil water content (ISWC) and soils representative to each of the islands. Details of the adopted methodology for the simulation and outputs are available in the annex of this report. A summary of the results is represented below:

São Miguel

The considered parameters for running the simulation were ISWC at 50%, and maize planted on 15th of April in loamy soil under rainfed irrigation conditions. Simulation results show that the mean yield of maize remains always higher in the baseline than in the mid and the end centuries. However, the yield goes down during the mid-century and increases again at the end of the century for SSP1-2.6 and SSP2-4.5. But under SSP5-8.5, the yield is the lowest at the end of the century than the baseline and mid-century (Figure 24).

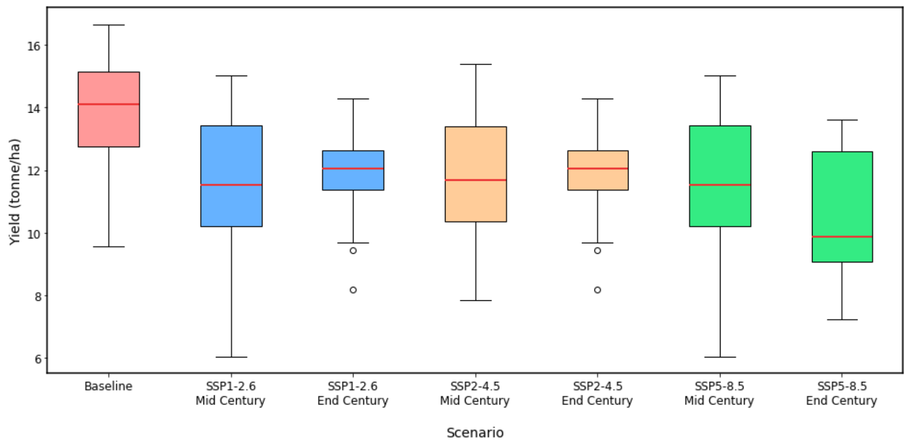

Figure 24: Mean yield of maize, (IWC 50%, PD 04/15) in different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) at three temporal scales (baseline, Mid Century and End Century) for Sao Miguel, Azores.

Pico

The dominant soil on Pico Island is loam (100%). Simulation was carried out for Maize, usually planted in the middle of April under rainfed irrigation conditions with ISWC at 20%. As like as Sao Miguel, the simulated yield of maize in Pico Island during the baseline period reached its maximum for all the SSPs.

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However, the yield fluctuates between the mid-century and the end of the century for both SSP1-2.6 and SSP2-4.5 including the failure of the crops in some years in the mid-century under the SSP1-2.6 scenario. Like Sao Miguel, in SSP5-8.5, the yield is the lowest at the end of the century than the baseline and mid-century including crop failures in some years, which was not evident in Sao Miguel (Figure 25).

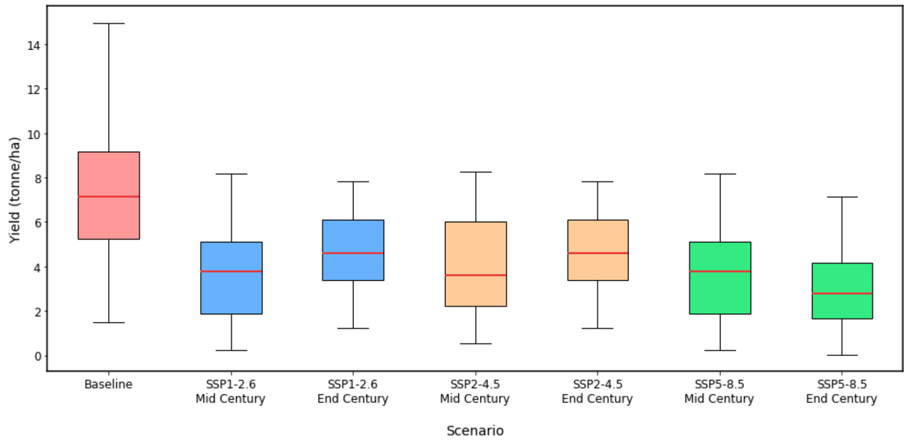

Figure 25: Mean yield of maize, (IWC 20%, PD 04/15) in different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) at three temporal scales (baseline, Mid Century and End Century) for Pico, Azores.

Terceira

The dominant soils of the Terceira Island are loam (68%) and clay loam (16%). The simulation was carried out for loamy soil as it represents the higher occupation of soil texture among the four different USDA soil categories identified on the island. Other parameters are ISWC at 20% and seeds are sown in mid-April. The results show the yield variability between mid and the end century under the SSP1-2.6 scenario. However, the yield continues to drop from the mid to the end century including the failure of crops in some years for both temporal scales under SSP5-8.5 scenario (Figure 26).

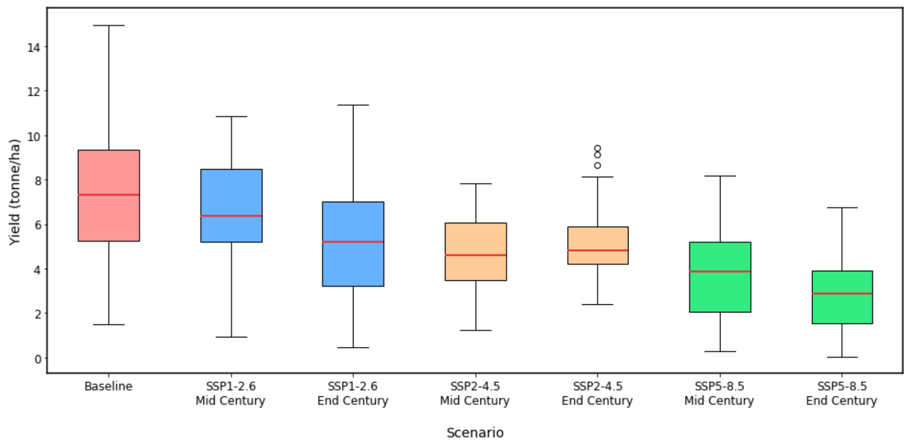

Figure 26: Mean yield of maize, (IWC 20%, PD 04/15) in different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) at three temporal scales (baseline, Mid Century and End Century) for Terceira, Azores.

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Based on the above narratives, it can be concluded that the variability in crop yield could be significantly associated with future climate conditions. As the temperature rises and the precipitation decreases, the crop yield will substantially fluctuate including the crop failures in some years.

3.4.7 Limitations and future work

AquaCrop-OSPy has some known limitations. The most important for this work is the absence of the possibility to implement a continuous soil–water balance, both in version 2.2.3, used in the beginning of the project, and the most recent version 3.0.1. This option would allow for modelling fluctuations in water availability in the soil and providing a realistic estimation of the soil water content at sowing, which is a critical parameter in AquaCrop. A further important limitation includes the lack of crop calibration, specific for each region (Saretto et al., 2024).

Future work should take into account these limitations, together with a higher number of crops and data studied; model with other soil types; make an improved calibration, with more intensive literature review; test LAMS as, for example, mulching and irrigation; and try to include the salt balance. Finally, the water balance problem can be solved using the AquaCrop stand-alone version, which allows to implement the soil-water balance continuously.

3.5 Most vulnerable sectors and problem statement

All six case studies highlight a common thread of water scarcity affecting specific sectors both within and across, mostly agriculture, tourism and to some extent energy and society (migrants). Water is most critical for regions facing aridity (Almeria, Spain), highly dependent on irrigation (Tarn-et-Garonne, France) and increased competition and interdependence for water resources (Gotland (Sweden), Southern Great Plain (Hungary), Almeria and Azores (Portugal). Albeit water resources not being a most vulnerable sector in Valle d'Aosta (Italy) and Azores the water scarcity issues, namely due to precipitation variability, are a concern. The groundwater resource management is a relevant issue in Sweden, Hungary, Spain, and Portugal. With the exception of Italy, the high temperature hazard is not a major reason for concern, except when this links to water scarcity or in the case of Azores where it's also relevant for other reasons. Flood related impacts are also a reason of concern in France, Italy, and Azores. Table 9 summarizes the different most vulnerable sectors associated with each case study.

Table 9: Most vulnerable sectors (marked with an X) across the six case studies

Sectors /CS	Agriculture	Tourism	Energy	Water resources	Forestry	Society
CS1	x	x		x	x	
CS2	x			x		
CS3	x			x		

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Sectors /CS	Agriculture	Tourism	Energy	Water resources	Forestry	Society
CS4		x	x			
CS5	x			x		x
CS6	x	x	x			

3.5.1 CS1 – Gotland (Sweden)

Most vulnerable sectors

The two largest economic sectors and employment sectors in Gotland are agriculture and tourism, when we remove the public employed, that work at the military, hospital, schools and similar. The third largest areal industry is forestry. Many people on Gotland are active and have their income from more than one of these sectors. 24 % of the employment places at Gotland are in areal industries (Agriculture/forestry) and approx. 13 % in sectors connected to tourism. The island's main land uses are arable land (31%), mainly growing crops for cattle and pastureland, and forest (40%), mainly smaller independent patches.

Table 2: Employment by industry sector, 2023, Source: Statistiska centralbyrån, Företagsregistret (SNI 2007).

Sectors	Amount		Proportion, %	
	Gotland	Sweden	Gotland	Sweden
Areal (eg. forestry, agriculture)	2 557	240 758	24	17,1
Production, energy, mines	644	64 011	6	4,5
Construction	1 072	125 978	10,1	8,9
Trade	798	148 219	7,5	10,5
Hospitality (hotel, restaurant)	502	38 519	4,7	2,7
Transport and communication	199	36 714	1,9	2,6
Property and insurance	2 585	418 123	24,3	29,7
Authorities, education, healthcare, and hospital	664	108 295	6,2	7,7
Other	1 628	228 807	15,3	16,2

Problem Statement

The island is originally a coral reef, based on limestone and large parts of the island has thin soil layers which limits the volumes of groundwater and the possibility to store water for long periods of dry weather (summer season).

Gotland has on several occasions suffered from severe water shortages; in the southern part the situation has been particularly hard. The south part of the island has very thin soil layers that have

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difficulty retaining the groundwater and is therefore dependent on "imported water" from a new desalination plant, which was inaugurated in 2019.

The problem is that most of the precipitation comes during the winter months, while the biggest outtake of water is during the summer. With the thin soil layers there is nowhere for the ground to retain the water in natural aquifers, the water must therefore be collected, stored, and reused. Due to past years long periods of drought, there is a rapidly increasing need for irrigation of crops and pasture for the cattle. The current shortage of water for irrigation, which is predicted to become somewhat permanent, calls for reformation of the land use and efforts from several different bodies.

3.5.2 CS2 – Tarn-et-Garonne (France)

Most vulnerable sector

The most vulnerable sector is agriculture in the case study 2, given its dependence on climate and natural resources, but also its weight in the department in terms of land use (62%), employment (5%) and economic impact (585M€ of gross value added). Cereals, oil seeds and fruit crops (apples, plums, kiwi fruit) are mainly grown in the region. Agriculture is highly dependent on irrigation, especially for tree crops (apple kiwis, plums, etc.), which concerns more than a quarter of the utilized agricultural area (UAA) and 50% of the farms (Chambre d'Agriculture Occitanie, 2022). At the same time the case study is facing a reduction in water resources and a deterioration in water quality due to climate change (Comité de bassin Adour-Garonne, 2018). The main climate risks are an increase in the average annual air temperature of at least 2°C, an increase in extreme events such as droughts and floods, and a downward trend in rainfall (Chambre d'Agriculture Occitanie, 2021).

Problem statement

Therefore, under climate change, the Department of Tarn-et-Garonne might face challenges in balancing economic activities in the agricultural sector and the preservation of natural resources, especially water. One of the risks identified for the case study is the water scarcity affecting the agricultural yields especially for the tree crops yield which are economically important for the region and highly dependent on irrigation.

3.5.3 CS3 – Southern Great Plain (Hungary)

Most vulnerable sectors

Most vulnerable sectors include agriculture and the water sector at first place, and manufacturing industry can be mentioned as well. The effects of drought are already significant and most visible in the water and the agricultural sectors, which are inherently connected. Within agriculture, the different

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kinds of farming producers (intensive, smaller scale, cereals, gardening, etc.) experience these effects slightly differently, but the risk is similarly high. The main grains on intensive lands experience increasing water stress due to the drought effects in the spring-summer terms, while irrigation is poorly developed. On smaller scale production farmers try to mitigate with irrigation but the water stocks, both groundwater and surface water, are decreasing severely in the spring-summer terms, and projected to decrease by 30-50% in general in the second half of the century. This affects the whole supply chain of the products.

While considered as a major water resource, groundwater is highly exposed to climate effects like precipitation, evapotranspiration, and other ones related to management like outtake or contaminations. Groundwater stocks show a decreasing trend in quantity particularly in the summer months. The illegal outtake can only be assumed but considered significant and highly increasing uncertainty in the system. Water saving measures and approaches could not yet gain real traction due to institutional and socio-economic reasons.

The water sector is still managed according to an optimistic approach, in a loosely connected manner towards agriculture (and forestry, industry). The risk affects all forms of needs and utilization, let it be irrigation, drinking water, recreational activities, fisheries, or ecosystems. Nevertheless, the valuation of risk among these fields shows large discrepancies depending on the lens through which we investigate the issues, and based on the level the valuation is conducted on (user or policy). On policy level, irrigation and drinking water supply are considered to have the highest risk among the fields of utilization. Consequently, the conflicts between these utilization forms and their users/actor groups are expected to increase. Similarly, it can continue or increase the trend of illegal/non-registered use of the water resources, in case of the lack of essential changes on institutional level and in the controlling mechanisms.

Problem statement

Effects of climate change intensify the effects of drought in the CS3 region particularly in the summer periods, having significant impacts on the local ecosystem services. It increases climate vulnerability of every element of the water resource system, which increases it further of the soils. These result in negative effects on the local ecosystems, decreasing its services. This leads to direct and indirect effects in multiple sectors, of which agriculture and the water sector are the most relevant and exposed ones. At the ecosystem level, the climate zone-related forests and the water-related ecosystems are considered the most affected. Adaptation strategies and mitigation plans are realized on a low and ineffective level because of institutional misfunctions, and the stalled management regimes related specifically to water resource and land management, which have inherently low adaptation potentials.

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Adaptation strategies, though rational, appear to stay on the level of mitigation in most cases and do not necessarily address fundamental causes, routed in systemic management, cooperation issues and finance. These affect further (and affected by) the social norms and strategies of the locals regarding resource allocation and lifestyle, increasing financial insecurity, distrust, and lowering social capacity.

3.5.4 CS4 – Valle d'Aosta (Italy)

According to the Climate Change Adaptation Strategy of the Autonomous Region of Valle d'Aosta 2021-2030, climate change will significantly affect the region's natural environments and socio-economic sectors. These changes will present both opportunities and challenges, necessitating adaptation actions to mitigate negative impacts and capitalize on potential benefits. Adaptation will require not only infrastructural changes but also cultural shifts, encouraging new habits and lifestyles grounded in greater awareness of climate change.

Most vulnerable sectors

Despite being particularly exposed to climate change, Valle d'Aosta remains attractive due to its acceptable temperature range and excellent environmental and landscape conditions. The "Interreg ALCOTRA AdaPT Mont-Blanc" project, coordinated by the Environment Department with contributions from ARPA Valle d'Aosta and Fondazione Montagna Sicura, analyzed the impacts of climate change on the region's socio-economic sectors. Rising temperatures could benefit agriculture by increasing productivity, extending the growing season, and enhancing the suitability of the land for viticulture and fruit growing. However, these benefits are countered by reduced summer water availability, the risk of late frosts, and the spread of pathogens. Livestock may also suffer from heat stress and new disease vectors.

Forestry will see increased woody biomass production, but reduced summer water availability might weaken some tree populations, making them more vulnerable to stress from parasites, diseases, and fires. Species will migrate to higher altitudes, potentially displacing specialist alpine flora and fauna with more generalist species, threatening biodiversity.

Precipitation patterns will see little change in volume but will decrease in frequency and increase in intensity, leading to more extreme weather events. This will affect hydroelectric production differently based on plant types. Plants with seasonal storage basins may maintain production levels, provided they are revamped for increased output. In contrast, plants with small or no reservoirs will see variable impacts, with potential increases in winter and decreases in summer flow. To ensure water availability, the construction and enhancement of reservoirs for drinking and agricultural use will be necessary.

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Energy consumption patterns will shift, with reduced heating needs due to higher average temperatures aiding decarbonization efforts, while increased cooling demands in summer will boost electricity consumption. The region's vulnerability to natural hazards, such as intensified water cycles and cryosphere changes, will increase. Permafrost degradation will compromise slope stability and high-altitude infrastructure, while glacier retreat will destabilize slopes, raising avalanche and flood risks.

Tourism, particularly winter tourism, will face challenges as ski resorts below 2000 meters become increasingly vulnerable. However, ski areas above 2000 meters, with effective snow management, will remain competitive. Higher temperatures might boost year-round tourism, extending favorable conditions into the spring and autumn. Summer tourism will likely attract those seeking refuge from heat, provided the necessary services are available. However, trekking and mountaineering will be impacted by changing conditions and increased risks, necessitating adaptations in trail and facility maintenance.

Healthcare will need to address the effects of heat on vulnerable populations and manage the spread of diseases by insects and rodents. The influx of elderly tourists seeking cooler climates may increase emergency healthcare demands. Overall, the strategy underscores the need for comprehensive, multi-faceted adaptation measures to safeguard Valle d'Aosta's natural environments and socio-economic sectors against the impacts of climate change.

Problem statement

The regional territory is particularly vulnerable to the natural hazards associated with the intensification of water cycle, the increase in the frequency of extreme events and the effects of the temperature increase on the cryosphere. The natural hazards triggered by these processes affect vast portions of the territory regional, from the valley and urbanised areas up to high altitudes, affecting directly and indirectly all the main socio-economic sectors. In this context of emerging risks, it is important to consider the criticality represented by the temporal variation of the population density, and therefore of exposure to hazards, due to the seasonality of tourist flows and the migratory flows from other geographical areas more exposed to the effects of climate change. To make the regional community less vulnerable and more resilient to these emerging risks, adaptation strategies and actions will have to consider the possible interactions between different sectors.

In the D6.1-CS4 Annex Report, the analysis focuses on the following risks in the following sectors:

- Energy – Risk of water scarcity due to higher temperatures affecting hydropower generation
- Winter Tourism - Risk of loss of attractiveness due to snow variation as consequence of climate change.

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3.5.5 CS5 – Almería (Spain)

Most Vulnerable Sectors

The most vulnerable sectors in this CS are Agriculture, Tourism and Migrant laborers. It is important to note that all three sectors intersect with water management. For example, the tourism sector exhibits a high demand for water resources, as it must cater to the daily water consumption needs of tourists as well as keep touristic amenities (such as swimming pools or golf courses) ready for use and in good shape. To do this, the sector demands a significant amount of water resources, especially given the aridity of the land in the province. Migrant laborers are also indirectly affected by water security in the province, as their livelihoods directly depend on the work they receive as part of the Agricultural sector. Furthermore, water scarcity also impacts the working and living standards that the migrant laborers are subjected to, as the social systems in place do not ensure that the conditions such people face coheres to national or international standards. This is all to say that all three vulnerable sectors mentioned above are very strongly conditioned by the availability of freshwater.

Problem Statement

In the context of the above, Almería's development model that has been heavily based on Agricultural produce may have to change significantly, to mitigate the impacts of the primary risk of this CS, Freshwater Scarcity. The continued over-reliance on aquifers, especially in the Agricultural sector, leaves the province at risk of future social and economic instability. It is imperative that farmers, industries (e.g. extractive, tourism, etc.) and local governance mechanisms collaborate on minimizing the water demand within each sector, while also finding new sources of water such as through desalination plants. This challenge should also be considered on a continental level, as the province of Almería does indeed provide a significant amount of food security to the European continent.

3.5.6 CS6 – Azores (Portugal)

Most vulnerable sectors

The selected most vulnerable sectors for Azores are Agriculture, Tourism and Energy. Stakeholders consider that agricultural crops have predominantly been rainfed, but changes in precipitation patterns have created a need for increased use of irrigation in the future. Specific localized areas have felt water scarcity issues due to saline intrusion issues along the coastline. The most relevant agricultural activity is related to bovine cattle (for meat and milk) and the associated fodder production. Localised effects of water scarcity combined with water use in agriculture and tourism were also felt by stakeholders. Precipitation patterns can also fluctuate in the opposite direction, leading to excessive precipitation

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events especially when combined with storms. Combined with changes in land use this can induce more frequent and harmful floods than nowadays. Tourism is dependent on ecosystem services namely Cultural. Stakeholders consider Azores is to be nature-based tourism destination. In fact, the region aims to continue being a sustainable tourism destination. As such, land use can undermine or strengthen this ambition depending on the solutions which are selected for implementation. The Energy sector albeit being resilient and autonomous is under constant pressures from the climate in all of the nine isolated electrical systems. Renewable Energy resources may become scarcer or become more variable and difficult to integrate in the energy matrix. The region has strong commitments and goals towards decarbonization, but these can further exacerbate the difficulties posed to the electrical system that currently depends on fossil fuel for backup power and quality. Land use for the energy sector has not been a major issue in the past, being reversed hydro power a possible exception. However, if more RES are put in service, then this has the potential to become an issue.

Problem statement

Ensuring a balanced development between the economy and ecosystems for future generations. Dependent on agriculture and on tourism, the Azores may face, under climate change, significant challenges to balance the economic activities with the preservation of ecosystem services, namely water resource provisioning and the natural landscape, while ensuring the continuation of its energy transition.

Solutions for land use need to be put in place as to help assure this balance. Small farmers and local authorities need to act together as to face challenges and guarantee some level of local food production and consumption. Farmers and tourism operators want to be able to cope with their energy needs.

3.6 Identification and development of Impact chains

The Impact Chains reflect the views of the stakeholders shared during the EUC Workshop III and following adequate methods and materials (Annex I of D6.2). Case study leaders performed the co-development of impact chains closely as possible to the defined methods. The Impact Chains development and the result of each Case Study is detailed in the corresponding D6.1-CSX annex reports (from Annex I thought VI).

3.6.1 CS1 – Gotland (Sweden)

The stakeholder community has mentioned water scarcity as a major challenge on Gotland. One respondent also shares that more people want to build houses on Gotland, but they believe that the water and sewage system cannot currently handle this. Water scarcity on Gotland is a significant

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challenge, especially during the summer months when the temporary increase in population leads to higher water consumption. The groundwater reservoirs in the soil layers and bedrock on Gotland are small or poorly known, contributing to the problem. While there is generally good water availability in Sweden, both supply and demand vary across the country. Water scarcity occurs periodically, especially in southern and central Sweden, as well as in coastal areas. In recent years, droughts and water scarcity have been discussed more seriously in Sweden.

During December 2023 a workshop on the theme of water scarcity was carried out in accordance with the methods described in D5.2. 17 stakeholders participated from different sectors. The stakeholders were divided into four different groups that created four impact chains. These impact chains have then been merged with literature review to create four different climate risk impact chains (Annex I - D6.1-CS1 Gotland (Sweden): Northern case study).

3.6.2 CS2 – Tarn-et-Garonne (France)

This impact chain below (Figure 27) is the result of merging the impact chains developed by 3 groups during the workshop held in Montauban on 23 January 2023, which brought together around ten stakeholders from the agriculture and water sectors of the case study.

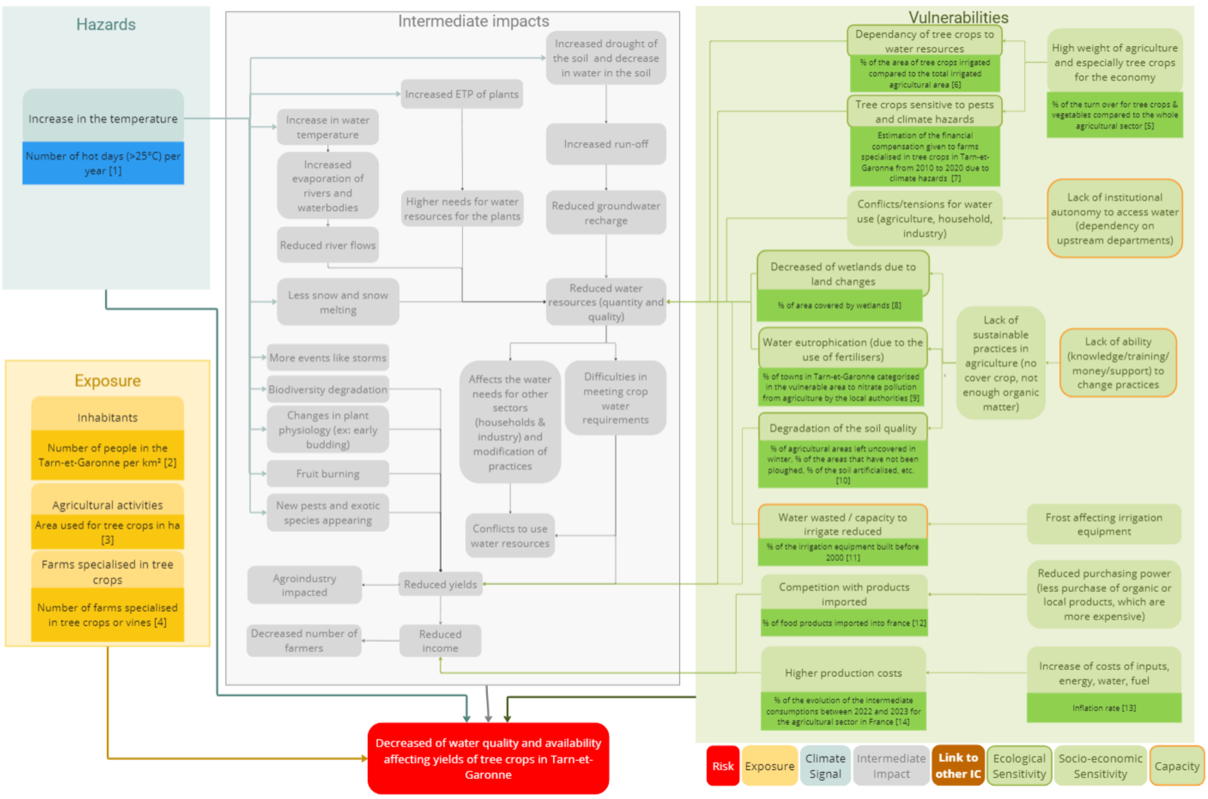

Figure 27: Impact chain developed for the case study number 2, the Tarn-et-Garonne, in collaboration with the local stakeholders.

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The effects of rising temperatures are an increase in plant and soil evapotranspiration and a reduction in river flows. These factors affect water resources and lead to reduced yields and incomes for farmers and other actors in the sector. The high dependence of agriculture on water resources, the lack of support for farmers to adopt environmentally friendly farming practices, and the lack of autonomy in accessing water in the case study have been identified as vulnerability factors. Rising costs and reduced purchasing power are also factors in vulnerability to climate change.

3.6.3 CS3 – Southern Great Plain (Hungary)

Local research, scientific reports and experiences of local stakeholders pointed all in the direction that the "most serious" realization of climate change effects is the decrease of crop yields within the agricultural sector, considered as one of the most important climate risks (Figure 28). Effects of drought are gaining increasing momentum in the region, experienced by all sectors, but agriculture, considering its local and national weight, is expecting, and already experiencing great damage. It means that local actors depending on this sector see their future livelihoods rather uncertain and at high risk.

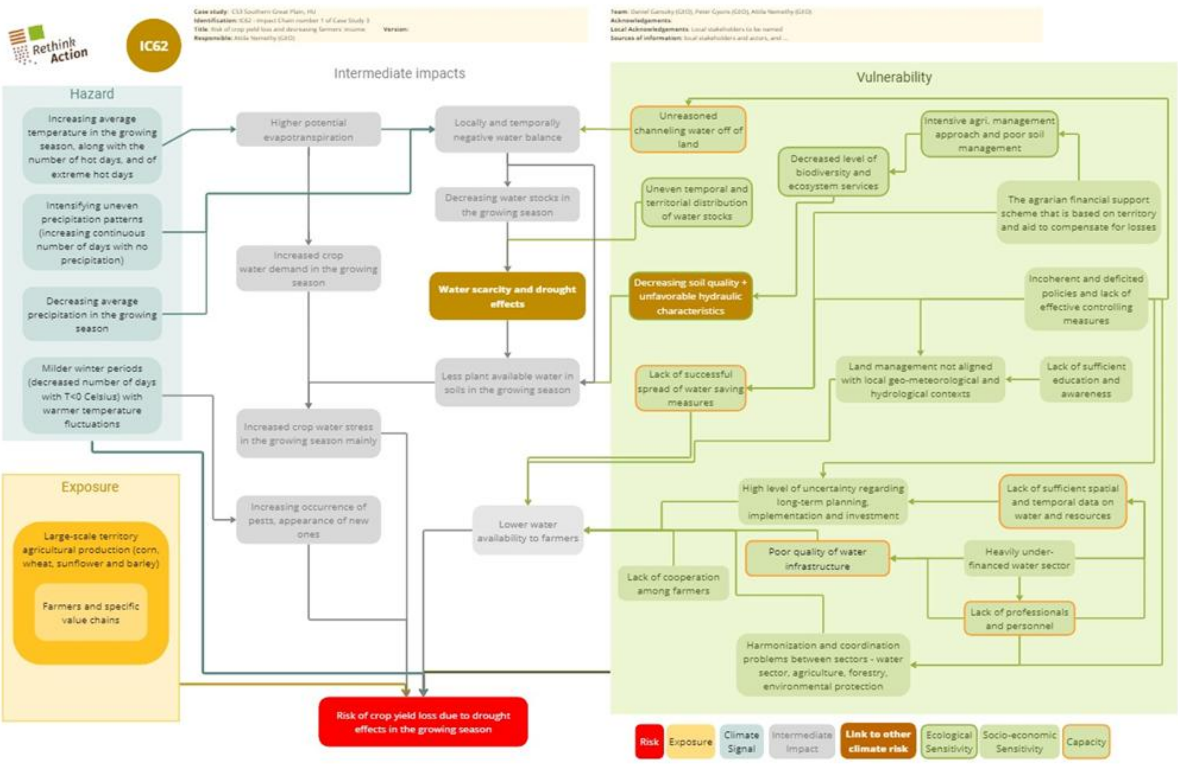

Figure 28 - Impact chain model developed for the risk of crop yield loss due to drought effects in the growing season in CS3.

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3.6.4 CS4 – Valle d'Aosta (Italy)

The main impact chain developed for Valle D'Aosta (Figure 29) addressed the risk of rising temperatures expected to reduce the availability of water for hydropower plants, significantly impacting their efficiency. This diminished water supply will force hydropower plants to operate less frequently and at lower capacities. Additionally, the higher temperatures will increase the frequency of maintenance required due to the strain on infrastructure.

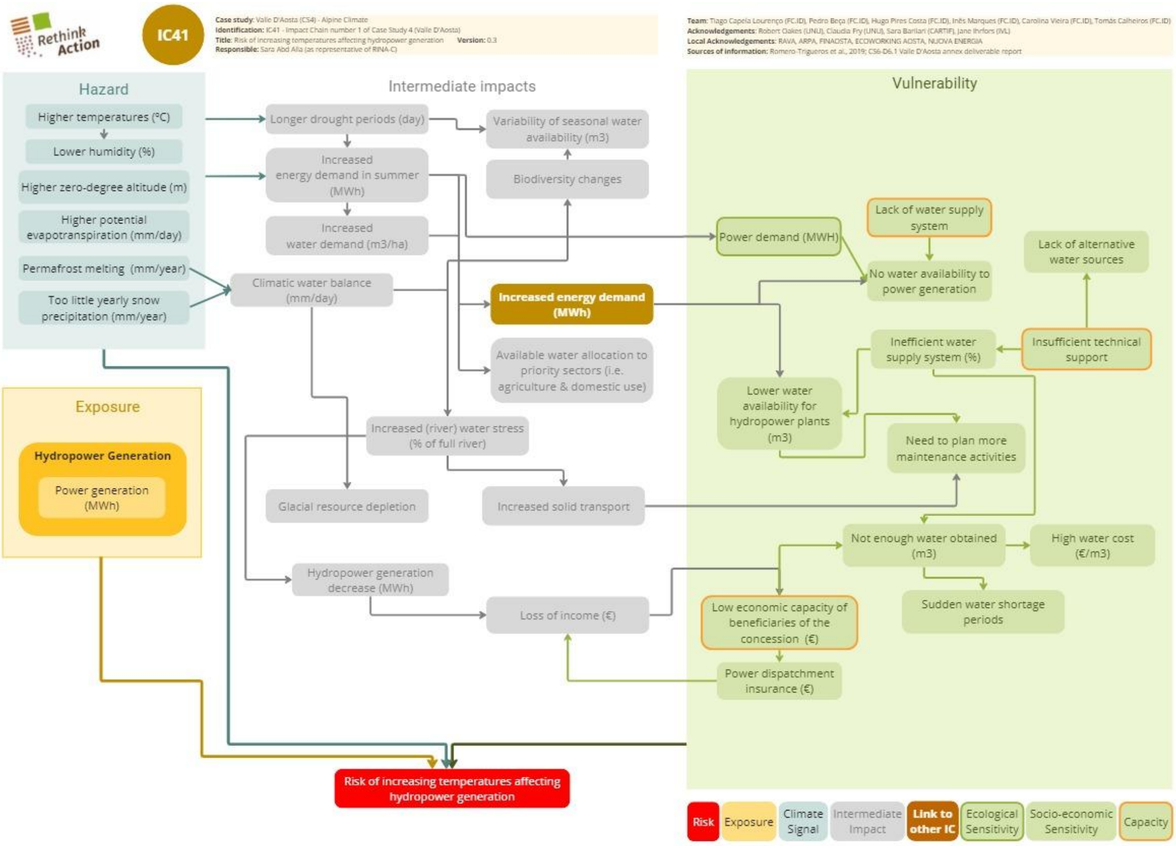

Figure 29: Impact chain model developed with stakeholders on Energy - Risk of increasing temperatures affecting hydropower generation.

3.6.5 CS5 – Almería (Spain)

The primary risk in focus of CS5's ICs was related to water scarcity. This was informed by the literature review completed as part of the work on this CS and interaction with the local stakeholders, with whom we engaged in previously held stakeholder consultations. This resulted in the development of three ICs in total. Even though the other two ICs deal with substantial risks (namely risk to farmers' livelihoods and reduced health outcomes for labour migrants), we found the risk surrounding water scarcity to be more central, as it exhibits causal impacts that feed into the other two risks.

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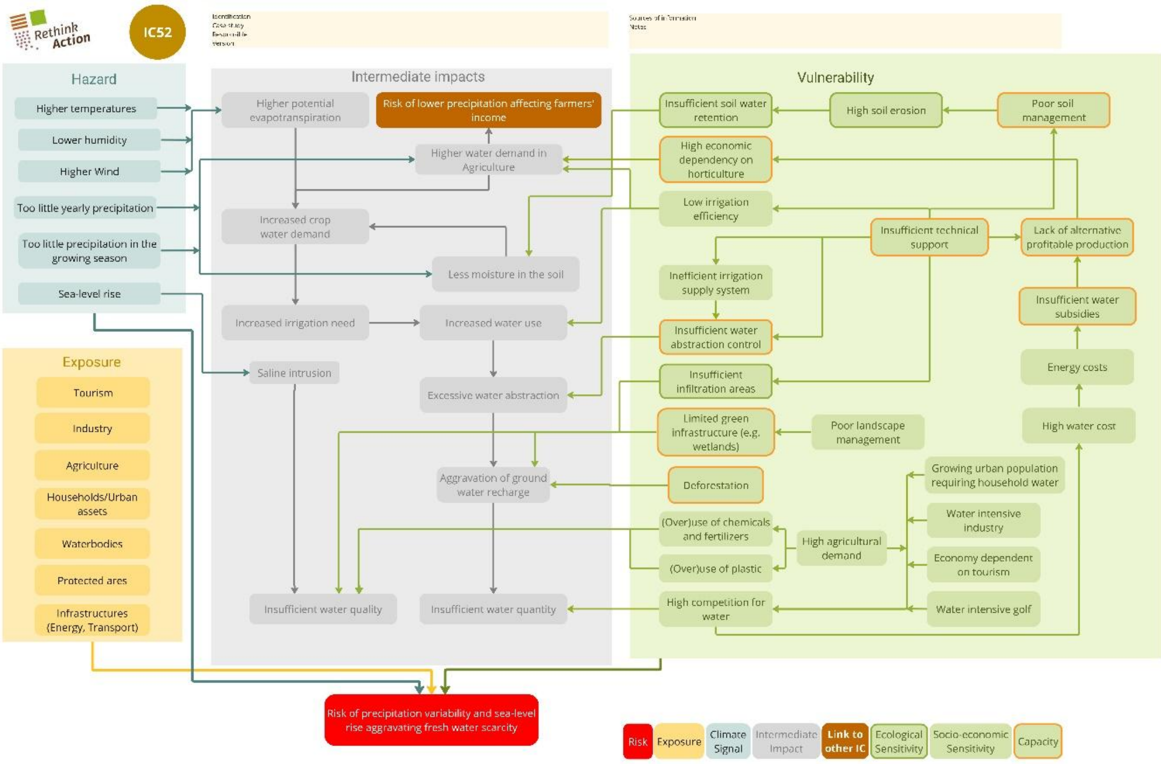

Figure 30: Impact Chain on the Risk of aggravation of water scarcity in Almería.

A sketch of the aforementioned IC produced for CS5 can be found above in Figure 30. The two complementary ICs can also be found within the Annex Report for CS5. Also, one can find the ICs the stakeholders created during the previous stakeholder engagement in January 2024 in the CS5 Annex report. The ICs from the stakeholders provides CS5 with new angles of investigation that we would have been unaware of without the contextual experience within Almería, such as the importance of the Almerían family model and values. In subsequent stakeholder engagements, we endeavor to better understand exactly how this plays a role within the wider context of water management and sustainable land use, as this may shape some of the findings and ultimate recommendations given for this CS.

3.6.6 CS6 – Azores (Portugal)

Three impact chains for CS6 were co-developed with the involvement of the local stakeholders in the January 2024 workshop:

- Agriculture - Risk of precipitation variability affecting crop yield stability
- Tourism - Risk of loss of attractiveness due to climate change
- Energy - Risk of energy production and demand affected by climate change

Stakeholders identified the risk components in the Impact Chains template, but they partially completed the links between the different elements. The established links were later completed by resorting to the

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workshop notes and literature sources. The developed impact chains and the selected quantification variables are explained in Annex VI.

In Figure 31 we can observe an Impact Chain example for the energy sector: IC63 - Risk of climate change affecting energy production and demand

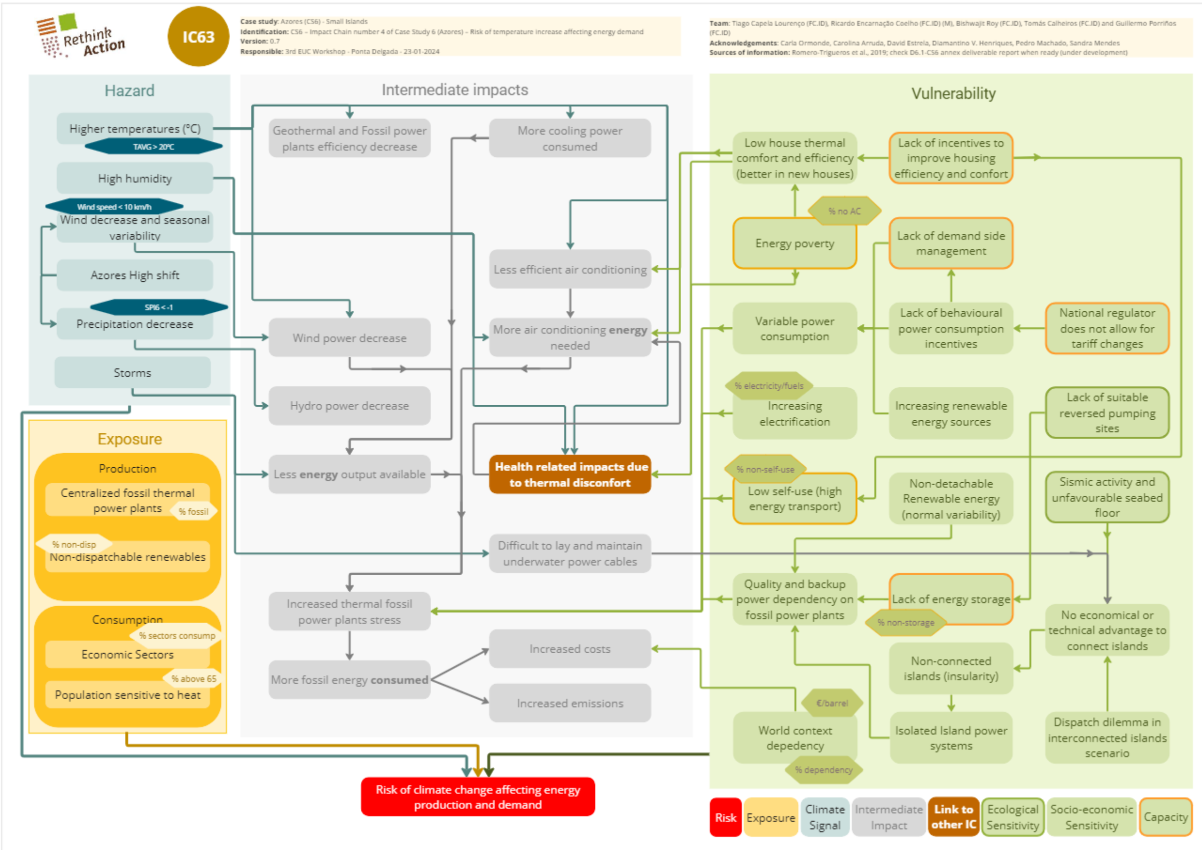

Figure 31: IC63 - Risk of climate change affecting energy production and demand

Following a desk-based risk analysis stakeholders were proposed to analyse the risk of climate change affecting energy demand. The co-development process led to include the production side and aspects related to energy poverty. Some of the links between the different the hazards and the intermediate impacts were made by the stakeholders. The links involving exposure and vulnerability were developed after the workshop and resorting to session notes and literature review.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037104.

4 Vulnerability and risk assessment

In this section an analysis of the vulnerability and risk is presented. As it was explained in the methodology section, the vulnerability and risk quantification are based on a semi-quantitative procedure with relevant indicators for each sector involving the main drivers of the impact chains (exposure, sensitivity and adaptive capacity) and the pre-selected indicators listed during the impact chain development. It is necessary to highlight that the vulnerability calculation was developed considering the sensitivity and adaptive capacity of each sector while the risk is quantified using the hazards, the sectoral exposure and the vulnerability per sector.

The main results obtained per case study are described along the following subsections covering the hazards, vulnerability and risk. As the calculation is based on geolocated data for each municipality according to the Local Administrative Units (LAU) subdivision, the number of maps comparing the results per case study is large to be included in this deliverable. For this reason, only the main results are included as part of this deliverable. All the maps covering the results of vulnerability and risk assessment will be available in the RethinkAction Platform.

For Gotland, considering that is only one municipality, the case study was divided into 15 functional subdivisions for the hazard, vulnerability and risk calculation. For each subdivision, geolocated indicators were used in order to cover the quantification process in a similar way as for the municipalities in the other case studies. The subdivisions used in the Gotland case study are included in Figure 32.

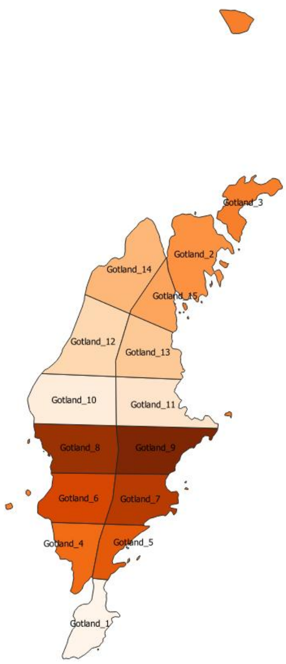

Figure 32: Subdivisions used for the hazard, vulnerability and risk quantification in Gotland.

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4.1 Hazard results

The selected hazards per case study join a description of the variables used for their quantification are presented in Table 10. Hazards are quantified per each selected climate scenario (SSP1-2.6, SSP2-4.5 and SSP5-8.5) and covering three different periods (2015-2040, 2041-2070 and 2071-2100). Considering that adaptation need to be calculated based on the most pessimistic scenarios that are those have the most critical impacts, we need to highlight the results obtained for the SSP2-4.5 and SSP5-8.5 scenarios where the changes in the climate variables are more obvious.

Table 10: List of selected hazards per case study and the description considering the threshold for calculation.

Hazard		CS1	CS2	CS3	CS4	CS5	CS6
Hazard 1	Id	Hot days	Hot days	Warm days	Hot days	Heatwave	Warm days
	Description	Number of hot days (Tmax>25) per year	Number of hot days (Tmax>25) per year	Number of days of Tmed>P90 of a reference period	Number of hot days (Tmax>25) per year	5 consecutive days with Tmax>P90 of a reference period	Number of days of Tmed>P90 of a reference period
Hazard 2	Id	Drought	Warm days	Hot days	Dry days	Drought	Drought
	Description	At least 2 consecutive months without precipitation	Number of days of Tmed>P90 of a reference period	Number of hot days (Tmax>25) above threshold per year	Number of days with precipitation in the growing season <1mm	At least 3* consecutive months without precipitation	At least 3 consecutive months without precipitation
Hazard 3	Id	Storm	-	Storm	High Wind	Storm	Dry days
	Description	Number of days with P>50mm	-	Number of days with P>50mm	Number of days of wind speed >21,6 km/h (6 m/s)	Number of days with P>50mm	Number of days with precipitation in the growing season <1mm
Hazard 4	Id	Precipitation changes	-	Dry days			
	Description	Number of days of Pmed>P90 of a reference period	-	Number of days with precipitation in the growing season <1mm			
Hazard 5	Id	-	-	Drought			
	Description			At least 3 consecutive months without precipitation			

* The threshold was defined in 15 days for CS1, CS3 and CS6 and in 30 days for CS5 in order to calculate real probabilities

Hazards are calculated comparing the probability of exceedance/occurrence of an event in the historical period and in the future for each selected period using the downscaled Essential Climate Variables at

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case study level developed in WP3. The hazards quantification was integrated in a processing algorithm running in Python with the results of the set of models used at case study level and a geolocated set of boundaries for hazard quantification. The results of hazard probabilities are presented in Annex IX as well as the coupled probabilities under a multi-hazard approach. The geolocated and normalized hazard results per case study are presented below.

4.1.1 CS1 – Gotland (Sweden)

For the Gotland case study, four hazards were selected, one related to temperature (hot days), two related to precipitation (storm and precipitation change) and another one that merges both (drought). The probability of occurrence is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 33) and aggregated results at case study level. If the aggregated results (Table 11) are analyzed, it is necessary to highlight the increase of hot day at long-term, being more relevant the changes in the SSP585 scenario. Also, the main result is that all the hazards provide medium probability of occurrence.

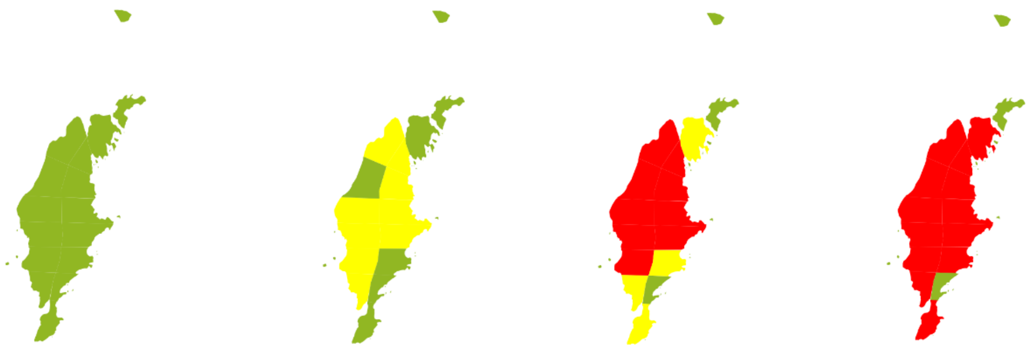

Figure 33: Geolocated dry days hazard for Gotland case study using data from SSP5-8.5.

Table 11: Hazard quantification considering the probability of occurrence of the hazards in the Gotland case study.

Hazard	Historical	SSP1-2.6			SSP2-4.5			SSP5-8.5		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Hot days	Low	Low	Med	Med	Low	Med	Med	Med	Med	High
Drought	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Storm	Low	Med	Low	Med	Low	Med	Med	Med	Med	Med
Precipitation change	Med	Med	Med	Med	Med	Med	Med	Med	Med	Med

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4.1.2 CS2 – Tarn-et-Garonne (France)

For the Tarn-et-Garonne case study, only two hazards related with the number of hot days and the warm days were selected. The probability of occurrence of these temperature change events is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 34) and aggregated results at case study level. If the aggregated results (Table 12) are analysed, it is necessary to highlight the increase of hot day at long-term, being more relevant the changes in the SSP2-4.5 and SSP5-8.5 scenarios.

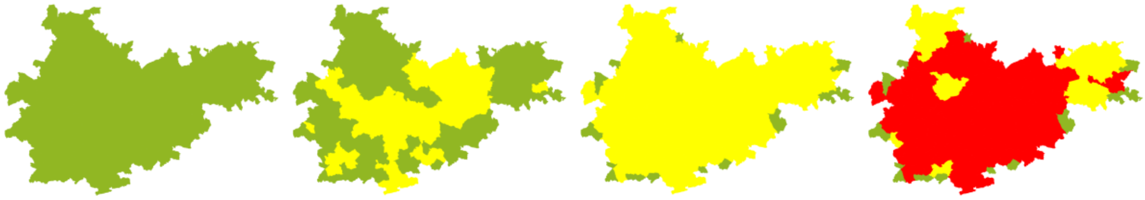

Figure 34: Geolocated hazards for Tarn-et-Garonne case study using data from SSP2-4.5.

Table 12: Hazard quantification considering the probability of occurrence of hot days in the Tarn-et-Garonne case study.

Hazard	Historical	SSP1-2.6			SSP2-4.5			SSP5-8.5		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Hot days	Low	Low	Med	Med	Low	Med	High	Med	High	High
Warm days	Low	Low	Med	Med	Med	Med	High	Med	High	High

4.1.3 CS3 – Southern Great Plain (Hungary)

For the Southern Great Plain case study, five hazards were selected, two related to the temperature (warm days and hot days), two related to the precipitation (storm and dry days) and another one that merges temperature and precipitation (drought). The probability of occurrence is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 35) and aggregated results at case study level. If the aggregated results (Table 13) are analyzed, it is necessary to highlight the increase of warm and hot days in the long-term, being more relevant the changes in the SSP585 scenario. Also, the main result is that all the hazards provide medium probability of occurrence, except for drought problem which has a low probability in this region.

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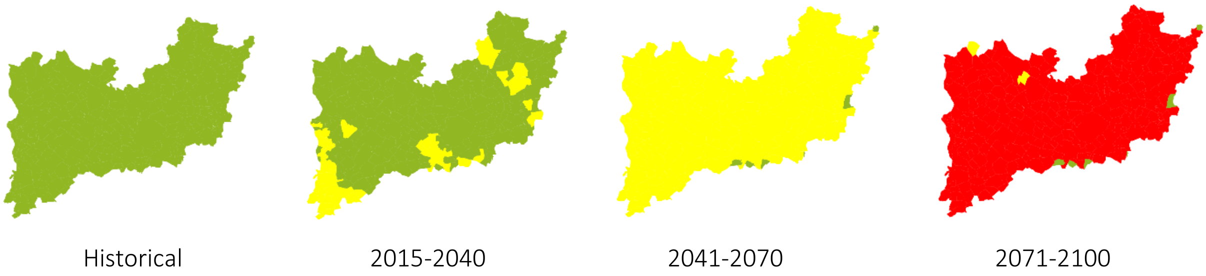

Figure 35: Geolocated warm days hazard for Southern Great Plain case study using data from SSP2-4.5.

Table 13: Hazard quantification considering the probability of occurrence of the hazards in the Southern Great Plain case study.

Hazard	Historical	SSP1-2.6			SSP2-4.5			SSP5-8.5		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Warm days	Low	Low	Med	Med	Low	Med	High	Med	Med	High
Hot days	Low	Low	Med	Med	Low	Med	High	Med	High	High
Storm	Low	Med	Med	Med	Med	Med	Med	Med	Med	Med
Dry days	Med	Med	Med	Med	Med	Low	Med	Med	Med	Med
Drought	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

4.1.4 CS4 – Valle d'Aosta (Italy)

For the Valle d'Aosta case study, three hazards were selected, one related to the temperature (hot days), one related to the precipitation (dry days) and another one related to the speed of the wind (high wind). The probability of occurrence is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 36) and aggregated results at case study level. If the aggregated results (Table 14) are analyzed, it is necessary to highlight the increase of dry days in a medium probability occurrence. Also, the main result is that hot days and high wind speed provide low probability of occurrence in this region.

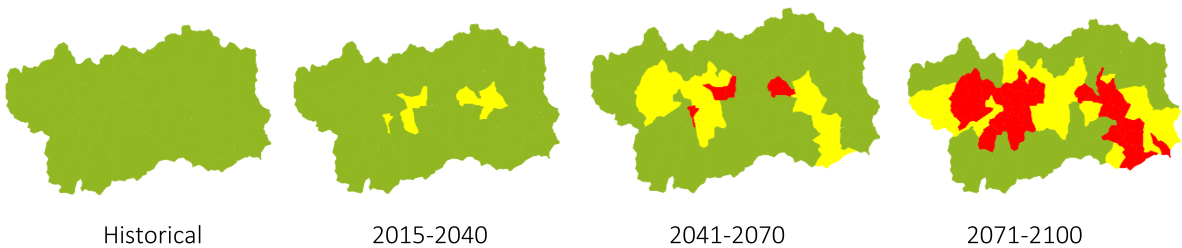

Figure 36: Geolocated hot days hazard for Valle d'Aosta case study using data from SSP5-8.5.

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Table 14: Hazard quantification considering the probability of occurrence of the hazards in the Valle d'Aosta case study.

Hazard	Historical	SSP1-2.6			SSP2-4.5			SSP5-8.5		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Hot days	Low	Low	Low	Low	Low	Low	Low	Low	Low	Med
Dry days	Med	Med	Med	Med	Med	Med	Med	Med	Med	Med
High Wind	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

4.1.5 CS5 – Almería (Spain)

For the Almeria case study, three hazards were selected, one related to the temperature (heatwaves), one related to the precipitation (storm) and another one related to temperature and precipitation (drought). The probability of occurrence is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 37) and aggregated results at case study level. If the aggregated results (Table 15) are analyzed, it is necessary to highlight the increase of the heatwave occurrence from a low probability based on the historical period to high probability at the end of the century. Also, the main result is that drought provides medium probability of occurrence in this region, and storms get medium probability in the worst scenario on a long period.

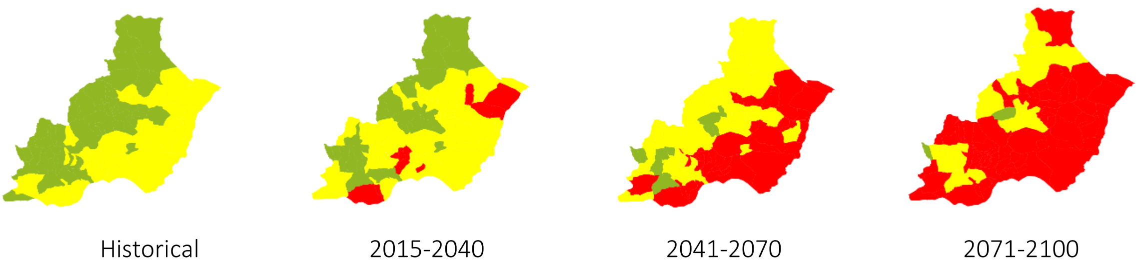

Figure 37: Geolocated heatwave hazard for Almeria case study using data from SSP5-8.5.

Table 15: Hazard quantification considering the probability of occurrence of the hazards in the Almería case study.

Hazard	Historical	SSP126			SSP245			SSP585		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Heatwave	Low	Med	Med	Med	Med	Med	Med	Med	Med	High

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Drought	Med	Med	Med	Med	Med	Low	Med	Med	Med	Med
Storm	Low	Low	Low	Med	Low	Med	Med	Low	Med	Med

4.1.6 CS6 – Azores (Portugal)

For the Azores case study, four hazards were selected, one related to temperature (warm days), one related to precipitation (dry days), one that merges temperature and precipitation (drought) and another one related to the speed of the wind (low wind). The probability of occurrence is translated into qualitative values (low, medium and high) according to the percentile 25 and 75 of the data to have geolocated data per unit of analysis (Figure 38) and aggregated results at case study level. If the aggregated results (Table 16) are analyzed, it is necessary to highlight the increase of the warm days occurrence from a low probability based on the historical period to high probability at the end of the century. Also, the main result is that drought provides low probability of occurrence in this region while dry days get medium probability along all periods and scenarios.

Figure 38: Geolocated warm days hazard for Azores case study using data from SSP5.-8.5.

Table 16: Hazard quantification considering the probability of occurrence of the hazards in the Azores case study.

Hazard	Historical	SSP1-2.6			SSP2-4.5			SSP5-8.5		
	1985-2014	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100	2015-2040	2041-2070	2071-2100
Warm days	Low	Med	Med	Med	Med	Med	Med	Med	Med	High
Drought	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Dry days	Med	Med	Med	Med	Med	Med	Med	Med	Med	Med

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4.2 Vulnerability results

4.2.1 CS1 – Gotland (Sweden)

The results of the vulnerability assessment for the Gotland Case Study are defined for the following sectors: agriculture, society and forest. In Figure 39, the radar graph displays the values of vulnerability of the five most populated sections in Gotland (Gotland_6, Gotland_8, Gotland_10, Gotland_12 and Gotland_15) for each sector of the analysis. The graph shows that the most vulnerable sector for Gotland_12 and Gotland_15 is society. In addition, forest is also a critical sector for Gotland_2 and it is affected at a lower level also in Gotland_6, Gotland_8, Gotland_10 and Gotland_12.

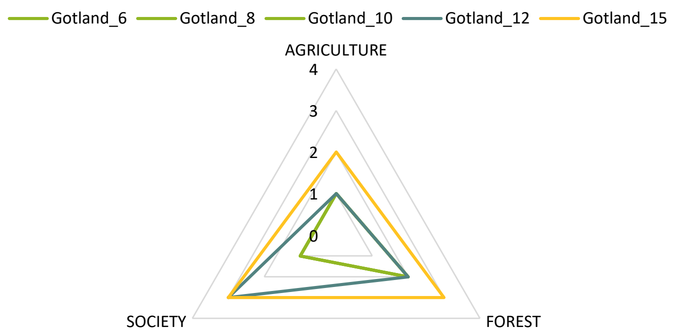

Figure 39. Radar graph of the Vulnerability in Gotland territorial sections Gotland_6, 8, 10, 12 and 15 for each sector.

As explained in the methodology section, the values of vulnerability are defined for the sectors and also for the average of all the sectors. In Figure 40, the map of Vulnerability shows the arithmetic average value of vulnerability of all the sectors in Gotland. The red values represent the highest level of vulnerability and the green values the lowest one.

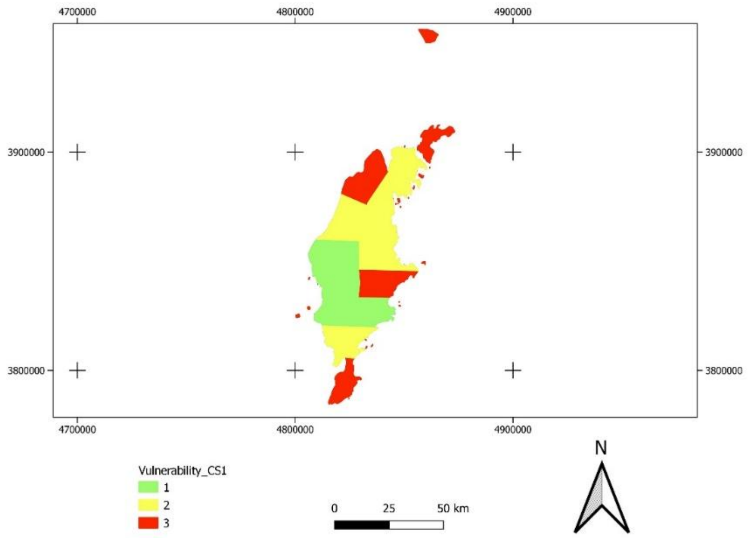

Figure 40. Vulnerability map of the average values of all the sectors in each municipality of the Gotland CS.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037104.

4.2.2 CS2 – Tarn-et-Garonne (France)

The results of the vulnerability assessment for the Tarn-et-Garonne Case Study are defined for the following sectors: agriculture, water management, biodiversity and society. In Figure 41, the radar graph displays the values of vulnerability of the four most populated cities in Tarn-et-Garonne (Montauban, Moissac, Castelsarrasin and Caussade) for each sector of the analysis. The graph clearly shows that water management is the most vulnerable sector for all four cities. Additionally, agriculture is particularly vulnerable for Montauban and Castelsarrasin.

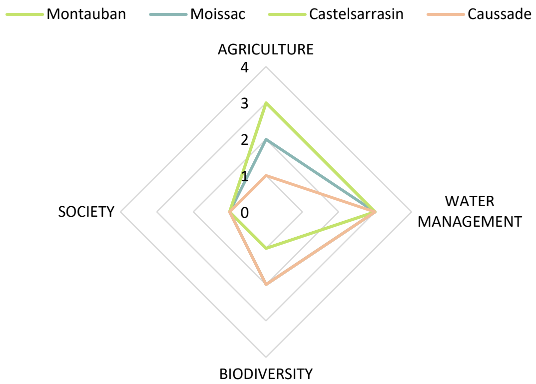

Figure 41. Radar graph of the Vulnerability in Montauban, Moissac, Castelsarrasin and Caussade for each sector.

As explained in the methodology section, the values of vulnerability are defined for the sectors and also for the average of all the sectors. In Figure 42, the map of Vulnerability shows the arithmetic average value of vulnerability of all the sectors in Tarn-et-Garonne. The red values represent the highest level of vulnerability and the green values the lowest one.

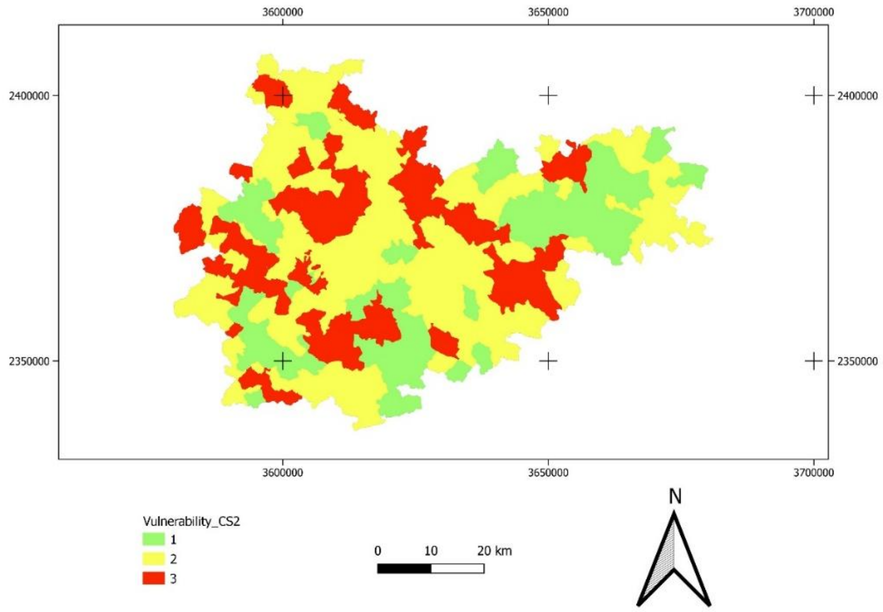

Figure 42. Vulnerability map of the average values of all the sectors in each municipality of the Tarn-et-Garonne CS.

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4.2.3 CS3 – Southern Great Plain (Hungary)

The results of the vulnerability assessment for the Southern Great Plain Case Study are defined for the following sectors: agriculture and water management. In Figure 43, the radar graph displays the values of vulnerability of the four most populated cities in Great Southern Plain (Békéscsaba, Hódmezővásárhely, Kecskemét and Szeged) for each sector of the analysis. The graph shows that the most vulnerable sector for all the municipalities represented is water management.

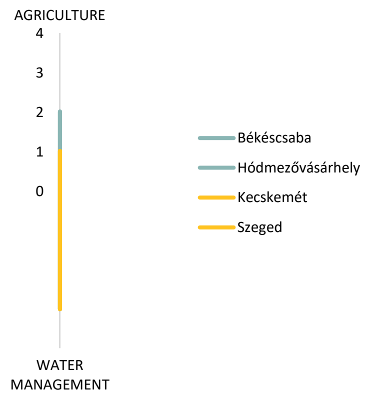

Figure 43. Radar graph of the Vulnerability in Békéscsaba, Hódmezővásárhely, Kecskemét and Szeged for each sector.

As explained in the methodology section, the values of vulnerability are defined for the sectors and also for the average of all the sectors. In Figure 44, the map of Vulnerability shows the arithmetic average value of vulnerability of all the sectors in Southern Great Plain. The red values represent the highest level of vulnerability and the green values the lowest one.

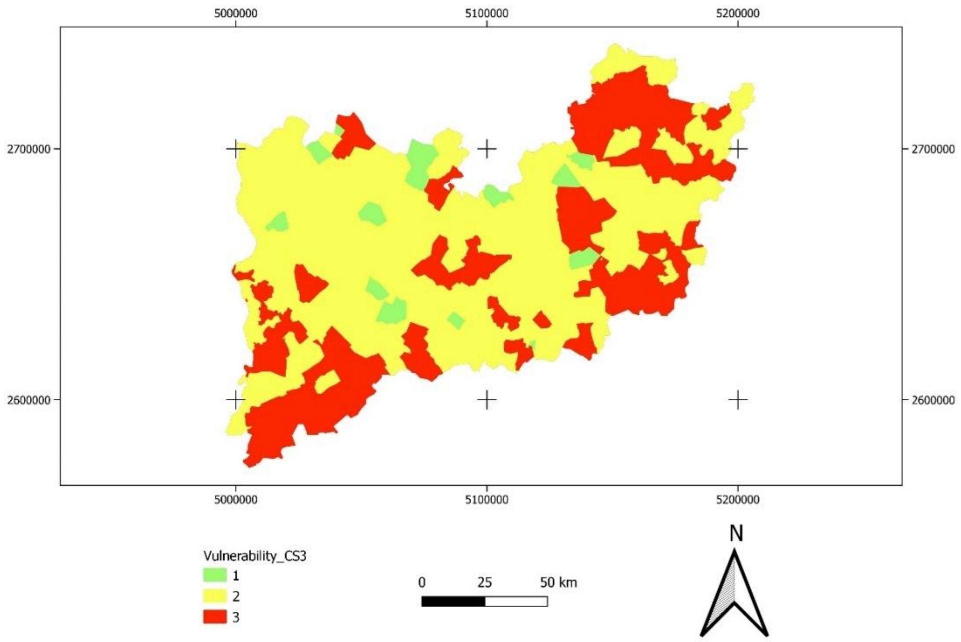

Figure 44. Vulnerability map of the average values of all the sectors in each municipality of the Southern Great Plain CS.

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4.2.4 CS4 – Valle d'Aosta (Italy)

The results of the vulnerability assessment for the Valle d'Aosta Case Study are defined for the following sectors: society, tourism and energy. In Figure 45, the radar graph displays the values of vulnerability of the four most populated cities in Valle d'Aosta (Aosta, Sarre, Châtillon, Saint-Vincent and Quart) for each sector of the analysis. The graph shows that energy is the most vulnerable sector for the municipalities except for Aosta and Châtillon. In addition, society has high vulnerability for Sarre and Saint-Vincent.

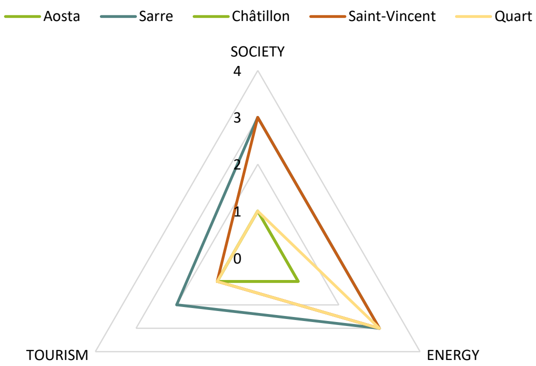

Figure 45. Radar graph of the Vulnerability in Aosta, Sarre, Châtillon, Saint-Vincent and Quart for each sector.

As explained in the methodology section, the values of vulnerability are defined for the sectors and also for the average of all the sectors. In Figure 46, the map of Vulnerability shows the arithmetic average value of vulnerability of all the sectors in Valle d'Aosta. The red values represent the highest level of vulnerability and the green values the lowest one.

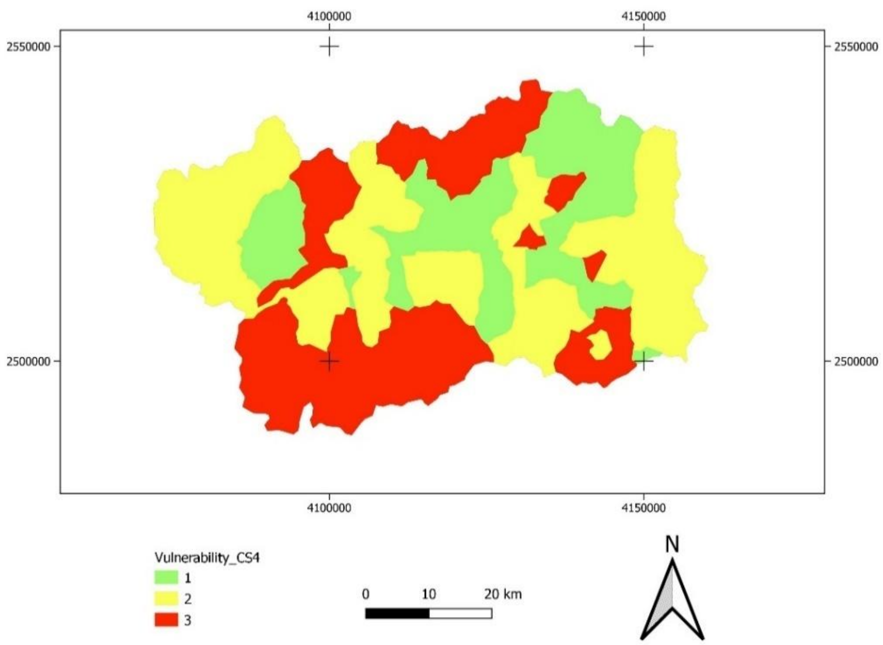

Figure 46. Vulnerability map of the average values of all the sectors in each municipality of the Valle d'Aosta CS.

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4.2.5 CS5 – Almería (Spain)

The results of the vulnerability assessment for the Almería Case Study (CS) are defined for the following sectors: agriculture, tourism, industry, energy, forest and biodiversity, transport, society, water management and urban. In Figure 47, the radar graph displays the values of vulnerability of Almería, El Ejido, Tabernas, Adra and Berja for each sector of the analysis. These cities were selected to guarantee the clarity of the outcomes in the graph and because they represent the main features of Almería province: coastal tourism, greenhouse farming, mountainous and rural areas, industrial and port cities, historical and cultural centres. Other radar graphs can be created for other groups of municipalities. The graph shows that energy is a highly vulnerable sector for all the municipalities. The urban sector also presents high levels of vulnerability for all the municipalities except for Tabernas which is the city with the smaller urban area.

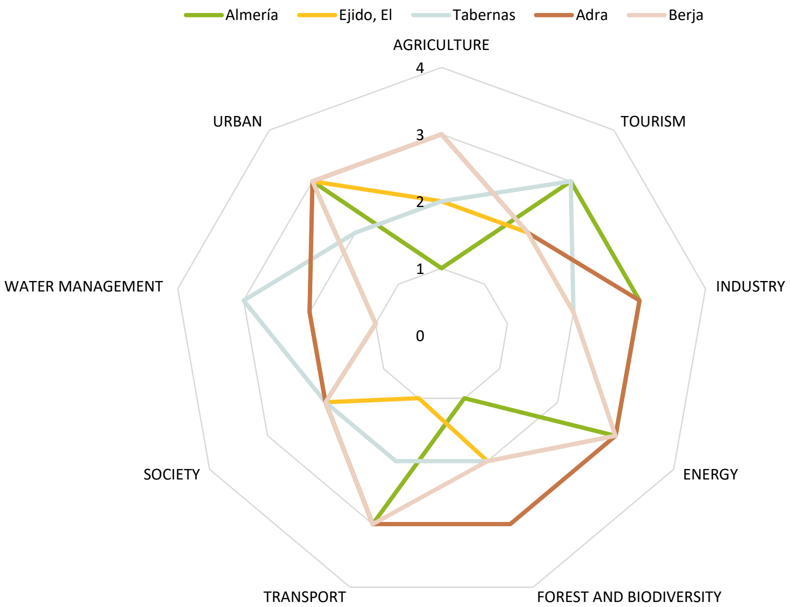

Figure 47. Radar graph of the Vulnerability in Almeria, El Ejido, Tabernas, Adra and Berja for each sector.

As explained in the methodology section, the values of vulnerability are defined for the sectors and for the weighted average of all the sectors. The weights for each sector of the Almeria CS are: Agriculture (3), Tourism (3), Water management (3), Industry (2), Energy (2), Society (2), Forest and Biodiversity (1), Transport (1) and Urban (1). In Figure 48, the map of Vulnerability shows the weighted average value of vulnerability of all the sectors. The red values represent the highest level of vulnerability and the green values the lowest one.

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research and innovation programme under grant agreement No 101037104.

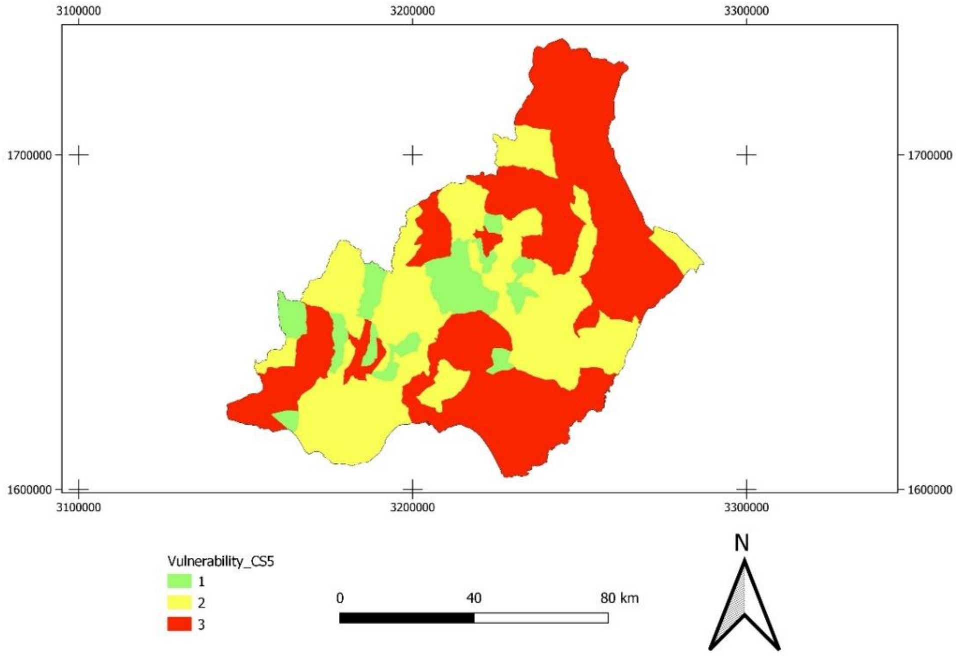

Figure 48. Vulnerability map of the weighted average values of all the sectors in each municipality of the Almería CS.

4.2.6 CS6 – Azores (Portugal)

The results of the vulnerability assessment for the Azores Case Study are defined for the following sectors: agriculture, tourism, energy. In Figure 49, the radar graph displays the values of vulnerability of Azores islands: Corvo, Faial, Flores, Graciosa, Pico, Santa Maria, Sao Jorge, Sao Miguel and Terceira for each sector of the analysis. The vulnerability of each island corresponds to the average of the vulnerabilities assigned to the municipalities located inside the island considered. The graph shows that Flores and Pico are highly vulnerable for all the sectors. Agriculture, tourism and energy are also critical respectively to Corvo, Santa Maria and Sao Miguel.

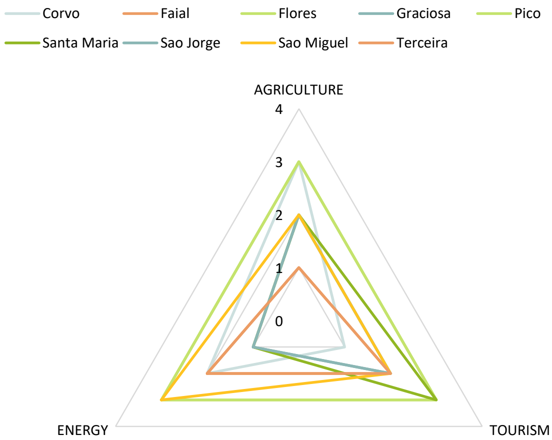

Figure 49. Radar graph of the vulnerability of Azores islands for each sector.

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As explained in the methodology section, the values of vulnerability are defined for the sectors and for the average of all the sectors. In Figure 50, the map of Vulnerability shows the arithmetic average value of vulnerability of all the sectors in Azores. The red values represent the highest level of vulnerability and the green values the lowest one.

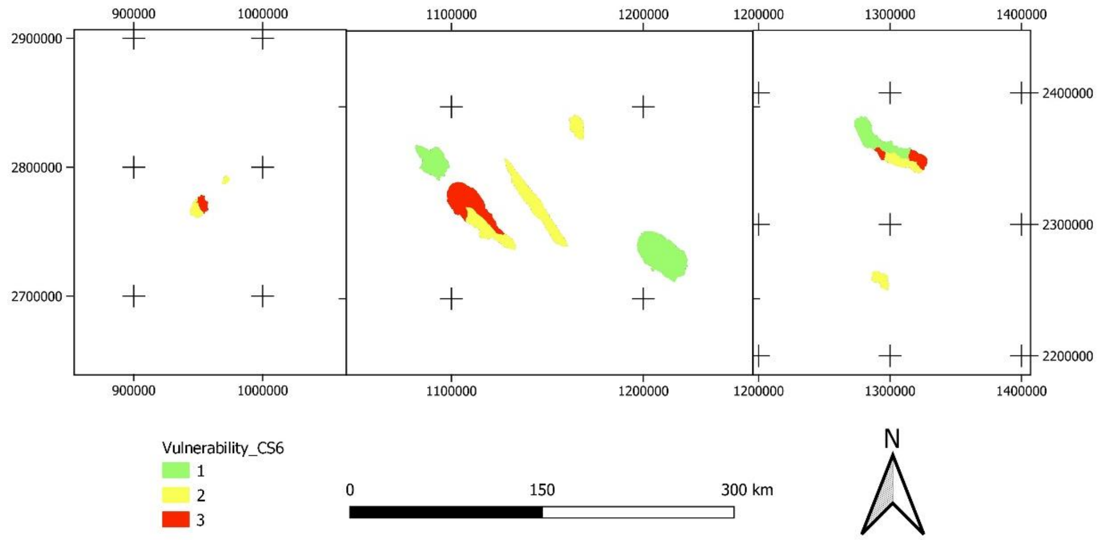

Figure 50. Vulnerability map of the weighted average values of all the sectors in each municipality of the Azores CS.

4.3 Risk results

Risk was quantified as the combination of the hazard, exposure and vulnerability. The results were developed with a geolocated basis in order to obtain results per each municipality or functional area (subdivision) understanding the differences according to the climate patterns and the location of each area of analysis. These results are the basis for the platform implementation providing information to the user about the most impacted sectors before the simulation of the effects of policy implementation. Below, information on the risk per case study is provided. More information on the risk at municipality level is available in Annex VIII – Results of risk quantification.

4.3.1 CS1 – Gotland (Sweden)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each territorial section. It will be crucial to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

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As a general conclusion, we could highlight that *Forest* is highly affected by all the hazards, particularly by drought and precipitation change. This is coherent with the features of the island, since Gotland is characterized by a large forest area which can be highly exposed to extreme hazardous events. *Society* is strongly affected by storm and precipitation changes that could be more intense in the future. Regarding the *Agriculture* sector, it is not greatly affected by drought because of the increasing use of artificial irrigation, but it shows high levels of risk for hot days and storms that could compromise the crop production.

4.3.2 CS2 – Tarn-et-Garonne (France)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each municipality. It will be crucial to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

As a general conclusion, we could highlight that *Society* is highly affected by both the hazards, hot days and warm days that could be more intense in the future. *Water management* also shows high levels of risk for increase in temperature. This is coherent with the problems of the region, since Tarn-et-Garonne's water resources are being overexploited and deteriorated in quality as a consequence of increase of water consumption due to climate change. In addition, the reduction of water compromise *Agriculture* and *Biodiversity*, which are also highly affected by increase of temperature, respectively regarding crop production and maintenance of protected areas.

4.3.3 CS3 – Southern Great Plain (Hungary)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each municipality. It will be crucial to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

As a general conclusion, we could highlight that *Agriculture* is highly affected by dry days and warm days. It is not greatly affected by drought because several areas are artificially irrigated. On the other hand, increase of temperatures and decrease of precipitation in the growing seasons are associated with higher levels of risk, and could cause negative effects on crop production. Regarding *Water management*, it displays high risk levels in mainly in hot days and drought, and at a lower level in warm days as well. This is coherent with the features of the region, since groundwater is the major water resource, but it is highly exposed to decrease of precipitation and increase in evapotranspiration. Moreover, hot days and drought could increase the water consumption causing overexploitation of the aquifers and contamination.

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4.3.4 CS4 – Valle d'Aosta (Italy)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each municipality. It will be crucial to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

As a general conclusion, we could highlight that *Tourism* is highly affected by all the hazards, particularly by high wind and hot days. This is coherent with the recreational activities performed in the region, since winter tourism, trekking and mountaineering could be compromised my increase of temperature and strong winds. The *Energy* sector is mainly affected by dry days and hot days due to the type of energy produced in the region, which is mainly hydroelectric production. Regarding the *Society* sector, it is characterized by high levels of risk associated with dry days and hot days. The decrease of precipitation and increase of temperature will cause people to emigrate in the region from the surrounding territories.

4.3.5 CS5 – Almería (Spain)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each municipality. It will be crucial to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

As a general conclusion, we could highlight that *Water management* is highly affected by all the hazards, particularly by storm and drought. This is coherent with the features of the region, since Almería is characterized by a semi-arid climate with scarce water resources. *Society and Urban* sectors are strongly affected by the changes in the precipitation patterns (storms) that could be more intense in the future. Regarding the *Agriculture* sector, it is not greatly affected by drought because the most productive areas are artificially irrigated. On the other hand, heatwaves and storms are associated with higher levels of risk, particularly storm that could generate negative effects on crop production as a consequence of the extreme events. *Tourism* is negatively affected by the high temperatures and reflected by the effects of the droughts and heatwaves due to the type of recreational activities that are performed in the region which require a lot of water to be maintained (e.g. golf).

4.3.6 CS6 – Azores (Portugal)

The set of matrices created for the case study that are included in the Annex VIII, provide a framework to identify the sectors at risk and the level of risk (High, Med, Low) for each municipality. It will be crucial

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to understand what is occurring in the region before the selection and implementation of measures to adapt to climate change.

As a general conclusion, we could highlight that *Tourism* is highly affected by all the hazards. This is coherent with the type of touristic activities in Azores, such as hiking, diving, beaches, and other nature-based activities, which could be menaced by high temperatures and low precipitations. *Energy* is also negatively affected by all the hazards, particularly dry days and warm days probably due to the increase of energy consumption by other economic sectors like agriculture (e.g. use of water pump for irrigation) and tourism (e.g. increase in the use of air conditioning). Regarding the *Agriculture* sector, it is not greatly affected by drought because some areas are artificially irrigated. On the other hand, dry days and warm days are associated with higher levels of risk that could lead to decrease in crop and, meat and milk production as a consequence of thermal stress and less precipitation in the growing seasons.

5 Conclusions

In Task 6.1 a climate risk analysis was performed using detailed data from WP3 and literature review, about the risks which affect the most vulnerable sectors. The most vulnerable sectors were co-selected resorting to stakeholder dialogue and considering land use as a background issue. Stakeholders were engaged by the project and co-developed impact chains which synthesize the analysis and lay the foundations of the risk quantification. Despite the fact that the case studies being representative of different EU realities, water scarcity appears as a common thread in all case studies, mostly affecting agriculture but also other sectors. Different nuances appear regarding the dynamics of the risks which are expressed by the impact chains.

Impact Chains are useful analytical tool with a relevant reach albeit with relevant limitations (discussed in D5.2). It is expected that the sketches can be used in the platform (WP7) as well after undergoing additional simplification. This will facilitate a shared understanding of the local risks both for local stakeholders and early replicators (T8.4).

The quantified risks include municipality level statistical data, or other detailed information, which provides adequate resolution to evaluate the differences throughout the territory covered by each case study. Risk was quantified for each scenario, period and hazard covering the most relevant sectors in each case study. The results are key to identify critical sector in which adaptation measures are a priority to fight against the climate change effects. The risk quantification results will be included in the platform as to facilitate informed decision making.

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The impact chains also inform local SD model development about the complex connections of each risk. Furthermore, work with InVEST Annual Water Yield (AWY) and AquaCrop will be refined as the lack of calibration and validation of the models was considered to be a limitation. This will be achieve mainly resorting to literature review but also additional work. Nevertheless, the models were capable of showing trends in the risk analysis stage.

Overall, the task reached the main objective of identifying the risks in the different case studies which will be considered in the future implementation of LAMS.

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Annexes

This document integrates eight annexes that are listed below. These annexes have been developed as supplementary documents to help improve the understanding of the results presented in the main document.

D6.1 |Annex I - CS1 Gotland (Sweden)

D6.1 | Annex II – CS2 Tarn-et-Garonne (France)

D6.1 | Annex III - CS3 Southern Great Plain (Hungary)

D6.1 | Annex IV - CS4 Valle D'Aosta (Italy)

D6.1 | Annex V – CS5 Almeria (Spain)

D6.1 | Annex VI – CS6 Azores Archipelago (PT)

D6.1 | Annex VII – ECVs Summary tables

D 6.1 | Annex VIII – Results of risk quantification

D 6.1 | Annex IX – Hazard exceedance probability results and hazards' interactions

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