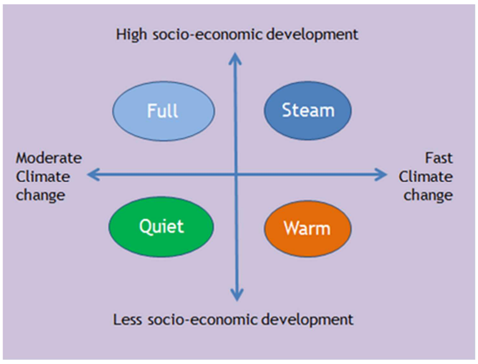
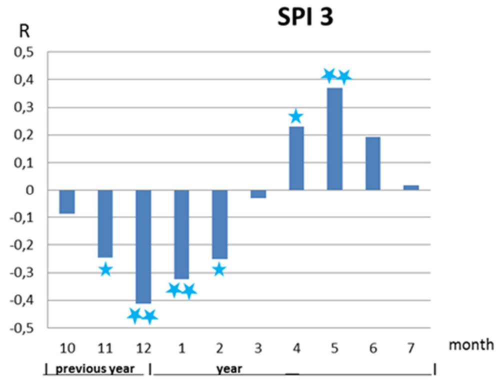
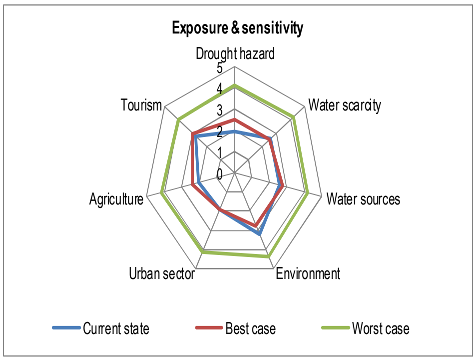
Technical Report No. 20

FUTURE DROUGHT IMPACT AND VULNERABILITY - CASE STUDY SCALE







Dionysis Assimacopoulos, Eleni Kampragou, Joaquín Andreu, Carlo Bifulco, Alessandro de Carli, Lucia De Stefano, Susana Dias, Lukas Gudmundsson, David Haro-Monteagudo, Dario Musolino, Javier Paredes-Arquiola, Francisco Rego, Irmi Seidl, Abel Solera, Julia Urquijo, Henny van Lanen, Wouter Wolters

17 October 2014

DROUGHT-R&SPI (Fostering European Drought Research and Science-Policy Interfacing) is a Collaborative Project funded by the European Commission under the FP7 Cooperation Work Programme 2011, Theme 6: Environment (including Climate Change, ENV.2011.1.3.2-2: Vulnerability and increased drought risk in Europe (Grant agreement no: 282769). The DROUGHT-R&SPI project started 01/10/2011 and will continue for 3 years.

Title:	Future drought impact and vulnerability - case study scale
Authors:	Dionysis Assimacopoulos, Eleni Kampragou, Joaquín Andreu, Carlo Bifulco, Alessandro de Carli, Lucia De Stefano, Susana Dias, Lukas Gudmundsson, David Haro-Monteagudo, Dario Musolino, Javier Paredes-Arquiola, Francisco Rego, Irmi Seidl, Abel Solera, Julia Urquijo, Henny van Lanen, Wouter Wolters
Organisations:	National Technical University of Athens (NTUA), Instituto Superior de Agronomia, Portugal (ISA-CEABN), Universita Commerciale 'Luigi Bocconi' Italy (UBCERTeT), Universidad Politecnica de Valencia, Spain (UPVLC), Alterra, The Netherlands (Alterra), Eidgenössische Technische Hochschule Zürich (ETH), Eidgenössische Forschungsanstalt WSL (WSL), University Complutense of Madrid, Spain (UCM)
Submission date:	17 October 2014
Function:	This report is an output from Work Package 2; task 2.5
Deliverable	DROUGHT-R&SPI Deliverable 2.5

Photos:
Top Left: Scenarios for the Netherlands Case Study
Top Right: Correlation between SPI3 and Wheat crop changes (1986-2009) in Portugal
Bottom: Photo: Vulnerability assessment in Syros Case Study

Executive Summary

This report presents the results from the future impact and vulnerability assessment in the DROUGHT-R&SPI Case Studies: The Netherlands (NL); Switzerland (CH); Portugal (PT); Jucar River Basin, Spain (JU); Po River Basin, Italy (PO); and Syros Island, Greece (SY). The analyses were performed for Task 2.5 "Future socio-economic and environmental impacts, and vulnerability assessments" with the objective to assess *"potential vulnerabilities of the studied systems, on the basis of climate projections, socio-economic drivers of change, environmental constraints and anticipated impacts of relevant EU policies*".

The Case Studies represent three spatial scales of analysis (local, river basin and national) and have different contexts (physical, environmental, socio-economic), priorities in water and drought management, and background information (e.g. data, management plans) related to drought. As a result different approaches were followed and alternative sources of information were used for the implementation of the three main Activities in the Case Studies: (i) Development of socio-economic scenarios for a mid-term time horizon (2030), (ii) Future impact assessment for the different scenarios, and (iii) Future vulnerability assessment. The analyses were supported by (i) existing information in reports on future drought impacts, vulnerability and management, (ii) modelling of the water system in the Case Studies, (iii) surveys, and (iv) consultation by local stakeholders.

The main findings can be summarised as follows:

- Water scarcity is an important exposure-related factor of vulnerability to drought. Any effort to cope with water scarcity will thus contribute to reducing vulnerability to drought.
- Agriculture remains the most affected sector by drought, whereas the risk of forest wildfires is expected to increase also in the future.
- Results from the future impact and vulnerability assessment show that the socio-economic development pattern is the most influencing factor on future drought-related risks, compared to climate change and its effect on drought characteristics.
- Factors that may reduce future vulnerability are: Improvement of institutional framework on drought, Overcoming policy gaps, Establishment of monitoring & early warning systems, Development of DMPs, Increasing water-use efficiency, Use of alternative water sources, and Increasing user awareness.
- Factors that may increase future vulnerability are: Conflicts due to water scarcity, Status of water sources (quality and quantity), Increased variability of water availability due to Climate Change, and Economic development patterns.

This report was developed by the NTUA with the cooperation of UPVLC, ISA-CEABN, UB-CERTeT, ALTERRA, ETH and WSL, who provided input for the Case Study analysis. The authors would like to acknowledge the significant contribution from UCM in the framing of vulnerability analysis, as part of cross linking Case Study and pan-European assessments.

Table of Contents

List of Tables

List of Figures

1 Introduction

Climate change scenarios indicate an increase in intensity and frequency of drought events (Christensen et al., 2007). However the type and magnitude of drought impacts cannot be projected as these are also influenced by non-climatic factors (Kundzewicz et al., 2007), increasing thus the uncertainty associated with future drought risk (in terms both of hazard and impacts).

Within the framework of the DROUGHT-R&SPI Project, future drought risk is analyzed from two perspectives: (i) future vulnerability to drought, and (ii) potential impacts, on the basis of future drought characteristics. The analysis focuses on: (i) socio-economic development scenarios, (ii) potential impacts in the high priority sectors in each Case Study, and (iii) changes in the vulnerability to drought under the different scenarios, in order to tackle uncertainty related to future conditions.

The analysis framework is illustrated in Figure 1. 1. Vulnerability is defined as a function of exposure, sensitivity and adaptive capacity (IPCC, 2007; Fontaine and Steinemann, 2009). Exposure describes drought hazard (intensity, duration, frequency, spatial extent), sensitivity the degree to which a system is affected by drought (as a result of social, economic, and technological factors), and adaptive capacity the ability to prevent or moderate potential impacts or cope with the consequences. Future drought impacts and vulnerability are assessed for different socio-economic development scenarios which are discussed with stakeholders, so as to represent their perception of the potential future state in the Case Study regions.

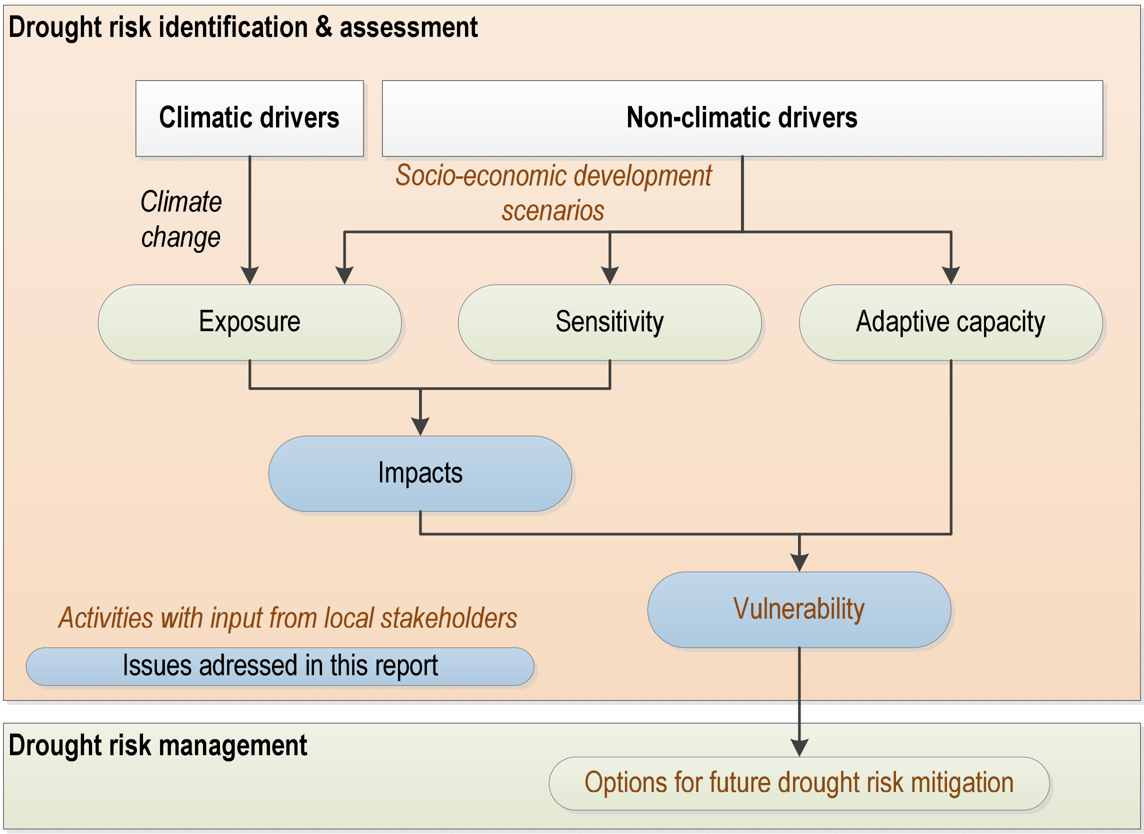


Figure 1. 1: *The framework for analysing future drought impacts and vulnerability.*

Results from the analysis will support the identification and selection of options for future drought risk mitigation in a subsequent project phase. In addition, results from (future) vulnerability assessments will be compared with the Pan-EU vulnerability assessments. The aim is two-folded: (i) to provide input from the Case Study analysis to the pan-European assessment regarding local vulnerability factors, and (ii) assess the contribution and limitations of European-wide assessments to local vulnerability analyses. Even though similar in scope, there are important differences in assessing vulnerability at the regional (WP2) and European (WP3) level, originating mainly from the (policy) priorities set in drought management at these two levels and the underlying factors that frame vulnerability. The narrower the scale of analysis, the more detailed and inclusive the assessment of vulnerability factors can be. However, similar 'aggregated' factors can be found for regions with similar socio-economic and climate characteristics, enabling thus a cross-comparison of problems and cross-learning for drought mitigation.

The report is organized in eight Chapters. Chapter 2 describes the methodological framework for future impact and vulnerability assessment in the Case Studies, whereas Chapters 3, 4 and 6 are dedicated to the results regarding socio-economic scenarios, future drought impacts and future vulnerability respectively. Chapter 5 provides a summary of the large-scale assessment undertaken in DROUGHT-R&SPI on future wild fires, focusing particulary on the Case Study areas. Chapter 7 synthesises the outcomes from the six Case Studies and includes conclusive remarks. Finally, Chapter 8 provides the list of references used in the report. Seven Annexes complement the report.

2 Methodology

The main objective of this study is to assess future drought impacts and vulnerability to drought in the six DROUGHT-R&SPI Case Studies. The research questions are listed in Table 2. 1 and were addressed through three Activities (Figure 2. 1):

1. **Activity 1 "Development of socio-economic scenarios"**: It concerns the development of scenarios on the "external" factors that define drought vulnerability in the Case Study areas for a mid-term time horizon (2030).
2. **Activity 2 "Future impact assessment"**: The Activity aims at the assessment, and if possible quantification, of potential socio-economic and environmental impacts for the scenarios defined in Activity 1. In addition, results from the impact assessment models at the large scale (pan-European) were analysed for the Case Study areas. Based on the bounding box coordinates for each Case Study area, the corresponding grid cells were selected and analysed.
3. **Activity 3 "Future vulnerability assessment"**: It refers to the development of future vulnerability profiles for the Case Study areas.

The analyses were supported by local stakeholder fora through the organisation of theme-specific Workshops (Table 2. 2).

Table 2. 1*: Research questions.*

Research questions
• Which drought events (in terms of severity or impacts) would justify a change in the "Business as Usual" scenario for drought management? • Which are the desired /undesired future (socio-economic & environmental) conditions for the Case Study? • Is the described future logical and/or plausible? • Which factors can influence future vulnerability to drought? • What is the vulnerability profile of each Case Study? • What type of drought impacts can be anticipated in the future?

Three main sources of information were used in support of the Activities: (i) information in existing reports on future drought impacts, vulnerability and management, (ii) modelling of the water system in the Case Studies, and (iii) strictly stakeholder-based assessments (e.g. surveys).

Table 2. 2*: Case Study Dialogue Fora in support of the research activities.*

Place, Date	Case Study	Themes discussed
Parma, Italy (12/2/2013 & 13/5/2014)	Po River Basin	• Future vulnerability to drought: Issues & challenges • Stakeholder's view of on future economic pattern & water management scenarios
Lisbon, Portugal (16/5/2013)	Portugal	• Development of future scenarios for the underlying causes of vulnerability to drought • Preliminary discussion on options for long-term drought risk mitigation
Valencia, Spain (27/6/2013)	Jucar River Basin	• Planning for future droughts: scenarios, vulnerability & impacts • Risk perception by stakeholders: options for confronting drought risk

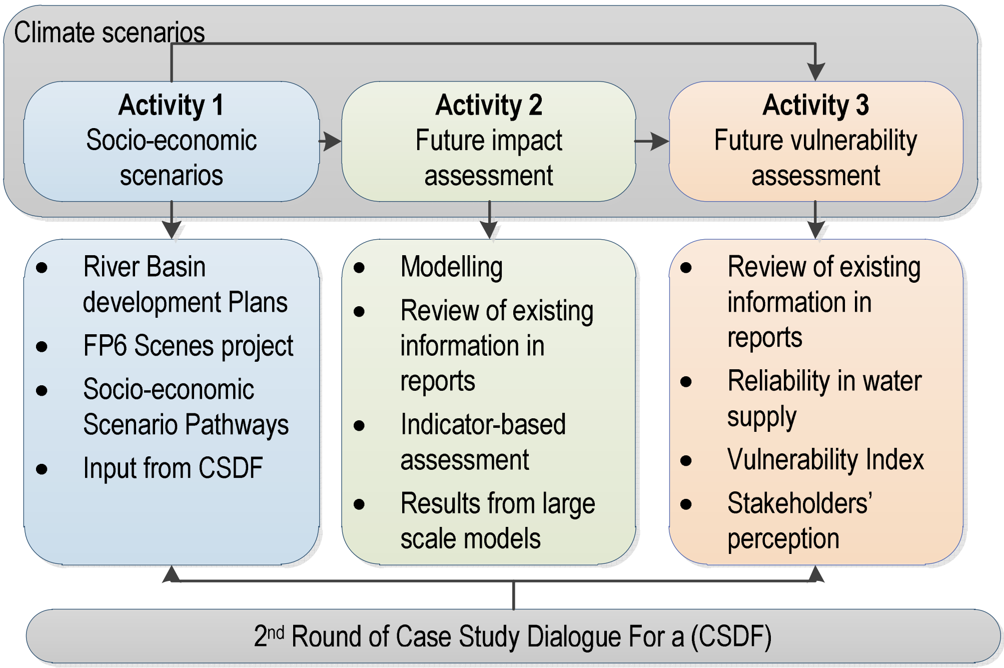


Figure 2. 1: *Activities in support of future impact and vulnerability assessments.*

The following sections provide a more detailed description of the methodological premises for each Activity. An overview of the approach adopted in each Case Study is given in Figure 2. 2, the selection of which was based on the spatial scale of analysis, data availability, existing models and tools and stakeholder priorities.

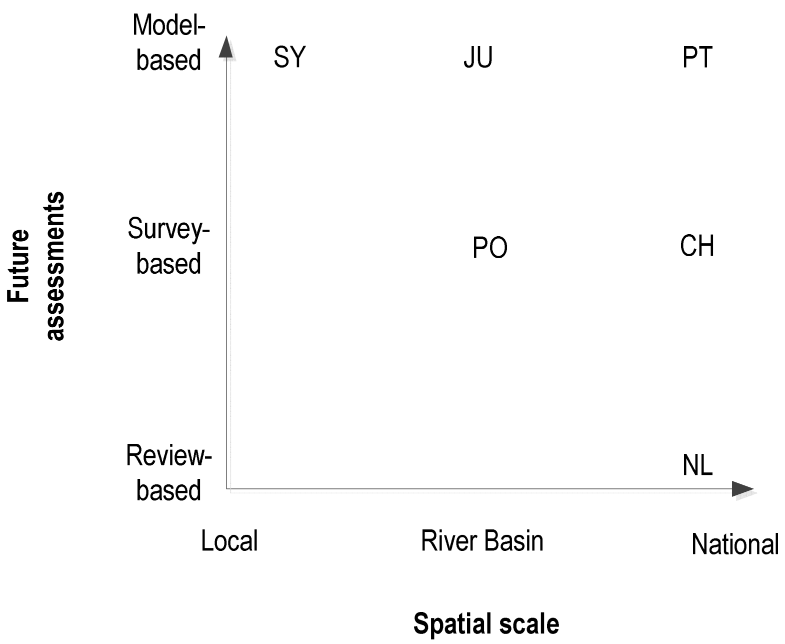


Figure 2. 2: *Sources of information used in future assessments.*

2.1 Development of socio-economic scenarios

Scenarios are used in climate change analyses, either as climate scenarios on the basis of future trends in greenhouse gases, aerosol precursor emissions and land uses, or as socio-economic development scenarios in order to support impact assessments and mitigation analysis. These describe a possible future state of a (social-economic-environmental) system, based on the anticipated changes in specific critical factors. Scenarios are used directly by policy or decision makers in order to support their decision making process, and intermediately by researchers, as an input to their research activities (Kriegler et al., 2012). In many cases these two groups of scenarios' users work together for the formulation of scenarios, to ensure that scenarios represent stakeholder perception of the future.

The past few years an effort is underway for the development of the so-called "Shared Socio-economic Pathways-SSPs" which are scenarios for climate change research developed jointly by researchers working on integrated assessment modeling (IAM) and impacts, adaptation and vulnerability (IAV) (e.g. Moss et al., 2010; Kriegler et al., 1010; van Vuuren et al., 2012). The new framework for scenario building combines alternative states for climate forcing (as represented by the Representative Forcing Pathways) and socio-economic conditions. Together, these two axes describe situations in which mitigation, adaptation and residual climate damage can be evaluated. The most important determinants of SSPs, with regard to impact and vulnerability assessments, are given in Table 2. 3.

Table 2. 3: *Key determinants of adaptation challenges (adapted from van Ruijven and Ebi, 2013).*

Determinant	SSPs variable	SSPs element
Average wealth	GDP projection	IAM element
Poverty	Income distribution	IAV element
Quality of governance	Governance	IAV element
People in coastal zones	Spatial population projection	IAV element
Urbanization	Urbanization	IAM element
Education	Education	IAM element
Innovation	Innovation	Storyline
Quality of healthcare	Health projections	IAV element

Socio-economic scenarios are used in DROUGHT-R&SPI for assessing future vulnerability to drought and estimating potential future drought impacts, in combination with climate scenarios (see Technical Reports No 5 & 11), in the Case Studies. The scenario development process aims at providing a description of the possible future evolution of the system examined for a short to medium timeframe (up to 2030) by combining quantitative projections and qualitative information (such as narratives) for the future. The formulation of scenarios followed the process described in Figure 2. 3:

1. The first Step aims at the identification of those characteristics which will most likely affect the future state of the analysed system, and its sensitivity and response to future droughts. Emphasis is given to the critical factors that shape current vulnerability to drought (e.g. Table 2. 4) and their plausible future state.
2. Subsequently, a first set of narrative descriptive scenarios (storylines) are developed regarding the future state of the Case Study, taking into account the factors identified in the previous Step. Storylines provide an "image" of the future for the studied system for the specified time horizon (2030) addressing, in addition to vulnerability factors, economic development trends (e.g. structure of the economy, orientation of the agricultural sector), water management priorities (e.g. supply enhancement vs. demand management), and land use planning. The quantification of the storylines involves: (a) the identification of suitable parameters describing the different storyline aspects (e.g. cultivated area in hectares for a specific crop, percentage coverage of water

demand by alternative sources), and (b) the assignment of values to these parameters, based on expert judgment and literature review.
3. As a next Step, storylines and their quantified parameters (i.e. the scenarios) are discussed and validated by the local Case Study Dialogue Fora. The objective of the discussion is to consolidate the scenarios and integrate local views on how the future may unfold.
4. The final version of scenarios is formulated on the basis of the outcomes of the discussion with stakeholders. These scenarios are subsequently used in Activity 2 for impact assessment.

Sources of information used for the draft development of scenarios are:

- The outcomes of the FP6 SCENES Project, whose aim was to develop and analyze a set of comprehensive scenarios of Europe's fresh waters up to 2050 through a participatory process. The Project formulated four numerical scenarios (Economy First, Fortress Europe, Policy Rules, Sustainability Eventually), based on different storylines, which were quantified using state-of-the-art models (Annex A);
- The River Basin Management Plans and the Drought Management Plans developed in the Case Study areas. These plans incorporate measures that will be implemented in case of drought, but also set the priorities for future water management interventions and drought risk reduction options. Thus, their provisions were integrated in the developed scenarios;
- Current or past economic development plans, land use plans and environmental protection strategies in the Case Study areas;
- EU policy documents (e.g. water policy priorities set in the EC Communications on Water Scarcity and Drought, etc.);
- Premises for the development of the SSPs.

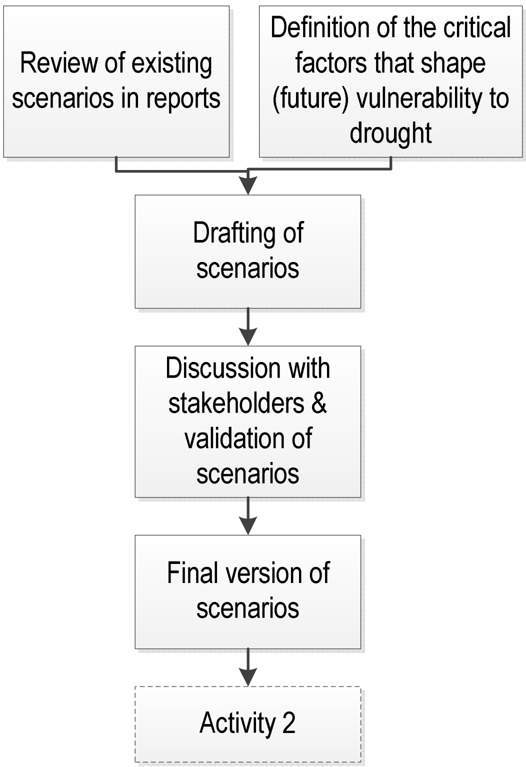


Figure 2. 3: *Flowchart of the steps followed in Activity 1.*

Scenarios are described using the Quadrant method, along two main axes (Figure 2. 4): (i) the economic development pattern (either balanced, incorporating environmental protection, or economic-oriented), and (ii) the drought management approach (crisis- or risk-based drought management).

Table 2. 4*: Factors that shape current vulnerability to drought in the Case Studies (factors encountered in more than one Case Study are highlighted).*

Institutional	Economic / Technical	Social	Environmental
• **Lack of DMPs** • Existing water use priorities • Lack of drought forecasting • **Lack of strategic reserves** • Lack of water use rights • definition	• **Water scarcity** • Inefficient irrigation systems • **Crop pattern** • Distribution & age of hydropower plants • Controlled water network • Dense & high-quality infrastructure	• Low drought awareness • **Water use conflicts**	• **Groundwater over-exploitation** • Limited potential for additional water sources • Status of glaciers • Salinity levels • Water-dependent ecosystems

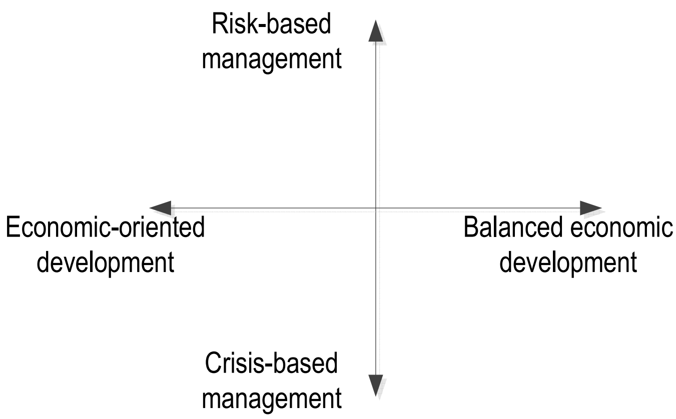


Figure 2. 4: *Quadrant for the presentation of scenarios in the Case Studies.*

2.2 Future impact assessment

Drought impacts cover a wide range of (economic) sectors and the environment and vary in a spatial and temporal scale that is difficult to characterise and even more quantify (Wilhite et. al, 2007). In the case of climate change analysis, the challenge of assessing future drought impacts is even higher, as future drought conditions and socio-economic factors that define vulnerability to drought are hard to predict.

Several approaches are adopted for impact assessments (Table 2. 5), which are typically performed for the agricultural and urban water supply sectors on the basis of variation of agricultural production and the corresponding economic return, and the cost of additional measure to minimise deficit respectively.

Table 2. 5*: Approaches for drought impact assessments.*

Approach	Description
Economic analysis	Economic evaluation based on the consumer surplus theory, macro-economic models, computable equilibrium models
Statistical analysis	Regression analysis of impact-related indicators with drought indices and other drought-impact related parameters $Impact = f(drought\ severity, water\ delivered, other\ parameters)$ $Economic\ losses = f(impact)$
Model-based analysis	Use of models (e.g. water balance models, crop yield models) for the estimation of impacts

Future impact assessment in DROUGHT-R&SPI refers either to the quantification of future impacts or an assessment of their type and trend (e.g. increase/decrease) on the basis of: (i) the characteristics of future droughts, and (ii) scenarios on the non-climatic drivers, which define the future vulnerability of the studied systems. The following approaches were adopted (Figure 2. 5):

1. Review of existing reports on anticipated future drought impacts. Drought management plans, for example, include measures to alleviate (anticipated) impacts and can be one source of information. National climate change studies can be another source of information.
2. Use of models for analysing impacts either for a specific sector or a water system as a whole. This approach enables a quantitative and probabilistic analysis of impacts, as both climate and non-climate drivers are used in modelling.
3. Surveys (stakeholder perception of future drought impacts).
4. Use of results from large scale models on drought impacts at the Pan-EU scale. DROUGHT-R&SPI undertakes an impact analysis at the European level, by linking drought and impact-related indicators. Results from this modelling exercise were extracted for the grid cells that correspond to the Case Studies.

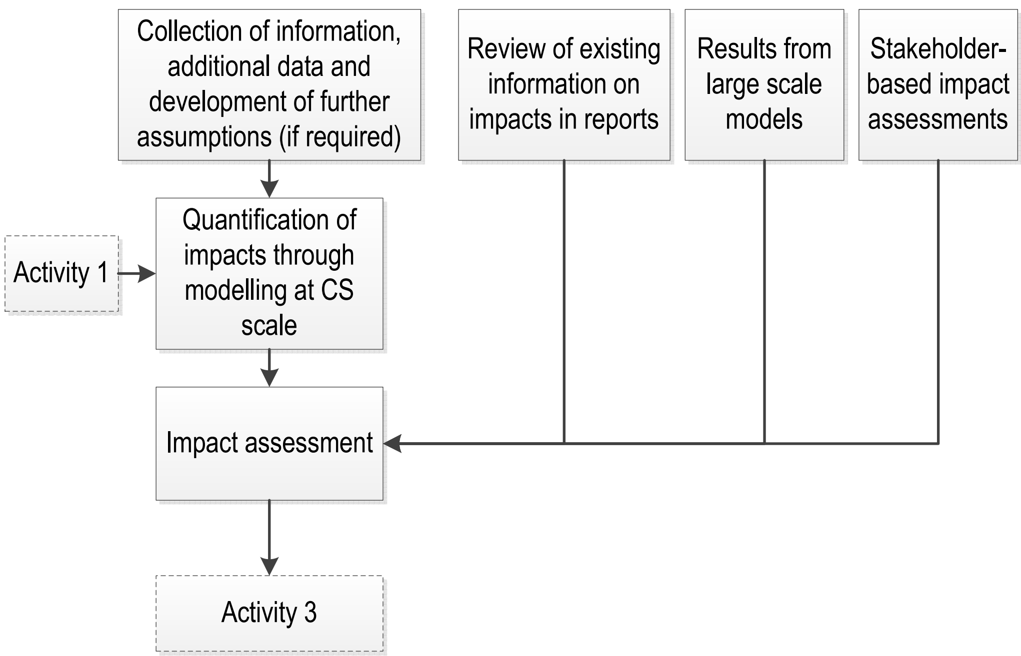


Figure 2. 5: *Flowchart of the steps followed in Activity 2.*

Box 1: Quantification of future drought impacts[1]

An ex-post assessment of past drought socio-economic impacts was undertaken in the DROUGHT-R&SPI Case Studies using the consumer surplus theory (see Technical Report No 9). The same approach for future impact quantification (ex-ante assessment) requires an analysis of potential management scenarios (i.e. options), fitting thus better to the scope of Task 2.6 “Identification and evaluation of responses and policy options for drought risk mitigation”. The ex-ante analysis of impacts will be reported in the corresponding D2.6 “Drought risk mitigation options – case study scale “.

The probability of occurrence of future drought events was not available for all Case Studies (see Technical Reports No 5 & 11), which is a required input for the quantification of potential socio-economic and environmental impacts using a risk-based approach.

2.3 Future vulnerability assessment

Vulnerability is a complex concept as indicated by the wide range of definitions (Table 2. 6) available in the literature and the corresponding methods and tools for its systematic assessment. The concept of vulnerability has evolved towards incorporating different dimensions (e.g. susceptibility, exposure, coping capacity and adaptive capacity) and categories (e.g. social, economic, environmental vulnerability), as illustrated in Figure 2. 6 (Birkmann, 2007). As a result a series of vulnerability indices have been developed, addressing either sectoral (economic), social or integrated vulnerability of regions (Kaly et.al, 2004; DMCSEE, 2012):

1. The Composite Human Vulnerability Index (Indian Institute of Technology in Bombay);
2. The Key Indicators for Global Vulnerability Mapping (United Nations Environment Programme);
3. The Coral Reef “Vulnerability Index” of Exposure to Climate Change (Greenpeace);
4. The Environmental Vulnerability Index (South Pacific Geoscience Commission, SOPAC);
5. The Climate Vulnerability Index (Sullivan and Meigh, 2005; Sullivan and Huntingford, 2009);
6. The NatureServe Climate Change Vulnerability Index (NatureServe[2] organisation);
7. The Social Vulnerability Index to environmental hazards (Hazards & Vulnerability Research Institute[3]);
8. The Livelihood Vulnerability Index (Hahn et al., 2009).

[1] Justification of deviation from Task 2.5 description: Quantification of potential socio-economic and environmental impacts, using the approach previously developed under Task 2.2. In this approach, droughts will be considered events with a given probability of occurrence and not as unpredicted. Sensitivity analyses will complement the analysis, in order to address the uncertainty of future predictions and external drivers.

[2] https://connect.natureserve.org/science/climate-change/ccvi

[3] http://webra.cas.sc.edu/hvri/products/sovi.aspx

Table 2. 6*: Definition of vulnerability as in various sources.*

Definition	Source
The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard	UN/ISDR (2009)
The degree to which a systems is susceptible to, and unable to cope with, injury damage or harm	EEA glossary
Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity	IPCC, 2007
Vulnerability is the magnitude of losses resulting from a potentially damaging phenomenon. It comprises exposure – the values and lives present at the respective location – and their lacking capability of resistance or defence to the threat. Vulnerability is an aggregate measure of human welfare that includes environmental, social and economic exposure to a range of harmful perturbations.	EC, 2007a
The degree to which human and environmental systems are likely to experience harm due to a perturbation or stress	Luers et al, 2003
The exposure to hazard by external activity (e.g. the climatic change) and coping capacity of the people to reduce the risk at a particular point of time	Laneweg and Guiterrez-Espeleta, 2001

Particularly for drought, vulnerability is linked to the associated impacts on people, economic sectors and the environment. Alcamo et al. (2008) use three concepts to define vulnerability of people to drought: (i) susceptibility, (ii) water stress, and (iii) drought-related societal ‘‘crises’’, whereas Iglesias et al. (2009) describe it by using four components: natural component, economic capacity, human and civic resources and agricultural innovation. Pandey et al. (2010) analyse vulnerability to drought on the basis of hydro-meteorological and physiographic factors. Other studies focus on environmental vulnerability to drought (e.g. Salvati et al., 2009), agriculture and food production (e.g. Simelton et al., 2009; Cheng and Tao, 2010; Antwi-Agyei et al., 2012), gender issues (e.g. Segnestam, 2009), political issues (e.g. Taenzler et al., 2008), or analyse vulnerability from a psychological perspective (e.g. Kromker et al., 2008).

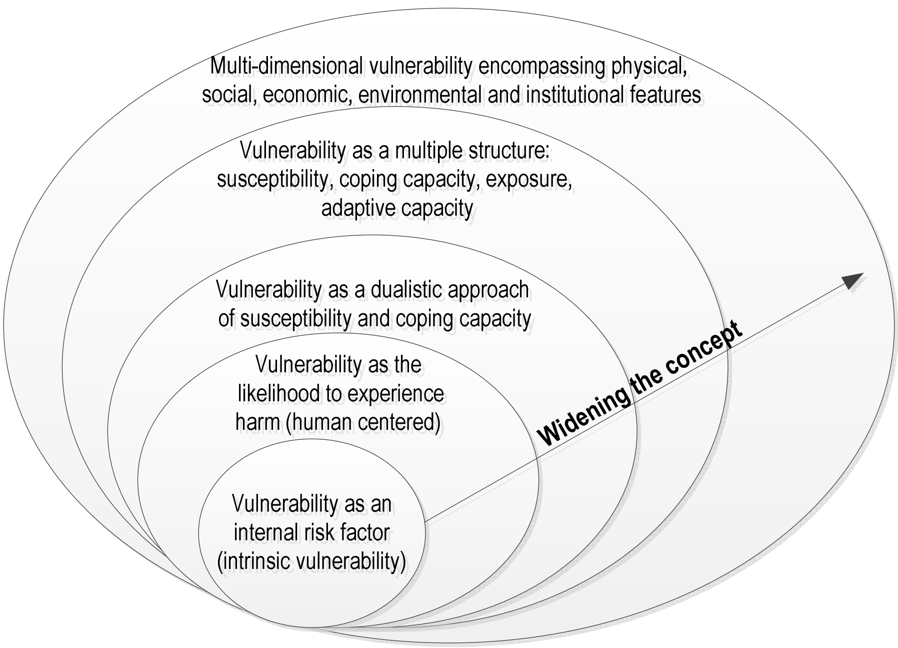


Figure 2. 6: *The spheres of vulnerability (Birkmann, 2005; Birkmann, 2007).*

Vulnerability profiles are recognized by the UN/ISDR (2004) as a cornerstone of drought risk reduction planning, as they help to identify and assess vulnerability factors and options for their mitigation. Examples of how a vulnerability profile can be developed can be found in Polsky et al., 2007; Adepetu and Berthe, 2007; Swain and Swain, 2011; Collins and Bolin, 2007. Employed methods include the definition of indicators for the different aspects of vulnerability (mainly exposure to the natural hazard, sensitivity of different sectors/population segments to the hazard, capacity to cope with the drought event) and their weighting to derive a composite Vulnerability Index (VI). Wilhelmi and Wilhite (2002) analyse vulnerability to agricultural drought and indicate that further research is needed about the indicators to use and their weighting schemes in vulnerability assessments. The same conclusion was drawn in the 2012 ETC/ICM technical report on "Vulnerability to Water Scarcity and Drought in Europe", in an effort to identify the drivers of vulnerability in Europe (Kossida et al., 2012). This report reviews approaches proposed in different research projects for analysing vulnerability (Table 2. 7) and concludes that "*the quantification is still challenging since data present limitations, relevant indicators that can represent or proxy the various components are still not clearly defined, while the degree of influence among them (magnitude of their importance) is still to be determined*". Annex B provides an indicative list of the indicators used in the pertinent literature for describing and assessing vulnerability.

Table 2. 7*: Methodological approaches in defining vulnerability to water scarcity & drought (Kossida et al., 2012).*

Research project	Approach
FP6 NeWater project	Baseline Rapid Vulnerability Assessment (BRAVA): Vulnerability profile described as: • Threats and stresses (surface and groundwater pollution, aquifer depletion, salinization, environmental degradation, economic uncertainty, agricultural desiccation, potential industrial accidents, etc.) • Exposure units/vulnerable groups (private farms, collective farms, private households, private fishermen, government agencies, tourist industry, power plants, recreation, navigation, wetland ecosystems etc.) • Rated sensitivity (combination of the above two steps) • Attributes of vulnerability (water usage, access, infrastructure, technology, political willingness, institutions, income etc.)
FP7 CLICO project	Vulnerability Index (VI), primarily dependent on three parameters (exposure, sensitivity and adaptive capacity) described by a series of indicators: • Exposure: Drought • Sensitivity: Water resources (precipitation, groundwater); Land resources (slope, soil) • Adaptive capacity: Human Capital (educational distribution, age distribution); Social Capital (population size, service institution); Financial Capital (agricultural employment, community workforce, unemployment); Physical Capital (agricultural area, holding size, irrigated area, government irrigation scheme, livestock, crop diversification, livestock diversification)
DMCSEE TCP project	Vulnerability assessment for the agricultural sector on the basis of two sets of indicators: • Physical factors (precipitation, solar illumination-radiation, soil water-holding capacity and slope) • Socio-economic factors (land use, irrigation)

Vulnerability is a major component of risk analysis (risk is typically defined as a function of hazard and vulnerability) and therefore vulnerability assessments are crucial parts of risk assessment. A number of studies exist on drought-related risks for water supply systems, following the general approach of Figure 2. 7. Jinno (1995), for example, uses a drought risk index to support the management of a water supply system under drought conditions. Tsakiris (2009) follows a similar approach and proposes a framework for the quantification of drought-related risks (Eq. 1).

$$R(D) = \int^{\infty} x.V(x).f_D(x)dx \qquad \text{(Eq. 1)}$$

Where:

R(D): Drought risk

x: Potential impact due to a drought event of a given magnitude D

V(x): The vulnerability of the system towards the corresponding magnitude of drought

$f_D(x)$: The probability density function

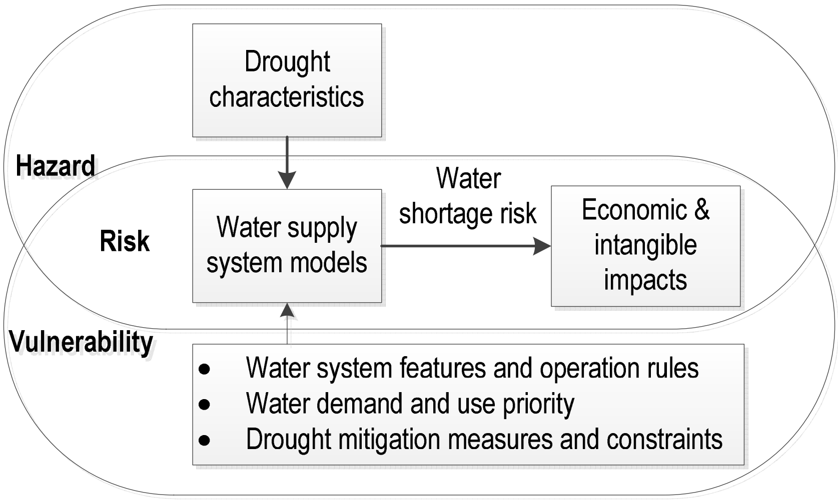


Figure 2. 7: *Assessment of water-shortage risk due to drought in a water supply system (adapted from Rossi and Cancelliere, 2013).*

Vulnerability assessment in DROUGHT-R&SPI is based on the approach proposed by Fontaine and Steinnemann (2009), where the vulnerability of each Case Study (either water system or specific sector) to a drought event of specific characteristics (severity, duration, spatial extent) is expressed as a function of exposure (E), sensitivity (S) and adaptive capacity (A), taking into account the future state of the vulnerability factors for the socio-economic scenarios examined.

Where possible, the analysis focuses on these three dimensions of vulnerability, by assigning "scores" (Table 2. 8) to each component of vulnerability for the sectors and/or regions analysed in each Case Study. The overall process is illustrated in Figure 2. 8. Table 2. 9 lists the components and variables that comprise the Vulnerability Index. The vulnerability dimensions (exposure, sensitivity and adaptive capapcity) and components (aggregared categories for the factors that frame vulnerability to dtrought)) are the same among Case Studies; however different variables are used, in order to account for the differences and special characteristics of each Case Study.

The vulnerability index (VI) is calculated as the weighted mean of the variables (Eq. 2), with values ranging from 1 to 5 (1 =very low vulnerability, 2=low, 3=medium, 4=high, 5=extreme vulnerability).

$$VI = \frac{\sum_1^n (w_i . s_i) + \sum_1^h (w_j . s_j)}{\sum_1^m (w_k . s_k)} \qquad \text{(Eq. 2)}$$

Where:

$w_{i,j,k}$: The weight of each variable

$s_{i,j,k}$: The score of each variable

n: The number of variables related to Exposure

h: The number of variables related to Sensitivity

m: The number of variables related to Adaptive Capacity

i: Index for Exposure

j: Index for Sensitivity

m: Index for Adaptive Capacity

Table 2. 8*: Scoring system in the Vulnerability Index.*

Dimension	1	2	3	4	5
Exposure	Very low	Low	Moderate	High	Extreme
Sensitivity	Very low	Low	Moderate	High	Extreme
Adaptive capacity	Very low	Low	Moderate	High	Extreme

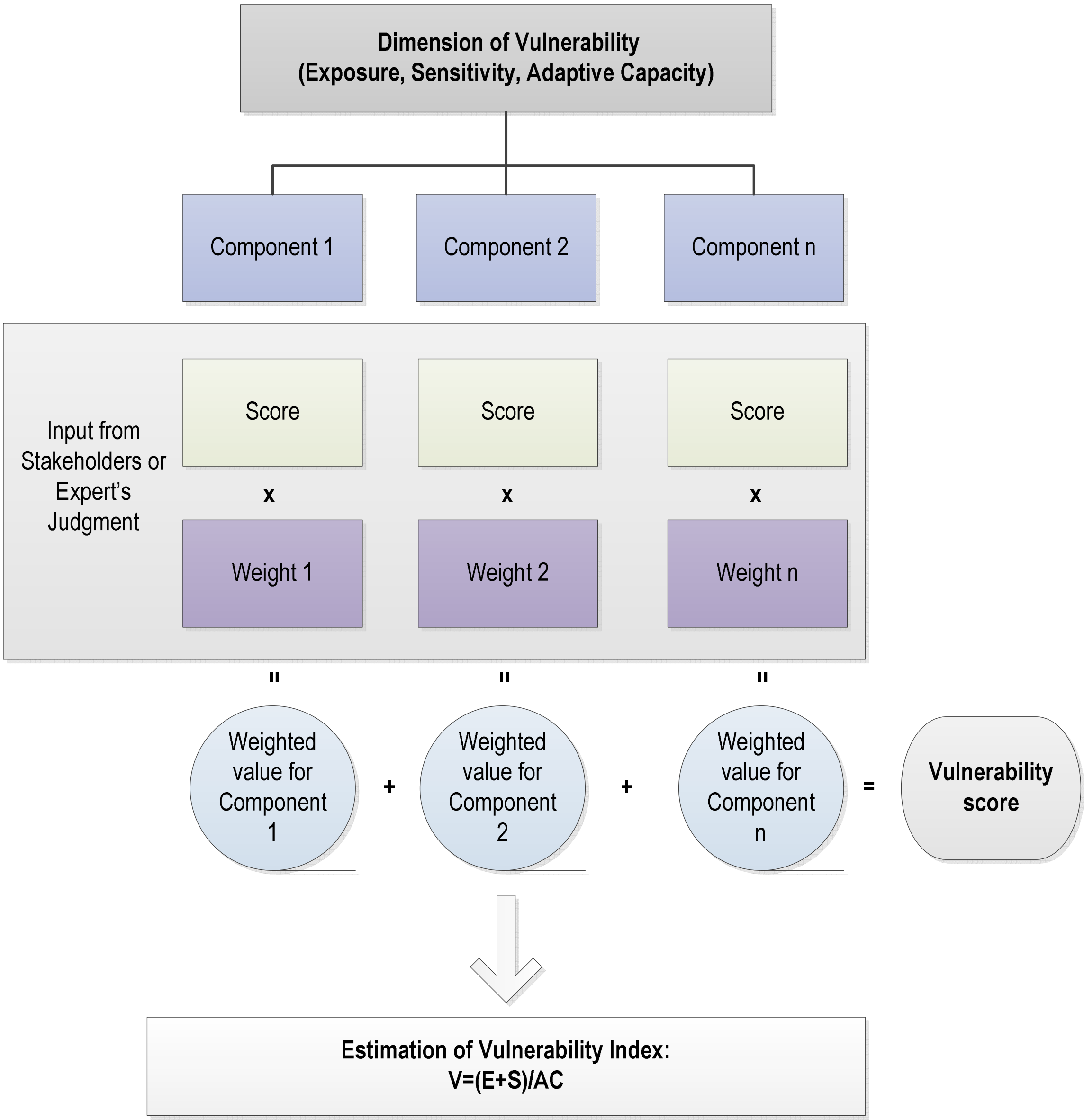


Figure 2. 8: *Drought vulnerability assessment (adapted from the Colorado Drought Mitigation and Response Plan, 2013).*

Table 2. 9*: Matrix for the Vulnerability Index.*

Dimension	Component	Variable
Exposure (E)	Drought Hazard	Number of drought event
		Drought duration
		Drought intensity
	Water scarcity	Water Exploitation Index
Sensitivity (S)	Water sources	Groundwater level,
		Status of surface water storages,
		Transboundary (or regional) index
	Environment	Water quality
		Sensitivity of wetlands/water-dependent protected areas
	Urban sector	Population density
		Demand coverage
	Agriculture	Demand coverage
		% irrigated land
		Share of agricultural GDP
		% small-scale farming operations
		Crop pattern/ diversity
	Energy production	Share of hydropower to total energy production
	Other (Case Study-specific)	
Adaptive Capacity (A)	Social	Access to information
		Willingness to change
		Conflicts
	Policy	Existence of drought management policies
		Actors & institutions (jurisdictions, availability to resources)
	Technology/ economic	Access to (water saving) technology
		Access to alternative water sources
		Infrastructure

The flowchart for the Vulnerability Assessment is given in Figure 2. 9 and includes the following:

1. Review of available information about future vulnerability to drought in the Case Study areas;
2. If possible, the estimation of the Vulnerabiltiy index:
    a. Selection of the components and variables to be included in the Vulnerability Index, taking into account the special characteristics and priorities in each Case Study.
    b. Relative weighting of the components, which expresses the importance of the component in the overall system (e.g. importance of agriculture in the local economy). Weights can be assignes either by using expert judgment or by statistical methods such as the Analytical Hierarchy Process (Saaty, 1980).
    c. Assignment of scores in each variable in the range of 1 to 5. In the case of exposure and sensitivity, the score reflects the magnitude of the anticipated impacts, whereas in the case of adaptive capacity, the score reflects the potential contribution of a system element or option in alleviating the impact. Scoring can be performed by stakeholders or be based on expert judgment (i.e. selected key stakeholders or the Case Study Leaders).
    d. The Vulnerability Index is then estimated using Eq. 2.

3. Framing of the vulnerability profile in each Case Study.

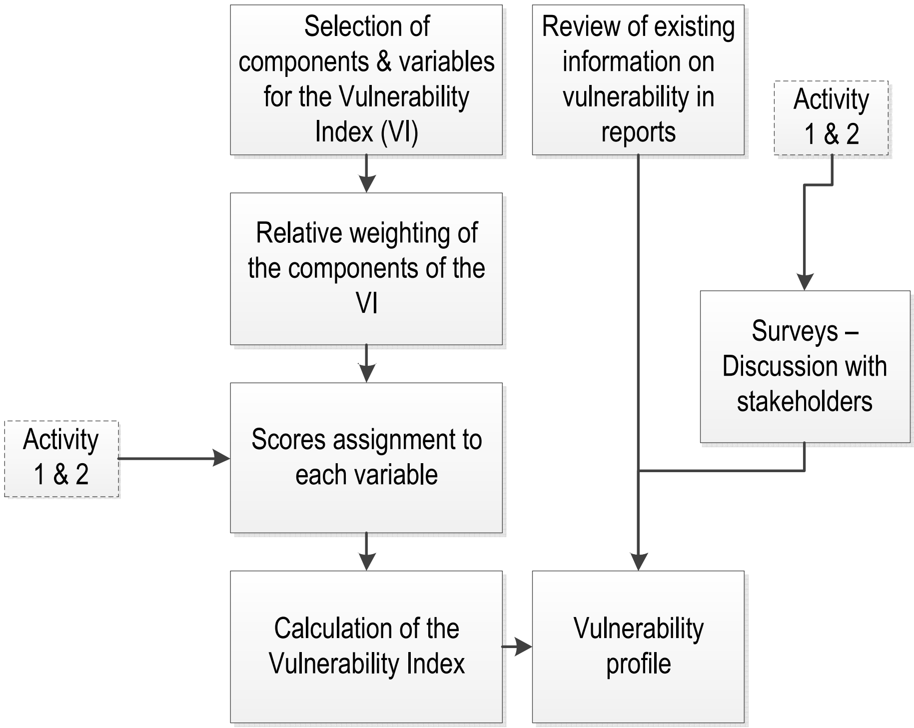


Figure 2. 9: *Flowchart of the steps followed in Activity 3.*

3 Scenario development in the Case Studies

3.1 Syros island, Greece

Scenarios for Syros Island describe assumptions for the external factors that can influence future vulnerability to drought, in order to eventually select those options that can mitigate drought impacts and at the same time support/enhance local development priorities and objectives. The storylines developed for Syros have been based on:

1. Mid-term scenarios (2020 timeframe) for Syros, formulated within the context of the water management study undertaken by the Ministry of Development (2001-2008);
2. Views expressed by local stakeholders, according to the discussions held in the first CSDF Workshop (17 July 2012) or through the personal interviews taken within Task 2.3 activities (Technical Report No 4);
3. Existing socio-economic features of the island and local development opportunities (information in existing reports);
4. Scenarios already formulated within the framework of another FP7 research project (Box 2).

Box 2. Discussing scenarios for Syros Island with stakeholders

Scenarios for the future have been discussed with members of the Case Study Forum during the stakeholder workshop on “Water-related security threats, climate change and adaptation options for Syros Island, Greece”, held on 17-18 June 2011 as part of the FP7 WASSERMed “Water Availability and Security in Southern Europe and the Mediterranean” project (contract number 244255).

The factors that shape vulnerability to drought in Syros island are related to water scarcity and existing water management and economic development patterns. The future state of these factors was discussed in the Workshop, resulting in the formulation and quantification of different scenarios.

Relevant (available to the public) documents: D 5.1.2 “Water demand scenarios for the case studies”; D6.3.3 “Proceedings of the Final WASSERMed workshop” at: http://www.wassermed.eu/

Currently, the socio-economic development of Syros is mostly dependent on the tertiary sector, while the primary sector is shrinking despite the private investments (e.g. greenhouses) made on the island. As agriculture and tourism are competing sectors -particularly in terms of land and water use - a main parameter for the scenarios is the future state of the local economy. The state of the environment, which is a comparative advantage of the island, is considered equally important. Environmental protection demands for a development strategy that will take into account the carrying capacity of the island and special/local features of economic sectors. The above are related to the availability of financial resources for investing in infrastructure, supporting development priorities and introducing new technologies in the water sector. Particularly with regard to water resources management, an additional aspect concerns the paradigm for managing local water resources. At present, water demand is mainly covered by desalination units, whereas private boreholes are used for irrigation purposes. A centralized water management approach is followed, in terms of water supply and sewerage, inhibiting the application of decentralized and potentially more efficient options, such as localized reuse schemes or privately-owned desalination plants for large hotels or holiday home developments.

Considering the above and the factors that shape current vulnerability to drought, scenarios for the Syros Case Study are given in Figure 3. 1 and summarised in Table 3. 1:

- Scenario 1 describes a future where measures are taken to support agriculture and cattle breeding in the island through appropriate policies, incentives, and infrastructure financing that among other will result in reduced demand for irrigation. In addition, as part of a Drought

Management Plan: (i) groundwater abstractions will be reduced in order to develop strategic reserves, (ii) the use of cisterns for rainwater harvesting will be increased in the domestic sector that will further reduce groundwater use, and (iii) more drought-resilient crops will be cultivated. Water demand for the domestic sector will increase due to population growth and tourism, which will be covered by increasing the capacity of desalination plants, promoting the installation of private ones in tourism facilities, and increasing the volume stored in cisterns.

- Scenario 2 focuses on a balanced economic development pattern (i.e. tourism and agriculture) without significant changes in the current water and drought management framework. The lack of investments for alternative water supply, particularly in agriculture, is expected to exacerbate the overexploitation of groundwater bodies. With regard to water management, emphasis is placed on centralized water supply enhancement and infrastructure development, through controlled desalination capacity expansion to meet increasing water needs. Decentralized options are not supported, thus minimizing the potential for exploiting alternative water resources.
- Scenario 3 describes a future where no measures are taken to maintain the primary sector as an important economic activity in the island (farming is simply applied to meet local needs, e.g. fodder). In addition a crisis-based approach is followed in drought management. With regard to water management, emphasis is placed on centralized water supply enhancement and infrastructure development: (i) limited desalination capacity expansion to meet increasing water needs, (ii) no measures are taken to promote the use of cisterns, (iii) limited incentives are given for the use of alternative water supply sources.
- Scenario 4 describes a situation where tourism is the single source of income for the island and agriculture is abandoned, due to the lack of resources and increased competition over land use. Drought management is promoted, as part of a (integrated) regional water management plan which promotes demand management, traditional and alternative water sources and the protection of groundwater bodies.

Figure 3. 1: *Scenario storylines for Syros Island.*

Table 3. 1: *Summary of storylines for Syros island.*

Underlying causes of vulnerability	Best case scenario	Worst case scenario
Intensive use of groundwater sources	Protection of groundwater bodies through the development of alternative water supply sources	Over-exploitation of groundwater to meet irrigation demand
Limited use of alternative water sources	Decentralised wastewater management & implementation of local solutions	Centralised wastewater management
Limited/ no use of insurance/ compensation schemes	Use of insurance schemes	No use of insurance schemes
Competition over groundwater sources	Desalination capacity expansion to meet increasing urban water demands Increase of water stored in cisterns	No further investments in desalination plants Abandonment of traditional practices to store water
Competing land uses (namely with tourism sector)	Controlled tourism development	Expansion of tourism infrastructure

The consistency of the scenarios was tested using the Cross Impact Balance method (Weimer-Jehle, 2005, Schweizer & Kriegler, 2012). The method includes the following steps:

1. Identification of Descriptors and Variants that define future vulnerability to drought in Syros island. Descriptors are defined as the key driving forces concerning vulnerability, while variants describe the possible states of each descriptor (Table 3. 2).
2. Assignment of a “score on influence” in the range +3 to -3 for each pair of future states of the descriptors (cross-impact analysis) in terms either of promoting (positive values) or restricting (negative values) influence. Scores were based on expert judgment and are given in Annex D.
3. Assessment of the consistency of scenarios. The consistent scenarios for Syros are given in Table 3. 3.

Figure 3. 2 shows the importance of each of the identified descriptors in the formulation of the scenarios: livestock production, domestic water use, water management and water use for irrigation are buffering variables; tourism development and groundwater use are considered as very important descriptors; traditional economic activities and DMP are influential variables with dependent variable water resources (governance). The plausible and consistent scenarios, according to consistency test, are given in Table 3. 3.

Table 3. 2: *Identification of scenario's descriptors and variants for the Syros Case Study.*

Descriptors	Variants
A. Traditional economic activities	A.1 Preservation (no change in the total cultivated area) A.2 Abandonment (30% decrease of cultivated area)
B. Livestock production	B.1 No change B.2 Only cattle breeding
C. Groundwater use	C.1 Increase (>100% abstraction) C.2 Decrease (<80% abstraction)
D. Domestic water use	D.1 Increase D.2 Stable D.3 Decrease
E. Water use for irrigation	E.1 Increase E.2 Stable E.3 Decrease
F. Tourism Development	F.1 Control (tourism growth 2%) F.2 Expansion (tourism growth 5.9%)
G. Drought Management Plan	G.1 Yes G.2 No
H. Water resources (Governance mechanism)	H.1 Centralised water management H.2 Decentralised water management
I. Water resources (Management)	I.1 Water supply enhancement (increase of desalination capacity to meet water demand) I.2 Water demand management (increase of no. cisterns)

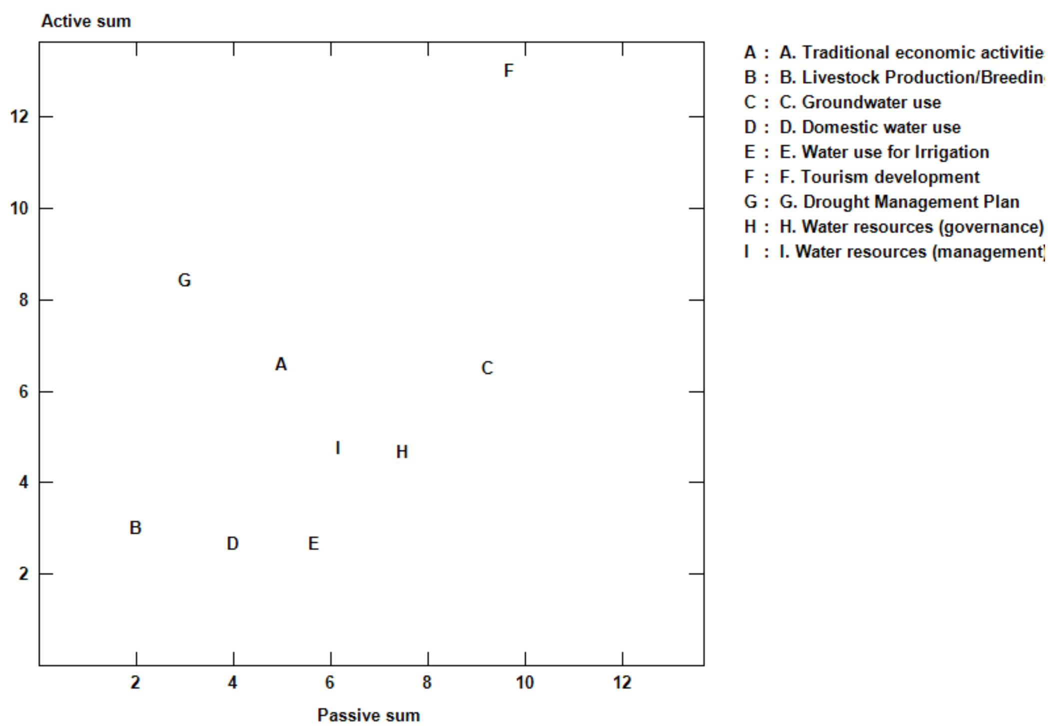


Figure 3. 2: *Graphical representation of impact scores.*

Table 3. 3: *The consistent Scenarios for the Syros Case Study.*

Scenario No 1 (best)	Scenario No 2 (worst)	Scenario No 3	Scenario No 4
Preservation(stable cultivation area)	Abandonment (30% decrease of cultivated area)	Preservation(stable cultivation area)	Abandonment (30% decrease of cultivated area)
No change in livestock production	Only cattle breeding	No change in livestock production	Only cattle breeding
Decrease (<80% groundwater use - protection)	Increase (>100% groundwater use- overexploitation)	Decrease (<80% groundwater use - protection)	Decrease (<80% groundwater use - protection)
Decrease in domestic water use	Increase in domestic water use	Stable domestic water use	Stable domestic water use
Stable water use for irrigation	Stable water use for irrigation	Stable water use for irrigation	Decrease in water use for irrigation
Control tourism development (2% tourism growth)	Expansion in tourism development (5.9% tourism growth)	Control in tourism development (2% tourism growth)	Control in tourism development (2% tourism growth)
Implementation of DMP	No implementation of DMP	Implementation of DMP	Implementation of DMP
Decentralized water management	Centralized water management	Decentralized water management	Decentralized water management
Water demand management (↑ of cisterns)	Water supply enhancement (↑ of desalination capacity to meet the rising demand)	Water supply enhancement (↑ of desalination capacity to meet the rising demand)	Water supply enhancement (↑ of desalination capacity to meet the rising demand)

The parameters selected to quantify the storylines for Syros Island are given in Table 3. 4. Indicative values for these parameters are assigned for the best and worst case scenario, taken into account: (i) the results from the consistency test, and (ii) stakeholders view of the future development of agriculture and tourism in the island.

Table 3. 4: *Parameters for the quantification of the storylines.*

Category	Parameter	Best case scenario	Impact on water demand	Worst case scenario	Impact on water demand
Population (permanent and seasonal)	Population growth (yearly)	0.8%	↑	0.8%	↑
	Tourism growth (yearly)	2% until 2020 & 1% for the rest of the period	↑	5.9%	↑
Land uses	Change in total cultivated land	No change	-	30% decrease	↓
Agriculture	Cropping pattern	20% decrease of the area of arable land and corresponding increase of the area of vegetables (greenhouse cultivations)	↓	30% decrease in the area of all crops	↓
Livestock breeding	Change in the number of cattle, sheep and goats, and pigs	No change	-	Only cattle breeding	↓

3.2 Jucar River Basin, Spain

The socio-economic scenarios utilized for assessing future drought impact and vulnerability in the Jucar River Basin Case Study come directly from the scenarios considered by the recently developed Hydrologic Plan of the Jucar River Basin District (DHJ). These scenarios are mainly the result of projections of the different water uses for three different horizons and were agreed among all stakeholders during the public information phase: the baseline scenario (2009); near future scenario (2015); and climate change scenario (2027). Additionally, four long-term climate change scenarios, periods 2040-2070 (1 scenario) and 2070-2100 (3 scenarios), were tested.

Different methodologies were used for modelling each of the different water uses of the basin that are summarized in the following sections.

3.2.1 Urban demand

Urban water demand is closely related to population. Thus, basic stating information to estimate urban demand for the three different scenarios is:

- Permanent and total equivalent population (including seasonal variability, particularly in the city of Valencia) of every municipality within the DHJ for the years 2009, 2015 and 2027. Estimated in all cases, except for 2009 that corresponds to the value obtained from official census.
- Data from urban consumption survey from a percentage of the municipalities from the DHJ. These include for the last years: data of supplied volume, registered volume, and volume for domestic use.

With this information it is possible to calculate total values of supplied volume, registered volume and domestic volume in the municipalities with data and to estimate them for the municipalities without it. Finally, from the results of analyzing the surveys and supply data, and the total equivalent population to municipal level, it is possible to obtain the total urban demand. The whole process is summarized in Figure 3. 3. A deeper explanation can be found in CHJ (2010a).

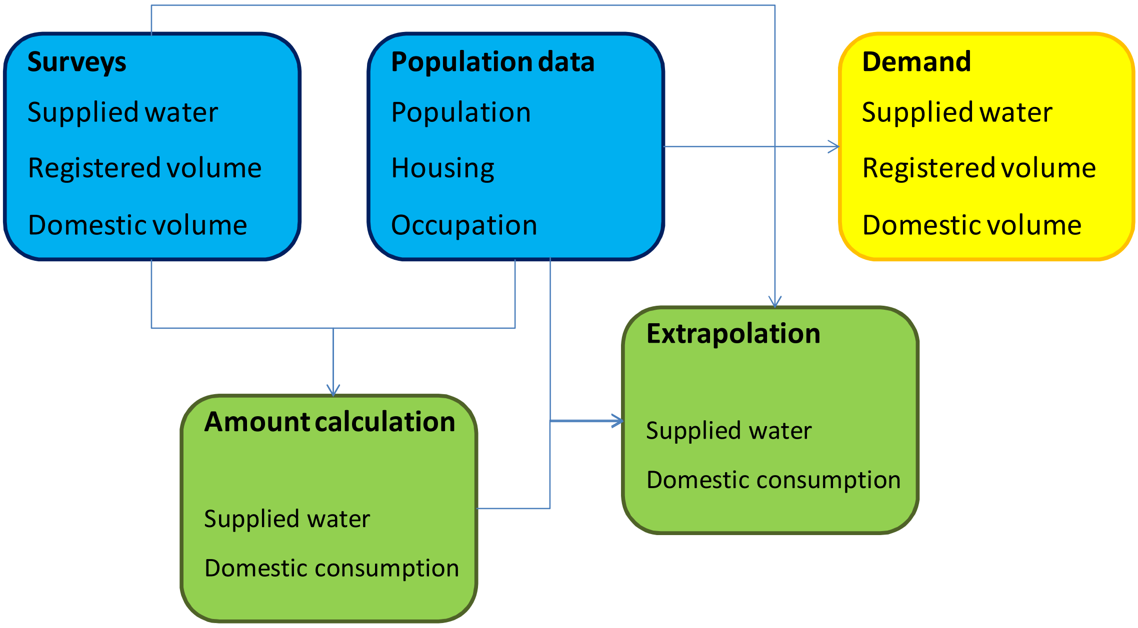


Figure 3. 3: *Scheme for the urban demand calculation (adapted to English from CHJ 2013).*

For the current situation scenario the data from the newest surveys and most updated population census were used. For municipalities without surveys data the demand was estimated using average values from municipalities with similar populations. For the near future situation, no changes in the water amounts are expected only total equivalent population. Finally, for the climate change scenario, amounts are estimated per Urban Demand Unit (UDU) instead of per municipality.

3.2.2 Agrarian Demand

Irrigation demand depends mainly on three factors: irrigated area, crop pattern and irrigation techniques. Therefore, the estimation of this demand must be done considering the evolution of these three in time.

The DHJ currently has an irrigated surface of more than 370,000 has, principally in the Castellón Plain, Eastern Mancha, "la Ribera" and lower basin of the Jucar River and the Vinalopo and Monegre Rivers valleys.

For the estimation of the irrigated area in the current situation scenario, the surface irrigated in the period 2001/05 was taken into account due to the more recent period would have meant introducing the effect of the last important drought episode, underestimating the real irrigated surface. The initial surface data was obtained from different sources: the Agrarian Census from the National Statistics Institute (1999) and the Agroalimentary Statistics Yearbook from the Ministry of Agriculture and Rural and Marine Environments (1999/05). Additionally, in the case of the main irrigated areas of the DHJ, complementary information was used either from field surveys or remote sensing. The methodology for the estimation of these surfaces can be found in CHJ (2009 and 2010b) and in Rivera Urban (2011). Figure 3. 4 shows the irrigated areas, differentiated by the estimation method.

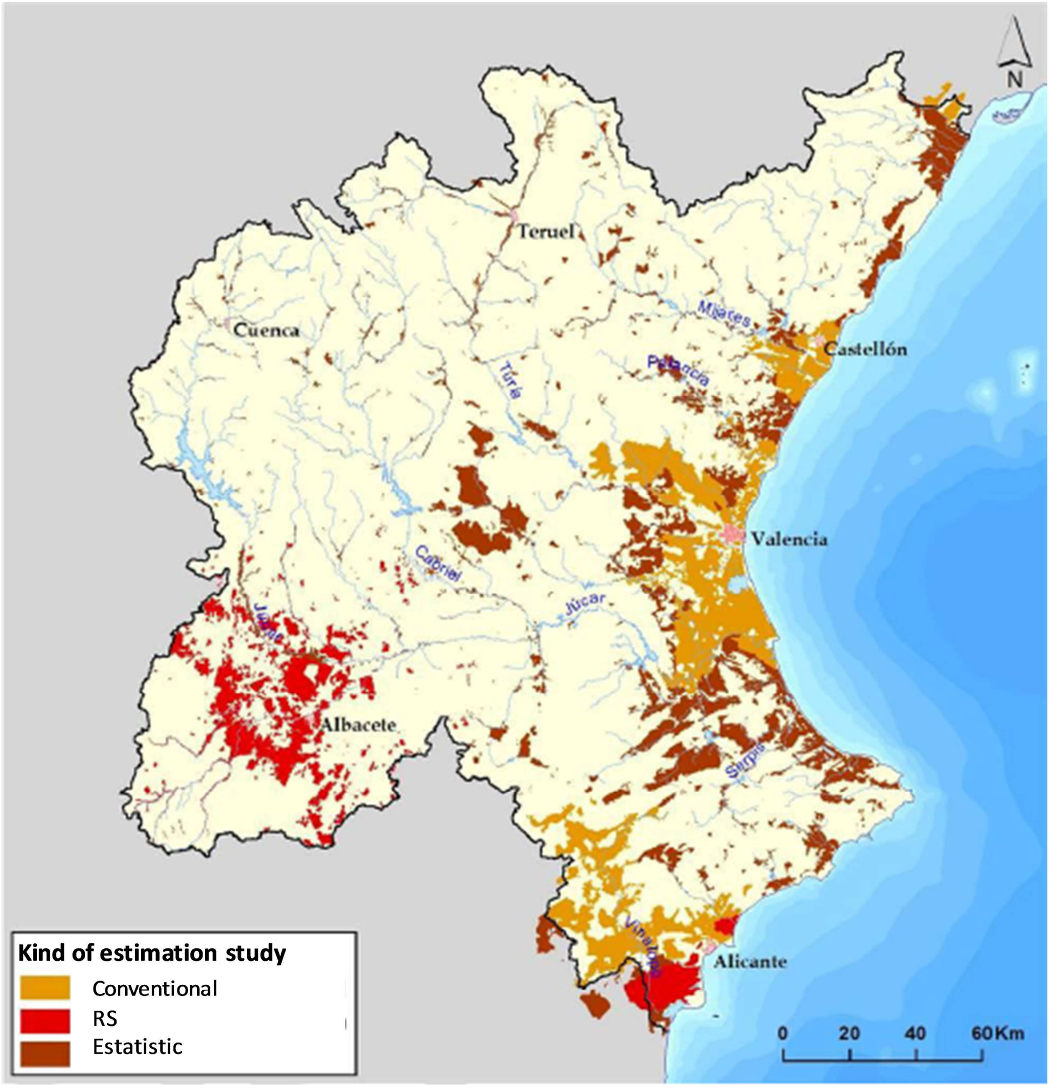


Figure 3. 4: *Irrigation areas in the DHJ (source: CHJ 2013).*

Crops distribution has adapted to the climate and geographic condition of each agricultural region. Herbaceous crops are predominant in the higher regions of the DHJ (Mancha Oriental) and in the Albufera Natural Park (intensive rive cultivation), while woody crops concentrate mostly in coastal areas, having each region a different main crop. Figure 3. 5 shows the evolution of the percentage coverage of the different crops in the DHJ from 2000 to 2009. It is possible to observe a change with an increase of cereals, vegetables and wine grape in front of a decrease of wheat and sorghum. Citrus, the main crop in the DHJ are experiencing a slow retreat from 2001. The change of the crops towards less water consumptive ones has an important influence in the estimation of the demand. Figure 3. 6 shows the adopted crop pattern with respect to the irrigated area.

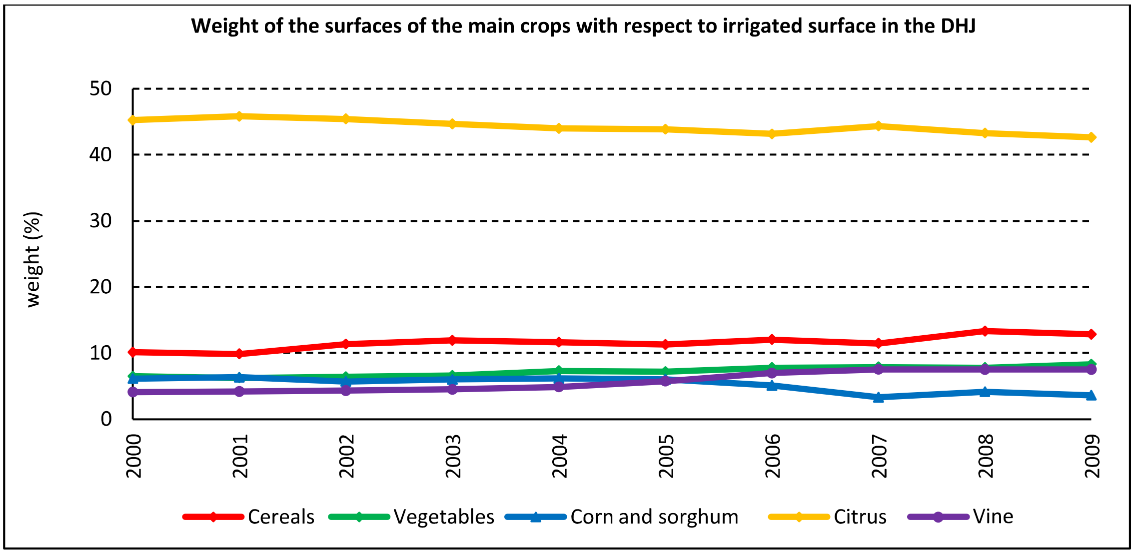


Figure 3. 5: *Weight of the surfaces of the main crops with respect to irrigated surface in the DHJ (source: CHJ 2013).*

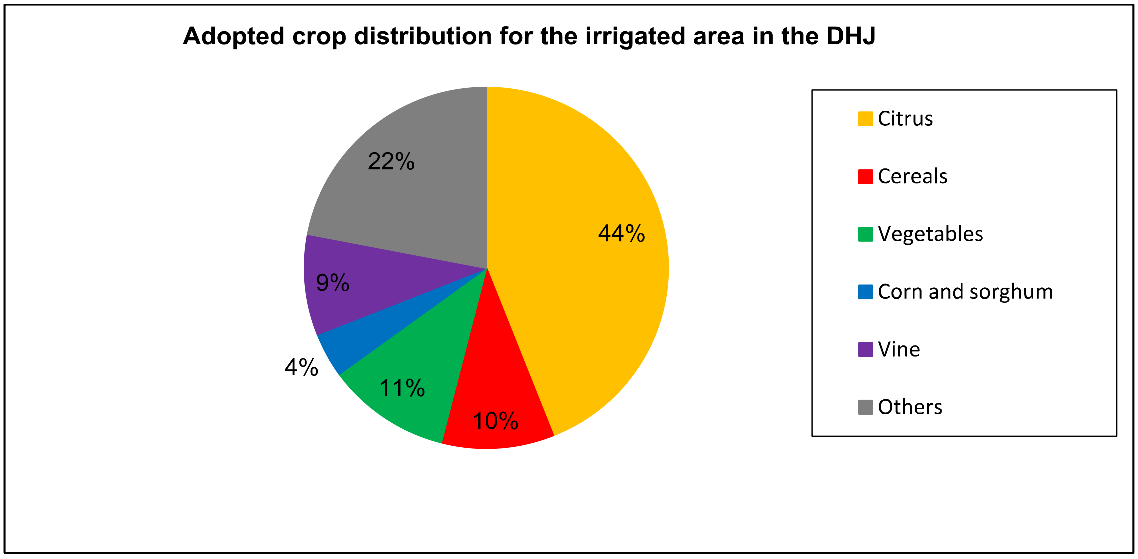


Figure 3. 6: *Adopted crop distribution for the irrigated area in the DHJ (source: CHJ 2013).*

The estimate of the irrigated area for future scenarios is subject to multiple constraints (expected benefits, development pressure on the major irrigation areas, availability and cost of resources, agricultural policies, etc.). According to the evolution of the factors in recent years, the trend appears to be downward. However, according to consulted experts in agrarian economy and sociology, on the basis of long-term economic analyses, seems that agricultural land is a secure value from the economic point of view. This, together with other future sociological and technological variables, suggests a long-term scenario in which agricultural activity is maintained at a very similar level as the current with regards to the irrigation surface is concerned.

Based on the above reasoning it has been considered to assume irrigated in 2015 and 2027 equal to 2009 surface, thus equal to 2005 (in addition to being the most conservative measure since the trend in recent years is the loss of surface). Regarding the crops distribution of each irrigation zone, in the absence of further information and the subsequent analysis, we conservatively consider also identical to the distribution of crops in 2009.

Finally, there is a significant decline of traditional agriculture and the modernization of farms with a more commercial nature includes significant efficiency improvements such as the optimization of operations, improved irrigation techniques and improved water distribution systems (less loses). For future scenarios, the combination of these trends will represent a decrease in the total demand for irrigation.

Therefore, the methodology for obtaining the irrigation demand for the three considered scenarios can be summarized in Figure 3. 7.

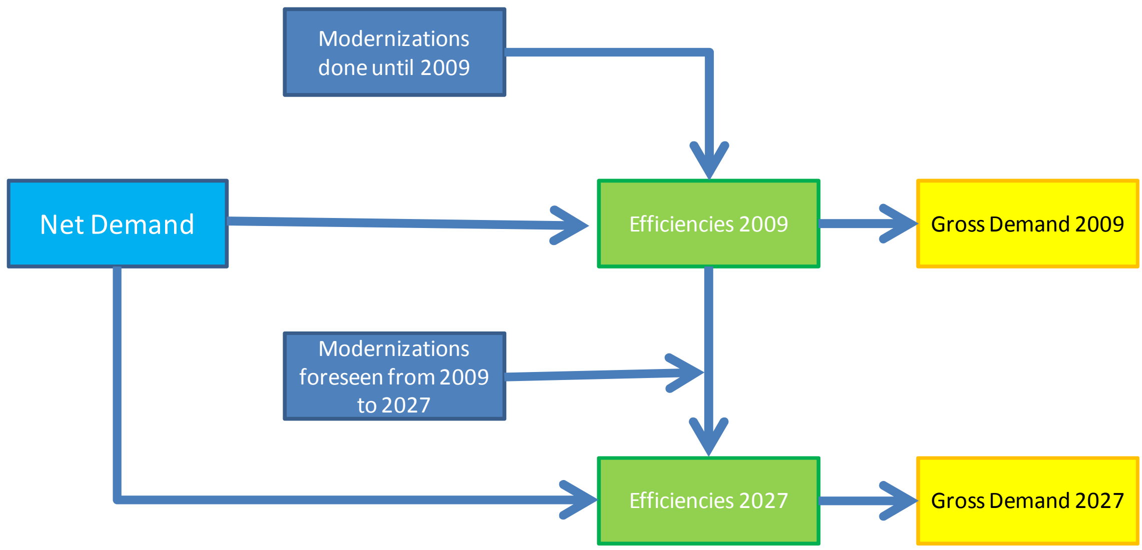


Figure 3. 7: *Irrigation demand estimation methodology.*

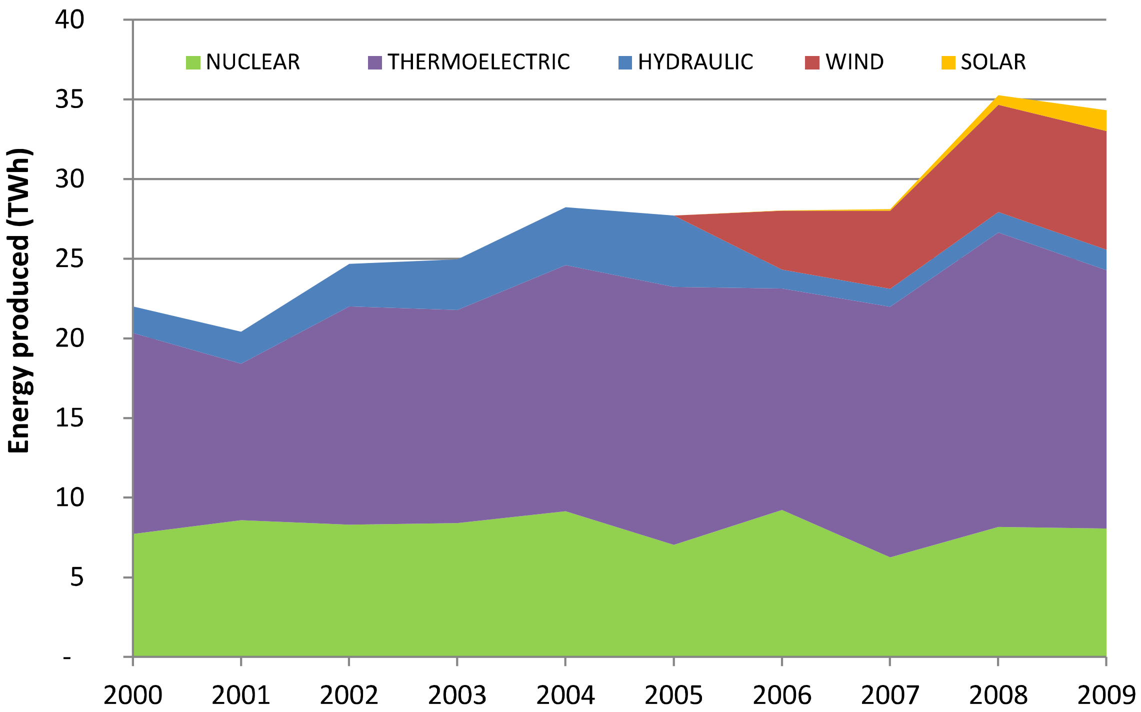
The net demand can be estimated from the irrigated surface and the crops distribution. Since these two factors are considered to keep constant, the net demand for all the scenarios will be the same. Next, the final gross demand is obtained dividing the net demand by the estimated future efficiency for each Irrigation Demand Unit (IDU). The estimated efficiency improvement for each IDU can be found in the annex 10 of the DHJ plan (DHJ, 2013). Under a conservative basis, the gross demand is considered to be the same in the baseline scenario and the near future scenario.

With regard to livestock demand, it is considered that, as in the case of agricultural demands, both the number of cattle and the distribution among species in the future horizons is considered constant and equal to the current situation (2009) given the uncertainties in the development of the livestock sector that advise keeping, as more conservative assumptions, the current scenario as future scenario.

Finally, for the long term climate change scenarios, new crops water demands were calculated given the expected changes in temperature and potential evapotranspiration of GCMs. The methodology to calculate the new water requirements follows the recommendations of Allen et al. (2006) and Steduto et al. (2012) considering that the irrigated surface will not change significantly.

3.2.3 Industrial demand

The most representative industrial demand in the Jucar River Basin, and in the DHJ, is electricity production in the form of hydroelectric generation and cooling in thermal, nuclear, thermo-solar and biomass plants. Figure 3. 8 shows the evolution of electricity production in the DHJ in the last years.



Note: Until 2005 hydraulic, solar and wind generated energy are represented together

Figure 3. 8: *Evolution of energy production in the DHJ (source: CHJ 2013).*

Production in 2009 was mostly of thermal origin (47.3%) followed by nuclear (23.5%) and wind (21.8%). Hydropower accounts for 3.7% and solar power, in continuous growth, for 3.7%.

In general, we must highlight the currently irreplaceable role of energy from hydroelectric sources with regulation, as demand coverage of the electrical system. Indeed, this type of energy, capable as any other of starts, stops and rapid changes in the load supplied to the system is the only one that can ensure the fine tracking of the demand curve and prompt attention to sudden changes in energy delivered either by possible failures of large thermal groups, localized problems in the network or, recently, by the significant increase in unmanaged (wind and solar) renewable energy that necessarily requires new hydropower capacity to deal quickly and effectively with the inevitable zeros, or excess production.

Hydroelectric production is concentrated mainly in the course of the Jucar River, deriving a maximum flow of 1,273 m^3 / s. The main production units correspond to hydroelectric Cortes-La Muela (three units of 209 MW), Cortes II (two units of 140 MW) and Cofrentes (3 units of 41.4 MW). The Júcar system has 91% of the total installed hydro capacity in the DHJ, and it is the operating system where more energy is generated. The maximum turbinated volume in the Jucar River was in 1999, with 5.118 million cubic meters. It has been estimated that the potential for hydropower generation in the DHJ would be 2,521 GWh/year (MMA, 2004). In 2013, a new central became operative in Cortes de Pallas with a nominal power of 850 MW. It is also foreseen the future installation of two centrals: Rio de Tous (two sets of 4.7 MW and 17.6 MW) and Tous Canal (12.6 MW). The start of their construction was expected in 2013.

Production of hydroelectricity is determined by the variability of river inputs rather than generation infrastructures. According to the latest projections made so far in Spain (MARM, 2011), future trends in surface runoff from the rivers of the DHJ show a decrease over the period 1961-1990, whose magnitude varies depending on the emission scenarios and regional climate models used as seen in van Lanen et al. (2013).

The water demand for hydroelectricity production was quantified like the turbinated water necessary for the power production each year. The turbinated water data were provided by the operating companies or estimated as the volume of water necessary to produce a kWh of electricity.

Additionally, the only nuclear plant in the CHJ is located in Cofrentes, next to the Jucar River course. Its power production can be considerate constant in time and thus its needs of water for refrigeration. The water demand related to the nuclear plant is not likely to change in the future.

Other industrial uses include manufacturing activities, excluding mining, energy and construction related activities. The water demand associated to this uses is estimated in a very similar way to urban demand, especially since many industries are directly connected to municipal networks. Industrial demand forecasts point to an average annual growth of 1.6% by 2015.

3.2.4 Recreational demand

Within the recreational uses we have to differentiate between those applications involving diverting water from the natural environment and those who use the water directly in reservoirs, rivers and natural areas. According to this typology, recreational demand can be divided into consumptive and non-consumptive.

Among the consumptive uses, the most significant are: artificial snow generation and irrigation of golf courses. The total demand associated to these uses is pretty low compared to the rest of uses and it is estimated with regard to the development of new recreational facilities.

On the other hand, the most of non-consumptive recreational activities are performed within the Public Water Domain, which has a direct effect on the economies of rural areas that support them and involve direct and immediate perception by the user of the existing problems, directly involving the public, through their leisure time, in their conservation. Common recreational uses are bathing, recreational fishing, canoeing, rowing, sailing, adventure sports, walking along the river banks, bird watching in a lagoon, visiting natural areas linked to water, etc. It is this second group what presents major problems for its satisfaction, mainly because being conditioned, rather than for the assignment of very low resources, by the need of good conservation of water bodies and their environment.

The estimation of the different amounts for recreational demand is done base on the current values supplied to the exiting activities and extending them according to the expected additional facilities or expansion of the existing ones. As said before, the most of the recreational uses do not require a large amount of resources but the quality of the water will normally be more restrictive. Drought situations will affect recreational uses for this second factor rather than because there is not enough water to supply.

3.2.5 Final scenarios

3.2.5.1 Demands

Table 3. 5 presents the water demands to be expected in the three scenarios considered in the scope of the Jucar River Basin Case Study, taking into account the considerations described in Sections 3.2.1 to 3.2.4.

Table 3. 5: *Summary of water demands (Hm^3) from the different water uses within the Jucar River Basin water resources system. Demands marked with * are considered in the simulation model included in irrigation, urban and environmental flows respectively, except for the refrigeration demand at the Cofrentes Nuclear Plant that is supposed not to change.*

Water Use	Baseline	Near future	Climate change (2027)	HadCM2 (2040-2070)	HadCM2 (2070-2100)	HadCM3 B2 (2070-2100)	HadCM3 A2 (2070-2100)
Urban	107.45	147.25	188	207	247	247	267
Irrigation	989.93	989.93	933.69	1034.17	1066.84	1236.57	1336.41
Stockbreeding*	5.80	5.80	5.80	-	-	-	-
Industrial*	33.60	40.40	48.50	-	-	-	-
Recreative*	1.90	3.10	5.50	-	-	-	-

3.2.5.2 Hydrology

Since hydrologic conditions are also very likely going to change, the expected demands must be considered in different hydrologic scenarios. These are defined in the Jucar River Basin District Plan (CHJ 2013) and summarized next:

- Scenario 0: represent the baseline situation in which water balance is done between the previous hydrologic time series and the consolidated demands with the current situation of infrastructures, and taking into account hydrologic and ecologic requirements set in the CHJ hydrologic plan. This analysis allows, on the one side, analyzing the current situation of the system and, on the other side, providing a baseline for comparison with the results of the next scenarios.
- Scenario 1: corresponds to the near future situation (2015) and has a double objective: a) allocating the available resources taking into account water rights, supplies and demands, and b) establish water reserves, either when there are surpluses after attending to current water rights and uses or when new resources are generated as a consequence of the application of the measures considered in the Hydrologic Plan. The balance between the available resources and the demands was done with the streamflow series from 1980-81 to 2008-09. Regarding the infrastructures, in the allocation hypothesis only the ones that are expected to be operative in 2015 were considered, while in the reserves hypothesis also the infrastructures that will be operative beyond 2015 can be taken into account.
- Scenario 2: corresponds to the medium-long future situation (2027), or climate change scenario, and it is analyzed using streamflow series that take into account the possible effects of climate change on the water resources of the basin. To this effect, a streamflow reduction of 12% was used. This reduction derives from the studies carried out by CEDEX regarding the effects of climate change on water resources (CEDEX-DGA 2011) and also reflected in Deliverable 2.4. Also renewable resources of groundwater bodies were reduced a 12% and environmental restrictions were maintained.

Additionally to the first three scenarios considered for the official planning of the Jucar River District, future climate scenarios obtained from GCMs were also used:

- Scenario 3: corresponds to the long future situation (2040-2070) with streamflow series obtained from HadCM2 model (Stott & Tett 1998), under the assumptions that greenhouse effect gases have an annual increase rate of 1% and considering sulphates.
- Scenario 4: corresponds to the very long future situation (2070-2100) using the same model than scenario 3.
- Scenario 5: corresponds to the very long future situation (2070-2100) with streamflow series obtained the regional model PROMES (Gallardo et al 2001) nested in the HadCM3 model (Pope et al 2000). The emissions scenario corresponds to SRES-B2.

- Scenario 6: like the previous one but changing the emissions scenario to SRES-A2.

The methodologies to obtain the streamflow values associated to these scenarios can be found in Hernandez-Barrios (2007), AEMET(2008) and CEDEX(2010), and were also summarized in van Lanen et al. (2013). Table 3. 6 summarizes the streamflow reductions in the three main reservoirs of the system and the average of all the streamflows reduction in the basin obtained from the climate change models.

Table 3. 6: *Summary of streamflow changes with respect to the baseline scenario.*

Streamflow change (%)	Near future	Climate change (2027)	HadCM2 (2040-2070)	HadCM2 (2070-2100)	HadCM3 B2 (2070-2100)	HadCM3 A2 (2070-2100)
Alarcon	0	-	-25%	-31%	-40%	-49%
Contreras	0	-	-27%	-34%	-42%	-50%
Tous	0	-	-18%	-25%	-34%	-43%
Jucar Average	0	-12%	-18.4%	-28%	-38.4%	-42.6%

3.3 Po River Basin, Italy

3.3.1 Methodology followed in the Po basin case study for the development of scenarios

The definition of the most probable scenario in the Po basin was undertaken following an exclusively qualitative approach. The absolute lack of literature in the field of quantitative projections for scenarios of drought impacts and vulnerability in the Po basin, in fact brought to privilege a qualitative methodology only aimed at obtaining at least a narrative plausible scenario. The involvement of experts and stakeholders participating to the 3rd Case Study Dialogue Forum (CSDF), held in Parma on the 13th of May 2014, was the main activity undertaken for the development of the scenarios. The qualitative approach to scenario definition has as theroretical and methodological background in the approaches known as exploratory and participatory scenarios storylines that have been developed and studied in several case study areas (e.g. Rounsevell and Metzger, 2010; Patela et al., 2007; Kok et al., 2006).

The preliminary step of the methodology was the identification of the key critical factors that are supposed to shape the current vulnerability to drought in the Po basin. Such critical factors (and the causal relations among them), identified making use of the outcomes of the fieldworks realized in the case study areas until then (1st and 2nd CSDFs, interviews, questionnaire surveys), were representend using the impact tree diagram (see Annex G).

The impact tree diagram was realised for each of the sectors that are supposed to be the most sentitive sectors to drought in the Po basin according to the empirical evidence collected for the past drought events (agriculture and energy). The draft of the two diagrams was sent to the experts and stakeholders in advance, before the date of the CSDF, in order for them to have time to study them, and to eventually send some feedbacks (propose some revisions) to the researchers who designed them. Then, the experts and stakeholders[4] were asked to answer the following questions during the meeting and then to have an open discussion:

a) How do you think such picture will change in the future?
b) Which tendencies will have such vulnerability factors in the future?

[4] The CSDF was organized dividing all activities in two themes: Agriculture and Energy. The Forum was divided in two tables, where one gathered experts and stakeholders in the agricultural sector (representatives of farmers associations, scientists expert in agriculture, representatives of local government istitutions competent for agriculture, etc.), while the other one gathered experts and stakeholdes in the energy sector. The “agriculture table” has enjoyed a wider participation than the “energy table” (six against three participants).

c) Which of them will be particularly relevant in affecting the impact of the drought?
d) Are there new factors that can arise in the future and that can significantly affect the vulnerability of the Po basin to drought events?

The time horizon taken into account for the discussion about the future state of the key drivers of the vulnerability of the Po basin socio-economic system was 2030. The most plausible scenario emerged therefore from the discussion provoked by such questions, and is described and illustrated narratively in the following sections.

3.3.2 Final scenarios

3.3.2.1 The future state of agriculture

Following the structure of the impact tree diagram, and in particular the main issues that there have been identified, the main reflections about the future scenario of the vulnerability of the Po basin to drought as regards agriculture, are given in the following paragraphs.

Production and market

As regards the role played by the hydro-demanding crops in the future, experts think that there should not be relevant changes in the medium and long term. Such factor then is not considered a key driver for the possible changes of vulnerability in the Po basin.

Experts do not foresee considerable shifts in the mix of crops production, caused by the market dynamics. Some of the crops might either increase or decrease their weight in the future, but not to the extent that they can significantly change the chemes of the land cultivations. In the Po basin there is such a wide range of cultivations (and almost all them are strongly connected to, rooted in their geographical area!), that it is hard to imagine that there might substantial changes. Unless some unpredictable exogenous factors intervene, as was the case of the beetroot, that was introduced in the Po basin some decades ago.

In the case of some specific crops, as said above, experts might imagine some peculiar dynamics in the future. For example, as regards biomass, given the lack of subsidies for the construction of new plants (which are very important), and given that new cultivations are being experimented, they do not think that there will be a relevant increase in the demand of corn for biomass. On the contrary, they suppose that it might occur a reduction of the most hydro-demanding cultivations in favour of the least ones (as sorghum).

As concerns the quality agricultural and food products, they think that a demand increase is likely to occur in relation to the boom of the Made in Italy food products in the world market. Anyway, as these products are strongly connected to their territory, to its identity and its culture, and they are made by means of specific and unique manufacturing processes and techniques, their production cannot be expanded too much over the current capacity as some crops cannot be cultivated out of the land historically devoted to them. If so, they would lose their peculiarities, and their original qualities. This is the case, for example, of Parmigiano Reggiano, Grana Padano, and so on. In the Po basin there are so many quality products (DOP, etc.) that it is hard to imagine that in the future something can change such schemes of land cultivations.

As regards rice, they imagine that some changes might occur in the future in relation to the kind of rice. But, at the end, the demand of water resources deriving from rice should not be relevantly modified. The production of high quality rice (such as Carnaroli), based on the shallow flooding irrigation, should increase in the future, driven by the dynamics either of the internal market or of the foreign markets. On the contrary, the production of other types of rice, which make use of water saving irrigation techniques, should decrease because of the competition of other countries, which are able to produce with a better price/quality ratio.

Moreover, experts imagine that there might be a reduction in the tomato production, as such agricultural product is less rooted, historically and culturally, in the places where it is currently cultivated. They finally imagine that fruit production should increase (for example kiwi, which is not so hydro-demanding, and that make use of drip irrigation).

Infrastructures and technologies

According to the experts, the question of the water storage infrastructures and of the irrigation network can have considerable influence on the future vulnerability to drought of the Po river basin. Increasing the water resources available, either by increasing the storage capacity, or by improving the efficiency of the irrigation network, is considered something that can significantly reduce the vulnerability of the Po basin.

Anyway, as far as the big investment projects for building new reservoirs are concerned, experts consider that it is hard to imagine that new big reservoirs, in the Alpine regions, or in the Apennine areas, will be built in the short and in the long term (although some regional governments have planned their realization). Costs related to such works are too high, and central and local governments currently have considerable budget constraints, and they also have other priorities. It is important to consider also the slowness of authorization procedures (bureaucracy). Moreover, some dynamics typical of the building sector (for example, the decrease of gravel demand), can affect the convenience for firms to realize such works. Therefore, experts do not think that vulnerability will be reduced through such measures. In some areas (for example, in Romagna), some small on-farm reservoirs, serving more than one farm, are being built, so solving local problems in terms of water shortage. Also in Piedmont, some small artificial basins are being built. These small works, anyway, will not have a significant impact of the total amount of water available.

The same financial constraints regard the works aimed at widening and improving the irrigation network, which also requires the realization of expensive investment projects.

On the contrary, as concerns the irrigation network, according to experts there might be considerable changes in the future. They imagine that there might be a upgrade towards the introduction of highly saving water technologies. Costs beared for doing such works and introducing such technological upgrade are less relevant. They suggest several good practices at local level that are making water supply for irrigation more and more flexible and efficient.

Representativeness

Experts consider that there are not critical points that might limit now and in the future the ability of farmers' associations to represent their interests and their demands, as concerns the water resources. Although there are several associations representing farmers in the Po basin, and although they may follow different strategies and approaches to such issue, according to the experts they are able enough to represent the interests of farmers in front of the local and national governments. Even in the local consortia which manage and distribute water to farmers (Irrigation and reclamation consortia), farmers are well represented.

Conflictual water uses

In the future relevant conflicts may arise only with the "environmental uses". In particular, as concerns the maintenance of the minimum ecological flow. According to the experts, it is not said that such conflict will get harder, but, provided that the environmental issues will get more and more important in the future (people will get more and more sensitive to such issues), it might get more and more dramatic in the future. On the contrary, no troubles should arise as regards the hydropower use (other renewable energy sources actually are increasing). Some conflicts, not so dramatic, might surge with thermoelectric uses, as regards the quality of the water resources that this sector gives back for other uses.

Lastly, experts point out new conflicts that may become relevant in the future, on top of the "traditional water conflicts". They are all internal to the agricultural sector: the conflict between agriculture for food, and agriculture for energy; and the conflict between farmers located in the northern part of Po river, and farmers located in the southern part.

Conclusions

Conclusively, it seems the narrative scenario emerged from the discussion among experts is not a scenario which foresee relevant changes of the current situation of vulnerability of the Po river basin to the drought events. Because of several reasons, the big investments projects (for example, new Alpine reservoirs) that should allow making less and less vulnerable the basin, will not be realized. Actually, they foresee a kind of "steady state" ("business as usual" scenario) that anyhow should make the situation more dramatic in the case that climatic conditions worsen. And, in this respect, the conflict with environment might become a rather important critical point. The only driver that realistically could reduce the level of vulnerability on the future is the introduction of new technological solutions in the irrigation network. In fact, according to experts this kind of, low cost, investments are very likely to be realized.

3.3.2.2 The future state of the energy sector

Differently from what happened with regards to agriculture, the open discussion on the scenario concerning the energy sector in the Po basin, was mostly focused on analysing in depth and refining the situation of the current vulnerability, as emerging from the impact tree diagram, rather than on the analysis of the future vulnerability, which at the end was supposed to have no relevant changes compare to the current one.

Production and markets

The key points highlighted by the experts with regards to energy supply and demand for hydropower generation in the Po basin, are:

- Power generation can vary on average from – 20% in drought years to +20% in rainy years. Hydropower plants are built to use 80% of the water available; therefore the hydropower system is adequately made;
- Seasonal reservoirs located over 2.000 meters of height, where snow is present from October to April, are used only after snow melting;
- All hydropower generation capacity that we have in the Po basin, is currently exploited;
- Programmable hydropower generation accounts for 30% of hydropower generation (the rest is not programmable);
- Nowadays, thermoelectric sector is made only of turbogas power plants, which use continuously water;
- Demand and supply unbalances caused by quick peaks or unpredicted variances are covered by programmable hydropower generation;
  - Turbogas power generation cover further demand peaks, although they do it difficultly, due to their bigger inertia;
  - Hydropower generation coming from high reservoirs (over 2.000 m height) is a highly strategic resource, compared to the hydropower generated by other plants.

Conflictual water uses

Differently from the experts consulted for agriculture, experts answering about energy underlined that potential conflicts currently involve bot only environment, but also agriculture. As regards this sector, they point out that there might be conflicts in areas where energy is accumulated when, at the same time, farmers need water (such critical situation might be really dramatic if it occurs in the beginning of the irrigation season). As regards environment, the key question is again the Minimum Ecological Flow, which clearly causes a proportional reduction in power generation. Such second type of conflict can become more and more dramatic in the future if there are changes in the environmental regulations, so that the minimum ecological flow is raised.

Another conflict, internal to the energy sector, may arise with thermoelectric generation, when water is lifted up from the river. Conflicts with other sectors, such as tourism (for example, winter tourism relatedly to artificial snow), are considered not so important, and anyway thwy would be limited to local territorial contexts.

Infrastructures and technologies

As regards the question of the sediments, the main problems are found in the not so high basins (500-600 m). Projects for sediment management are the solution to cope with such phenomenon. They should identify the ways to release sediments. And they should identify the most important and strategic reservoirs that have to be adequately maintained and preserved, even in the case that such work should have relevant environmental impacts.

Conclusions

Conclusively, according to the experts, the most important aspect which will be decisive in the future scenarios of vulnerability to drought of the energy sector in the Po basin is the dynamics of the electricity market, both on the demand side (the consumption decrease) and on the supply side (high supply of not programmable renewables with priority dispatch). In this respect, programmable hydropower generation assumes a strategic role. As far as conflicts are concerned, experts have in particular emphasized the conflict between hydrpower and environment, at any time during the year. The conflict with agriculture can dramatically arise only in the case that farmers anticipatedly demand water resources for irrigation (for example, in spring, when snow is melting and unpredictedly there is very hot weather), and then water can be released only from mountain reservoirs.

3.4 Portugal

3.4.1 Methodology followed for the development of scenarios

The methodological approach envisaged for the development of scenarios in CS Portugal aiming at 2030 was inspired by literature on scenario planning and participatory foresight for resource management (e.g., van der Heijen 2005, Hatzilacou et al. 2007, Rounsevell & Metzger 2010, Van Berkel et al. 2011, Wright & Cairns 2011, Wulf et al. 2010, 2011a, 2011b) and included the following steps:

a) Identify a significant number of drought vulnerability factors through stakeholders´ contact and literature review (mainly from scholarly and practitioner-oriented water management sources, e.g., Mañez Costa et al. 2011, Santos et al. 2013, Stigter et al. 2013, García de Jalón et al. 2014);
b) Grouping those factors into “driving forces”, (themes that emerged from group factors);
c) Ranking the factors in a matrix according to uncertainty and impact;
d) Analysing the critical uncertainties and grouped in meta-categories or major driving forces;
e) Selecting two of those to derive a set of scenarios;
f) Developing storylines for different scenarios;
g) Quantifying scenario parameters.

The application of this methodology relied on complementary sources of information, namely:

a) Statistical information describing recent trends in regional and national sectors (agriculture, tourism, demography), along with the evolution of different factors (e.g., EEA 2006, Diogo & Koomen 2010, Jones et al. 2011, Amatulli et al. 2013, INE 2014, Vale et al. 2014);
b) Pre-existing scenarios defined at national and international levels (e.g., Ferreira et al. 2009, Pereira et al. 2009, Alvarenga et al. 2011, Simões et al. 2011, APA & ARH Norte 2012);

c) An identification of factors of change/vulnerability to drought made through stakeholders workshops (1st CSDF) and interviews;
d) Individual and collective visions of the future expressed by stakeholders during interviews and workshops (2nd CSDF).

The available information was also used to summarize the baseline conditions (sf. 3.4.2).

The scenario building process included several internal research and analyses stages as well as the participation of Portuguese stakeholders panel from the DROUGHT R&SPI project. Along the way, the analysis of national and international literature regarding scenarios provided the basis for the meta-analyses done with workshop and interviews outputs.

During the first workshop stakeholders helped the research team identify a set of macro (driving forces) and micro (local factors) parameters according to their expertise and perception influenced past drought impact and drought vulnerability. Moderators guided a brainstorming session where impact trees were developed for the most significant impacts from past drought events in Portugal, on the basis of two fundamental questions:

- What are the drought problems faced by a specific sector or component (e.g., agriculture, domestic supply)?
- What are the main factors (causes) that have produced the impacts?

After the first workshop, the CEABN team elaborated a meta-analysis of the outputs producing a consensual list of underlying factors of vulnerability to drought in Portugal, grouped in four driving forces that corresponded to the dimensions of analyses suggested by the drought project team in the scope of other activities (WP4):1) Societal, 2) Institutional/Political, 3) Economical/technological and 4) Environmental.

At the second workshop stakeholders were invited to elaborate with CEABN team future possible states of the local factors that will shape vulnerability to drought in the future, within the identified driving forces.

During the first plenary session climatic and drought scenarios for Portugal were presented along with some open questions about the uncertainty of those scenarios. The next session was oriented to understand stakeholders' perception about how will underlying factors of vulnerability to drought evolve over the next 20 years and /or will other factors or other relevant problems emerge.

The stakeholders were asked to pinpoint on four large panels (Figure 3. 9) their views about:

- The future state of underlying vulnerability factors (as defined in the 1st CSDF Workshop), according to three classes of importance trend (increase, decrease and stable), using colour stickers (in green);
- The vulnerability factor considered most important in the future (orange colour stickers).

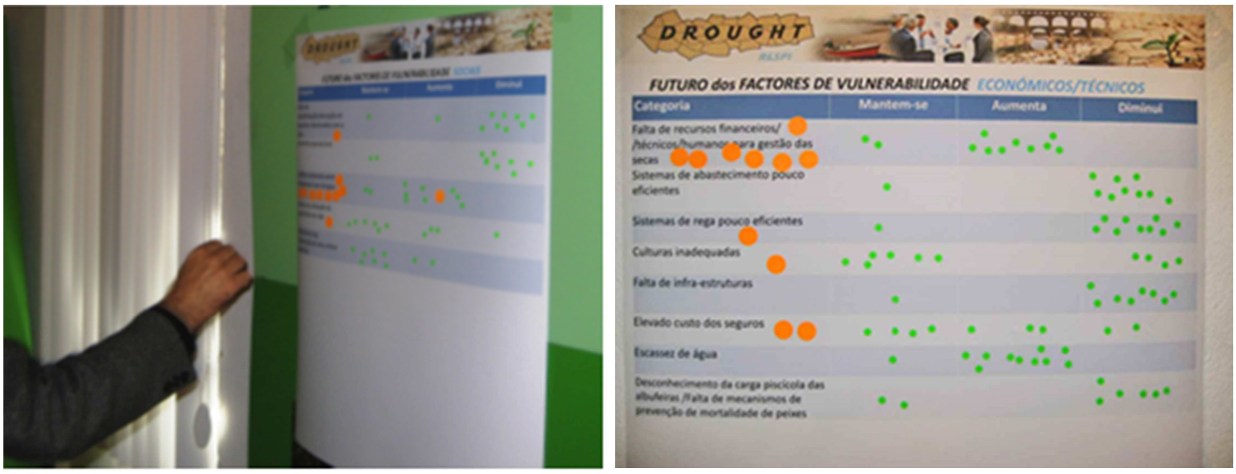


Figure 3. 9: *Panel description during the second CSDF held in Lisbon (May 2013).*

The meta-analysis done with the workshop outputs allowed us to identify a number of crucial exogenous factors, which according to the stakeholder's view of their future trends, will affect drought management in the future. We placed the factors on a grid according to their rating in terms of its performance impact and uncertainty on a scale from low/weak to high/strong. For that we used the degree of variability in the answers as an indirect way of rating each factor. As such, factors considered by the majority of the stakeholders as the most important in the future were ranked high in the impact axis, whereas high values of uncertainty were attributed to those factors that did not attain a consensual answer about their outcome in the future. We also used information from the plenary sessions and interviews to address a final position of each factor in the grid. At this point we should stress that ranking of uncertainty and impact were based on the perception of those involved in the project. This implies that the outcome of this exercise provides one view of the critical uncertainties confronting drought effects in Portugal.

Forces of low impact and low uncertainty are not of concern, nor are forces of low impact and high uncertainty and both were clustered into secondary elements. Forces of high impact and low uncertainty were clustered into pre-determinant elements or trends, as they are things that we know about and can count on with some level of certainty (e.g., aging of population). Forces ranking high on uncertainties and high on impact were considered the critical uncertainties (Wulf et al., 2011). Those were then grouped into meta-categories based on common elements and topics.

Two of these meta-categories were chosen to provide the basis for scenario building step. Each key future uncertainty was projected with an extremely positive and negative outlook along the x and y axes of a matrix thus generating four distinct scenarios. A water-related name was given focusing on the chain of causes and effects behind each scenario description (van de Heijen, 2005).

In the next step the stories behind the scenarios were elaborated, by building a chain of causes and effects leading to these end-stories. The description of each storyline was inspired on previous scenarios done for Portugal under the scope of different projects and initiatives (e.g., Pereira et al., 2009; Alvarenga et al., 2011; APA & ARH Norte, 2012a; APA & ARH Algarve, 2012; Vale et al., 2014) from where we extracted the components with implications on drought management. We also look for scenarios targeting drought vulnerable regions (southern Portugal, Máñez Costa et al., 2011, Santos et al., 2013) and/or sectors (e.g., agriculture, urban water supply, energy, Jacinto et al. 2011, Simões et al. 2011, Stigter et al. 2013). Most of the stakeholders involved in those scenario exercise's, namely in its validation, are linked with the panel of stakeholders (e.g., same persons, representing the same institutions) currently on DROUGHT R&SPI which may enhance robustness to the process presented here and promote acceptability of results.

As a final step of the scenario exercise the state of the underlying causes of drought vulnerability were summarised facing two opposite/contrasting socio-economic developments, the pessimistic/minimalist and the optimist/maximalist case scenario. As a result of the 2nd CSDF and in line with other projects (Alvarenga et al., 2011), it was intentionally planned that none of the scenarios would be catastrophic, all show some capacity for managing the most serious crisis that Portugal faces in both the short and the long term.

No macroeconomic models support the quantification of the described scenarios. Instead, the results from previous publications were used. Quantitative values for some socio-economic indicators that framed available scenarios at national level are summarized in Annex E. Moreover, indicative values for future water consumption by the main sectors of activity in Portugal, obtained in the context of the of current river basin management plans (RBMP), were used to illustrate three of the four scenarios (a baseline, pessimistic and optimistic case). The scenarios within RBMP, done with a different perspective and methodology (DPSIR), account for most of the driving forces also addressed in our scenario exercise (e.g., EU economic policy, economic and demographic growth), although baseline conditions date back to the onset of the European crisis that hit hard the Portuguese economy. Furthermore, this processes involved public consultation and their outcome was considered validated by different stakeholders (http://www.apambiente.pt/?ref=16&subref=7&sub2ref=9&sub3ref=834) and presented in CSDFs.

3.4.2 Definition of the baseline conditions

Baseline conditions addressed in this section focused on the current state and recent evolution of five main topics that, according to the Portuguese participants in the project, frame drought vulnerability in Portugal mainland. Those topics were thoroughly revised in the scope national assessments, such as the Millennium Ecosystem made for Portugal (Pereira et al., 2009), National management plans (INAG, 2001; MAOTDR, 2007; APA, 2009) or climate change strategies (Santos et al., 2002; MAMAOT, 2013; Santos et al., 2013).

3.4.2.1 Demographic patterns and distribution

Recent demographic trends are characterized by a reduction in resident population, a continuous increase in life expectancy, a decrease in infant mortality, increased emigration, the sharp decline in fertility and the resulting population aging.

In any of the scenarios projected up to 2060 taking in consideration fertility, mortality and migrations components, the resident population in Portugal tends to decrease between 2012 and 2060 (INE, 2014). The worst projections indicate a reduction of about 40% going from the current 10.5 to 6.3 million residents). This trend cuts across all regions, except for the most optimistic scenarios in the Algarve, where the population increases, and in Lisbon, where the population size remains the same. In addition to the population decline, changes in the age structure of the population are also expected, resulting in a strong and continuing demographic aging of population in all the scenarios.

About 60% of the population inhabits the coastal zone, where most of the larger cities are situated, rising up to 80% in the touristic summer months. The coast line also concentrates most of the economic activity and industries.

3.4.2.2 Economic growth

Currently the socioeconomic development of Portugal is mostly dependent on the tertiary sector, mainly tourism, commerce and services, accounting with 74.8% of the gross domestic product (GDP) in 2013. The share of agriculture GDP was 2.6% and Industry 22.6%. Since 2002 Portugal faces economic stagnation and, during the last years, economic recession with a continuous increase of the public debt.

Recent data (INE 2014) show a decline of 1.4% of GDP over the year 2013, increasing to 5.83% the total contraction of the economy since the end of 2010. State estimations are for a GDP of 1% in 2014 that will rarely grow above the threshold of 1.5% in the coming decade. Agriculture and land economy are highly dependent on market and EU subsidies. Energy economy is still highly dependent on fossil fuels, although 60% of generated electricity is renewable based (RES-E) and 31% of final energy consumption is from RES. Current policies aim at reducing the external energy dependency to 74%. The Portuguese National Action Plan (PNAER) within the Directive 2009/28/EC sets even more ambitious policies and measures that will allow reaching 70% RES-E in 2020 and 10% biofuels in transport (Simões et al. 2011).

3.4.2.3 Land use and land cover in continental Portugal

Mainland Portugal in 2006 was basically dominated by forest and agriculture (71%). About 15 % was a mixture of agriculture and natural areas. Artificial surfaces represented 3.5 % and natural vegetation 8.6 % of land cover (Julião & Fernandes, 2009). Trends from the last three decades show an increase of the areas occupied by forests (3.1%), uncultivated soils (0.9%), artificialized land (2%) and water bodies (0.3%). The later have registered the largest growth: a total of 18 000 hectares between 2000 and 2006, mainly due to Alqueva dam (Guadiana River, southern Portugal).

Urbanization and agricultural land abandonment were the most prevailing processes (EEA, 2006). While urbanization occurred mainly next to urban centres in coastal areas, agriculture abandonment took place in marginal areas with scarce water resources. Intensification of agriculture was also a significant process in areas where water is available, as a response to EU policies and market incentives (Diogo & Koomen 2010). Currently, about 35% of the total arable land is irrigated (MAOTDR, 2007). Land use changes due to increasing wildfire extent, intense agriculture and silviculture resulting in a significant increase of soil loss estimates, particularly in the south and in the interior of Portugal, bordering Spain (Jones et al., 2011; MAMAOT, 2013).

Sea-side tourism is big business and over the last decades it was almost impossible to hold urban sprawl, illegal dwellings and tourism pressure. In fact, artificial areas increased by 10% in the last decade, mainly at expenses of agriculture and forestry land (Vale et al. 2014), but also as a result of disperse urbanisation. Urban sprawl and soil sealing are continuing apace in Portugal and both tendencies are expected to increase in the future (Rounsevell et al. 2006), particularly in the northern and in Lisbon regions (between 10% and 30%). In the next decades, land occupied by agriculture is continuing on the downward trajectory (EC 2007), reaching a decrease of 15% in North and Alentejo, whereas, a reduction in forested land is only forecasted for Lisbon region (Vale et al. 2014).

3.4.2.4 Water: availability, uses and demand

Currently, the levels of water production by the Portuguese ecosystems fulfil the national demand. In fact, about 80 % of water resources are not exploited. From the remaining, 54% is groundwater and the rest is surface water. Less than 10% of the annual precipitation is used. There is, however, a large spatial and temporal variability on the availability of water resources, most precipitation occurs in the north of the country between October and March. Some aquifers are overexploited particularly in the south; diffuse pollution and industrial contamination occurs in al river basins, although with different intensity (INAG, 2001; APA, 2009; Pereira et al., 2009)

In 2000 the market value of water supply was of 2 thousand million €/year, which is equivalent to about 2% of the Portuguese economy. Nearly ¾ of the water is use for agriculture. This sector has the highest level of water demand (estimated 87% of the total demand, ~6.55E+09 m^3/year) but is also responsible for 44% of the water returns to the system. The energy sector is responsible for a significant share of water use (14%, mainly derived thus not consumed), corresponding to 27% of the water returns to the system. The remaining 10% of the exploited water is used by urban supply (6%) and industry (4%).

The share of distributed water for consumption by main sectors varies among river basins (Table 3. 7).In the northern basins (Minho-Lima, Ave-Cavado-Leça and Douro), values are basically shared between urban supply and industry, given that other sectors extract water directly from the origin (river, wells, etc.). In the southern basins, agriculture mainly supported by extensive irrigation infrastructures, leads statistics.

In Portugal water use inefficiency corresponded to about 41% of the total withdrawals (INAG, 2001), but at least for agriculture, in the last decades water consumption efficiency gains attained 46% (15.0 x10^3 m^3/ha/year) (Arranja, 2013). A more ambitious target was set towards efficiency in water for human consumption at short term (80% improvement) according to National Program for Efficient Use of Water-PNUEA (PCM 2005). Portugal intends to increase hydroelectricity from 46% to 70% (~7000MW) of the hydrological potential by 2020 (Cortes, 2013).

Table 3. 7: *Share of distributed water (in %) consumed by main sectors in each of the hydrographic regions of CS Portugal (APA & ARH Norte 2012, 2012a, 2012b, APA & ARH Centro 2012, APA & ARH Tejo 2012, 2012a, APA & ARH Alentejo 2012, 2012a, APA & ARH Algarve 2012). Negligible amounts (na) for livestock were accounted in the agriculture sector; same for Tourism (included in urban supply) and golf (included in tourism). Livestock density and agricultural area (ha) were considered for evaluating baseline conditions (and scenarios) in northern river basin management plans.*

	River basins/Hydrographic regions							
Main sectors	Minho & Lima	Ave, Cavado & Leça	Douro	Vouga, Mondego & Lis	Tejo	Sado & Mira	Guadiana	Algarve
Urban supply	56.9	67.2	41.0	25.8	27.2	9.5	12.0	27.8
Agriculture	(ha)	(ha)	(ha)	55.3	65.4	81.7	84.7	57.0
Livestock		(head density)		0.8	0.5	*na*	*na*	*na*
Industry	41.9	31.9	52.4	17.9	6.4	7.2	1.9	4.0
Tourism	0.6	0.6	4.0	na	na	0.7	1.4	11.2
Golf	0.6	0.3	2.5	0.2	0.4	*na*	*na*	*na*
Energy	*na*	*na*	*na*	*na*	*na*	0.9	0.0	*na*

Beside internal legislation and regulation (e.g., cooperation for transboundary water management - reservoirs Convention), Portugal, in line with other European countries, signed and adopted a series of directives (e.g., WFD), adaptation strategies (National Strategy for Climate Change Adaptation - ENAAC) and programmes (e.g., PNAER , PNUEA) towards the conservation and efficient use of water resources. Their implementation is underway with some gaps and inconsistencies.

3.4.2.5 Climate drivers

Climate change precipitation models predict a drier climate in Portugal (e.g., Santos et al., 2002; MAMAOT, 2013), with a shorter and wetter rainy season, followed by a long dry summer. Although with some uncertainty, the annual precipitation may vary three-fold from year to year and five-fold from the dry interior south to the wet mountainous north-west. The increasing trend in temperature and the decreasing trend in precipitation will significantly influence the frequency and severity of drought events in Portugal (Garcia-Ruiz et al., 2011; van Lanen et al., 2013). The increase in average drought duration (median) values in the near future (2021-2050) range between 30% and 126% of the values for the control period (1971-2000). Average drought intensity increases up to 170% while volume is expected to decrease up to 674% in the far future with regard to the control period (in SRES A2 scenario). A future significant reduction in precipitation and groundwater resources, foreseen mainly for the southern river basins (e.g., Sado, Guadiana) will increase regional and seasonal asymmetry in water availability and in terms of higher exposure and sensitivity to droughts (Pereira et al., 2009; MAMAOT, 2013).

3.4.3 Final scenarios

3.4.3.1 Development of alternatives

The outcome of the process previously described allowed the identification of several critical uncertainties confronting drought vulnerability in Portugal (Figure 3. 10), namely:

- The way drought management evolve and the origin and funds availability to support it.
- How will the agriculture sector evolve in the context of EU policy
- Globalization trend and in particular the dependence degree from EU in political and economic terms
- Society perspective towards crisis in environment and economy
- Evolution of society habits and preferences regarding environmental friendly assets, activities, products, crops

The political/administrative and economic drivers that emerged are common for most scenario exercises and represent changes at higher level than local factors. Currently environmental concerns are gradually being internalized by the society towards the demand for a “greener economy”. However the pace of the process is determinant and mostly ruled by external factors.

Considering the above, scenarios for Portugal case study were formulated along to main axes (Figure 3. 11):

X - Economic development based on pre-ecological knowledge vs blue-green economy supported by ecological knowledge;

Y – Political decision and financial capability done at EU level vs national/regional level.

The resulting scenarios share similarities with outputs from other scenario exercises made at international level (MA, IPCC, etc.), which are identified in Figure 3. 11.

In the scenario “Go with the tide” prevailing trends will be allowed to continue without major intervention; is thus considered the baseline scenario (~Business As Usual) built with projections taking into account the current state of national government programs, European policy options and global economic factors (e.g., fuel price trend) and assuming the implementation (although weakly articulated) of the ongoing governmental investment policies. The other scenarios (“The water is mine”, “Every drop counts” and “What comes around goes around”) depict alternative futures with shifts in policy measures and in EU society towards sustainable economy.

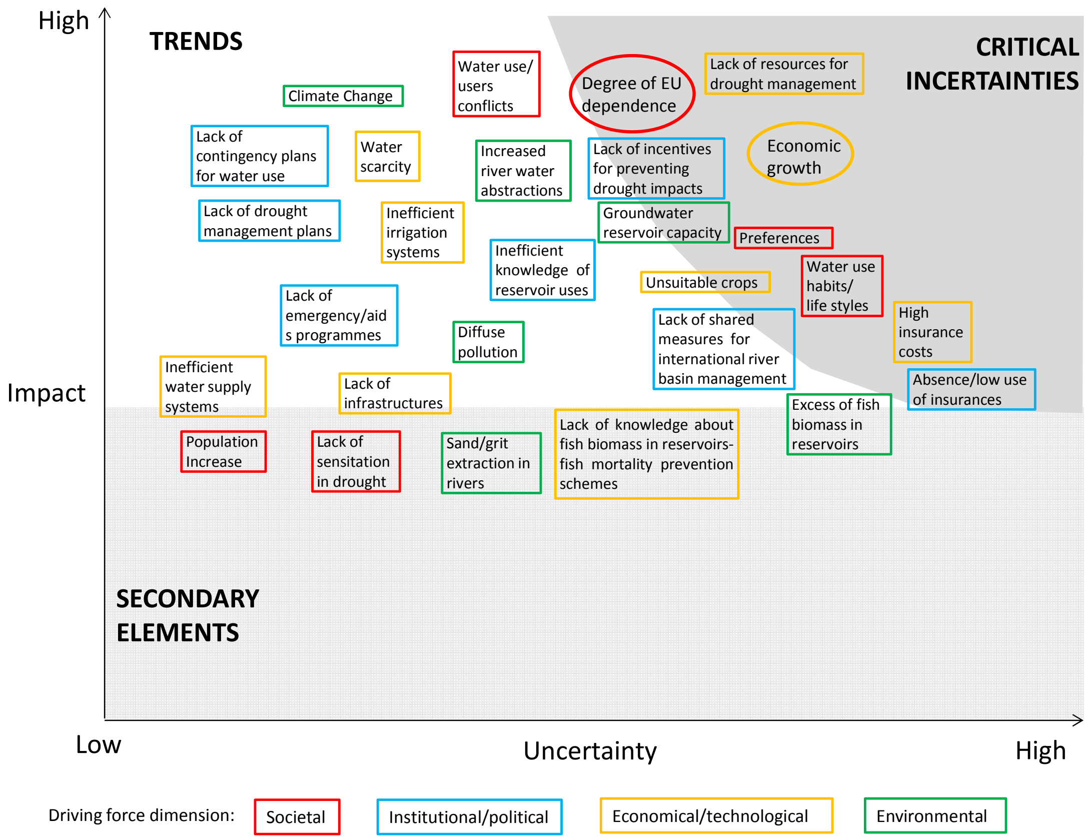


Figure 3. 10: *Impact/Uncertainty grid for underlying causes of drought vulnerability in Portugal. Drivers such the dependence from EU policies and economic growth, although not individualized in the 1st CSDF, emerged as a sum-up of several other factors during subsequent discussion with stakeholders.*

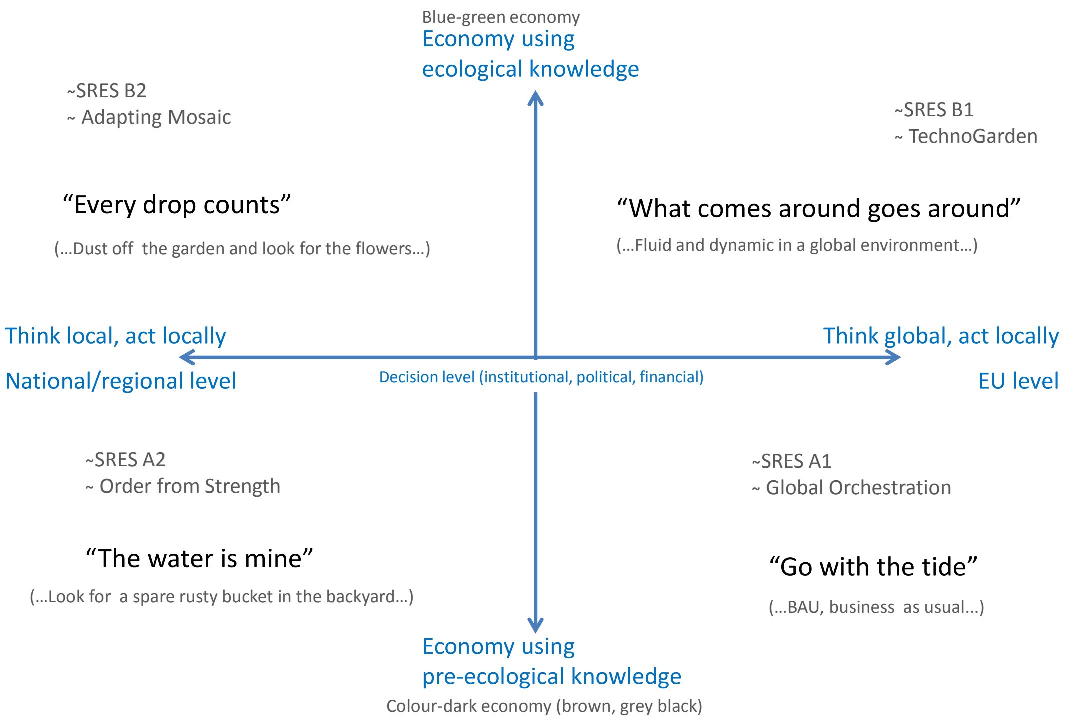


Figure 3. 11: *Future scenarios for socio-economic and water related issues in Portugal mainland.*

3.4.3.2 Storylines

The main features of the four storylines for Portugal Case study are outlined below.

The "**Go with the tide**" scenario describe a future with no major shifts from the current economic and demographic trends, where the climate of globalization triggered a series of processes in the EU with the enlargement to Eastern Europe. In the process Portugal lost a significant amount of EU support, but could overcome the pessimistic growth option due to technological investment, diversification of the productive base and training of skilled labour (attaining an average GDP ~1% to 1.5%).

Although marketing of national products expanded, agriculture remains highly dependent on market options and EU support. Land abandonment continues and traditional agriculture is gradually being reduced, particularly in the interior and northern regions. However, EU support was reinforced to make European olive market more competitive against other markets and thus projects developed over the Alentejo and Algarve and along the coast, with multinational investment, made Portugal gained some expression in the fruit and vegetables sector. These intensive farming carries increases in diffuse pollution, and water use reaches levels never attained before. In a long term, this situation changed, due to land abandonment led by recurrent reductions in crop yields driven by the increase of heat waves and multi-year droughts, particularly in regions where no EU support was given to face these natural disasters.

In the meanwhile, investments in agriculture were unable to slow down the rate of rural depopulation and migration to the coast and major urban centres and, as such, the demand for water in these locations increased. Furthermore, renovation in the cities led to proliferation of green areas with an escalation of water consumption. Along the years, however, the investment on water leak reduction proved to be a good solution to a net downturn in water urban consumption.

Agricultural abandonment led to forest land consolidation and the overall management of the forest, but the woods remained underutilized and accumulated in some areas leading to cyclic years with large burned areas. Monocultures proliferate and riparian galleries are under pressure.

The growth in tourism has led to the construction of large infrastructures and golf camps near the coast and in the interior of Alentejo as a way of profiting from Alqueva reservoir, the largest artificial lake in Europe. As a result, soil sealing and degradation increased with negative impacts on water resources.

The increase of dam construction with inherent environmental costs still is the main solution used to regulate water availability. Portugal and Spain have shown a spirit of cooperation in joint management of surface water. The management of water resources promoted the development of more efficient irrigation systems and reuse of treated waste water systems. At national level, drought events are still managed as a crisis with focus on contingency and emergency plans, but adaptive management has being gradually implemented, particularly for southern river basins, where drought management plans were in place. Conflicts persist however regarding the share of allocated water for each sector, where domestic use and tourism along with EU supported crops maintain priority.

Hydro-powers were built according to plan and Portugal is in line with the EU biofuels strategy producing its share of fuel crops at expenses of increases in water demand and diffuse pollution. Yet, energy economy remains highly dependent of fossil fuels. The economy thrives, but with little careful for natural resources especially at local level. Limitations in resources (financial and other) inhibit proper environmental law enforcement and monitoring. As a result, early warning systems for natural catastrophes are rarely operational and some environmental indicators have worsened, such as the percentage of rivers with natural dynamics and not fragmented or the number of contaminated aquifers.

The ""**The water is mine**" scenario describe a future where protectionist trends and difficulties in global regulation will be strengthen, taking into account the existence of quite different economic and political models. The stagnation of the European project led to a reduction in internal support policies from EU, namely CAP. The gradual reduction in EU funds for Portugal and a low economic growth (GDP less 1%

/ year) forced the postponement of important infrastructures (new airport, TGV) and kept the country in diverging line from the rest of Europe. This multispeed Europe tends to reinforce the peripheral nature of Portugal, the worsening of social and regional asymmetries.

The world population growth continues to increase in a context of widening trade liberalization. In order to keep European agriculture competitive in the world market there was a partial withdrawal of environmental legislation leading to a postponement of major goals in terms of environmental sustainability in a framework of severe financial constrains. EU keep exporting cereals and other crops, however the production was not enough and cereal prices increased. Portugal tries to seize this situation. As a result small properties vanish and some highly competitive farms succeed at international level. The land abandonment in marginal areas led to a reduction in water demand for agriculture in all river basins with the exception of the Alentejo region were intensive agriculture (some for GMOs) and irrigation crops increase significantly. This region suffers the consequences of increase in soil erosion, diffuse pollution and aquifer contamination along with eutrofication of reservoirs and surface waters. In a few decades with the gradual reduction in EU subsidies, the degradation of the irrigation infrastructures, low quality water at high prices, only some farms survive. This leads to an increase in water available for nonfarm uses and a depopulation of the region. In the meanwhile, contamination will achieve preoccupant levels. However, due to a strong technological investment in water system treatment, industrial and urban waste water, coupled with the need to assuring water supply, the objectives of chemical quality were a priority and will be achieved.

The higher importance of the agriculture sector in some regions allowed controlling the rural exodus. It also resulted in trend reduction for human concentration in coastal areas. However, a clear concentration on the tourism/hospitality sector with large touristic projects including golf camps, particularly near the coastline, have deepening the scarcity of productive soils for food production, competing between them and with soil conservation, water and biodiversity.

Forestry is basically maintained through monoculture of maritime pine and eucalyptus leading to high number of fires and an increase in burning area. In the south, the montado systems were reduced as result of land abandonment or agriculture conversion to intensive crops or livestock.

General difficulties in inter-regional country coordination had as exception tourism and some urban-rural articulation capacity. Cost saving techniques is used to a minimum. Cities maintain high levels of water and energy demands. Efficiency on the supply systems is a major goal but difficult to attain in all regions and highly dependent of available funds.

The Portuguese energy policy remains highly dependent on fossil fuels. Renewable energies are strongly supported by an increase in hydroelectric infrastructures, with some of them linked in reversible systems and water diversion between basins in order to optimize water resources and energy production. The lack of energy worldwide resulted in private investments in technology towards the use of some eutrophic lakes and biofuels.

Water management is relatively regulated although it monitoring is fund constrained. As water need also increased in Spain, particularly in the southern basins, several drawbacks are slowing down the negotiations for co-managing of transboundary waters. Main concern of the state are satisfy the water demand, assuring supply and water services namely in food and energy production; priority is given to the construction of infrastructures that guaranty the basic needs in spite of their multiple purpose. Scarce investments in the study of those ecologic systems are having high costs, though.

Droughts are faced in a reactive mode with application of contingency and emergency plans or by mitigation measures that need a strong investment in a context of lack of funds and increase in the recurrence of these events.

The “**What comes around goes around**” scenario describes a future where the international recognition of the values of ecosystem services, along with the need for a sustainable economy, led to the development of EU policies on ecological property to protect biodiversity and ecosystem services. The Portuguese society is aware that putting a price on carbon and valuing natural capital is vital to maintain scarce resources in a fluid and dynamic global environment, thus sharing responsibility in the protection of the full cycle of natural resources.

Economic growth and infrastructure investment in airports, railways in articulation with Spanish logistic platform has enabled the convergence of GDP / capita with the rest of Europe (GDP ~1.5-2%/ year). The economic optimism and openness of the labor market meant that the population did not reduce as expected in the beginning of the century.

Environmental legislation was reinforced and CAP reform accounted with the payment of services such as soil protection, climate regulation, and water cycle. Soil Directive is introduced along with Water specific legislation tailored to acknowledge regional and local differences, namely in terms of its vulnerability to drought. As a counterpoint there was an increase in the tax burden in particular with environmental taxes.

The use of renewable energy increased substantially, which allowed reducing external energy dependency below 75% in a decade. Investments move from hydropower to wind, wave and solar renewable sources. The development of lignocellulosic technology allowed the efficiency in the use of grasses, coppiced wood, biodegradable wastes of all sort and a reduction in land allocated to biofuel from cereals, oilseeds and sugar beet. Those were gradually transferred to land originally in set-aside.

External subsidies towards the introduction of new environmental technologies and biobased materials in numerous applications allowed a continuous trend in cost saving technical progress.

After the dramatic situations experienced in southern basins due to over-exploitation of water resources and pollution levels difficult to control, intensive production was reduced and mostly allocated to the best soils, but with less water and chemicals needs. Most of remaining agricultural area is subsidized and dedicated to experimental low water demanding crops or high quality products, growing indigenous cultures. The abandonment of marginal agricultural areas occurred in all regions. Former rice fields near natural protected areas were converted to natural wetlands.

Forest spread in mountainous areas allowing an increase in water retention in upper basins. The forest policy was changed after successive years of fires, for the conversion of monoculture into native forests multi-use, annual burnt area. Cork oak montado extended due the value of the ecosystems services provided and to new investment in water save technologies for crop and livestock production.

The water management is based on more eco-efficient technologies in various fields of activities, properly adjusted to objectives of demand and supply, particularly in megacities where most of the population is concentrated. Those metropolitan areas (e.g. Lisboa and Porto), profited from a large investment in unconventional infrastructure, such as housing with green roofs, the recycling system, wastewater reuse, separate networks for different urban water uses.

Portugal is capable of managing water and secure coastal protection and the balance between development and the meeting of the environment protection requirements. Implementation of environmental flows as well as restoration of degraded sections of significant parts of the basin is strongly enhanced. Remediation projects of degraded groundwater and implementation of monitoring and early warning systems have a strong increase. Cost recovery in water services and payment for ecosystem services is current practice. In situations of drought and water scarcity, transfer of virtual water is factored into the rules for the internal agricultural trade. There is an effort to adjust the local planning in response to drought, with a pro-active strategy leading to a reduction of environmental costs.

The "**Every drop counts**" scenario describes a future where a general perception of failure in managing common resources led a steepened disbelief in global institutions. The European project began to lose strength with conflicts between member states regarding the political future of the EU. Portugal was losing Community support over the decades but the impact of reduced funding to the economy was not as bad as it looked. The investment in protecting national natural and human capital and in technology gave results in terms of creation of innovative products and services. Portugal gained a good market share in products of sustainable agriculture that are now a third of trade in Europe; These goods are produced and sell across the country, thereby decreasing exports and slowing down the Portuguese economy (DGP ~1% to 1.2%/year)

The population decreases due to economic insecurity, low rates of immigration and concerns with human pressures on ecosystems. In urban areas there is the use of sustainable architecture and natural engineering for maintenance of green corridors, urban gardens. Investments in diversification of renewable energies continue, aiming to surpass fossil fuels supply in a long term. In large cities predominate the photovoltaics and in rural areas, small wind generation.

International mass tourism decline and touristic preferences turned to heritage and eco-tourism which led to a decrease in pressure on the coast and increased in the interior, particularly in the Guadiana basin.

The regionalization implemented in Portugal led to a greater effort to preserve local ecosystems, significant settlement of people, mainly young, investing in sustainable agriculture and eco-tourism. The increasing migration to urban centers was gradually reduced along with the pace of increase land abandonment.

Agriculture practices focus on a mix between traditional knowledge and agricultural science assisted by local organizations of farmers and foresters. Certification products are an asset promoting the adoption of best crops, minimum tillage soil techniques, protection of riparian galleries, and establishment of biodiverse pastures. There is renewed interest by local indigenous breeds of small ruminants, the protected designation of origin (PDO), protected geographical indication (PGI), and traditional specialties guaranteed (TSG), innovative food and forest products. This trend has reduced erosion and increased water conservation but kept some pressure on land due to the latent new energy and food crises; therefore, improper area continues to be cultivated with technologies that, despite being considered environmentally friendly, biophysically are beyond the capacity of the territory. Noteworthy is the Alentejo and its irrigated fields with high levels of productivity achieved with vegetables, fruit and some cereals and now beet for the production of bioethanol.

Monocultures were gradually replaced by multifunctional forests in the north and by montado in the south with an adaptive management according to the prevailing system of each region. This led to an increase in the use of biomass for heating out contributing to a significant reduction of forest fires.

The institutional model of water management by river basin was carried out and implemented in the first decade of the century, with financial and administrative autonomy, evolving into a model of joint management of international river basin districts ensured by competent authorities of Portugal and Spain. This difficult process resulted in the implementation of joint early warning systems to the natural and man-made risks, with success in the southern basins, where the largest problems subsist.

Management policies are more consistent and trade in the right of emission rejections was established in some basins after assessing the carrying capacity of aquatic ecosystems. Water management at the local level is strongly encouraged and decisions are taken in a bottom-up process. However scale up conflicts emerges when measures to preserve natural resources in the context of climate change collide with other policies of local development.

The state of the underlying causes of drought vulnerability facing two contrasting scenarios are summarised in Table 3. 8, Table 3. 9, and Table 3. 10. The scenarios “What comes around goes around” and “The water is mine” were selected, respectively, as the maximalist and minimalist in terms of socio-economic development.

Table 3. 8: *Summary of storylines behind two case socio-economic scenarios for mainland Portugal regarding underlying factors for drought vulnerability under the societal and institutional/political dimensions.*

Underlying cause of vulnerability	Maximalist scenario "What comes around goes around"	Minimalist scenario "The water is mine"
Societal Dimension		
Lack of sensitation/ education in drought	Investments in successful campaigns, targeting specific publics to increase adherence; continuous education towards the efficient water use	decreases investment in public campaigns/ poor adherence of the population to awareness campaigns to reduce water consumption and waste
Population growth	Small negative growth, or stable population, dynamic and young	Strong decrease in resident population, particularly in the interior, aging
Water use/ users conflicts	Conflict reduction (controlled) due to adequate planning of water uses/users and carrying capacity monitoring	Conflict increases due to poor knowledge on water uses/users and lack of planning at national and basin level
Water use habits/ life styles	Progressive life style change towards environmental protection of water resources, all year around and at faster pace in drought prone regions	Slow change in life style and water use, particularly for touristic purposes and southern regions
Preferences (e.g. use of a specific crop)	Effective change demand towards products and services that internalize water/environmental costs	Small changes, highly dependent of markets, subsidies
Institutional / Political Dimensions		
Lack of drought management plans	Drought adaptive management plan in action, at national and regional level, articulated with other planning instruments and duly monitored	Management plans only for the southern river basins; difficult articulation among regions and with other planning instruments
Lack of contingency plans for water use	As part of the drought management approach	Ad hoc plans in situations were drought is managed as a crisis
Lack of shared measures for international river basin management	Shared measures in place and monitored, e.g. mandatory ecological flows, river diversion, payment of virtual water	Directive not fully implemented nor monitored; particularly in the southern river basins
Absence/low use of insurances	Insurances available and commonly used; alternative compensation schemes as part of the drought management plan	Low use of drought insurances which are seldom available, compensation schemes in crisis situations
Lack of incentives for preventing drought impacts	Proactive view towards drought management made available a diversification of incentives	Reactive view towards drought, maintained the lack of incentives
Lack of emergency/aids programmes	Available and used as part of the drought management plan; articulated with other legal instruments	Available only for some sectors or basins; depending of funds available during a drought crisis
Inefficient knowledge of reservoir uses	Updated register of reservoir uses/users, independent of their capacity and localization; ecological/environmental uses fully accounted	Register of reservoir uses/users incomplete, not regularly updated; only for major reservoirs with no consideration of environmental uses

Table 3. 9: *Summary of storylines behind two case scenarios for mainland Portugal regarding economical/technical dimension.*

Underlying cause of vulnerability	Maximalist scenario "What comes around goes around"	Minimalist scenario "The water is mine"
Economic / Technical dimension		
Lack of resources for drought management	Available human and financial resources (national and EU); profiting from advances in technology and knowledge from adaptive management	Less skilled personnel, less budget apply mainly to crisis situations, deficient coordination, no plan
Inefficient water supply systems	Technological innovation and available budget to implement water safety plans allowed a large increase in supply system efficiency	Small inputs from technology, limited budget and incomplete monitoring led to small increase in efficiency (due to leak reduction mainly)
Inefficient irrigation systems	Technological innovation, monitoring, reuse of waste waters led to a large increase in irrigation system efficiency, in all the process' phases	Increase in efficiency variable between basins, but generally small, technological inputs constrained by available budget
Unsuitable crops	Large reduction un the use of unsuitable crops and gradual change towards more resilient vegetation cover (forest/crops)	Maintain the use of unsuitable crops and vegetation cover; crop type selection highly dependent on subsidies; increase in water demand crops mainly in the south
Lack of infrastructures	Conclusion of projected reservoirs and reinforcement of current infrastructures for long term needs accounting environmental impacts;	Low level of infrastructures maintenance; partial and delayed conclusion of projected reservoirs; environmental impacts not fully accounted
High insurance costs	Significant reduction of insurance costs	Maintenance or increase of insurance costs
Water scarcity	Small increase in water scarcity, controlled within water resources management plan	Large increase in water scarcity, mainly in coastal areas and southern regions
Lack of knowledge about fish biomass in reservoirs-fish mortality prevention schemes	Knowledge about fish communities and their aquatic system increased and regularly updated; actions taken in due time as part of adequate management plans	Improved knowledge about fish communities and biomass; insufficient monitoring, thus actions only in a crisis situation

Table 3. 10: *Summary of storylines behind two case scenarios for mainland Portugal regarding environmental dimension.*

Underlying cause of vulnerability	Maximalist scenario "What comes around goes around"	Minimalist scenario "The water is mine"
Environmental dimension		
Diffuse pollution	Reduction in most of the country; maintenance of pollution levels in restricted areas, with compensation schemes implemented	Significant increase particularly in the south; insufficient monitoring and no compensation schemes
Increased river water abstractions	Updated register of surface water abstractions; levels maintained according to each river basin plan; control of illegalities,	Significant increase particularly in the south; insufficient monitoring and no control
Sand/grit extraction in water domain	Control of illegal and above carrying capacity, according to specific management plan	Increase in inert material extraction, not controlled
Low production of groundwater/ small reservoir capacity	Reservoir capacity maintain and increase by using below recharge capacity, alternatives sources, promoting infiltration, reducing ground pollution and account with intersazonality in demand	Accentuated recharge reduction, mainly in the south, increase contamination of those in use; exploitation above capacity, not accounting with sazonality; groundwater abstraction become unsustainable in Algarve
Climate Change	Lower than predicted although contributing to widening differences in water availability between regions; accounted in national and regional strategies for climate change adaptations;	Horst than expected; increase asymmetry in water availability and drought impacts between north and south of the country, not accounted in regional development /economic projects
Excess of fish biomass in reservoirs	Excess of fish biomass controlled; monitoring according to management plan	Increase excess of fish biomass, lack of monitoring,
Soil degradation	Reduced due to measures to counteract erosion, new technologies, green infrastructures	Increase in some regions, not monitored, liked with intensive farming practices

3.4.3.3 Quantification of scenario parameters

For the quantification of the described scenarios, data at river basin level were taken in consideration. In the River Basin Management Plans (RBMP) for Portugal mainland, water consumption trends were forecasted for short (up to 2015) medium (2009-2021) and long (2009-2027) terms, but not in all basins. For the southern ones (Sado-Mira, Guadiana and Algarve), projections for medium and long term were considered not significant in view of the plan objectives and its short lifetime (plan in force until 2015) (APA & ARH Alentejo 2012, 2012a, APA & ARH Algarve 2012).

Gross Domestic Product was the most important aggregate indicator in defining the baseline scenario (GDP increase ~1.1% to 1.2%/year), but many other factors were taken into account (e.g., demographic trends, the implementation level of governmental plans to develop the national economy and to preserve water resources). The minimalist scenario ("The water is mine") is associated with a more unfavourable perspective of economic development, compared to the present and with a moderate (or poorly) effectiveness of public policies, forecasted for 2015. It may lead in some sectors to a lower pressure, in terms of demand on water resources. The maximalist socioeconomic scenario ("What comes around goes around"), corresponds to a higher pressure on water resources due to the accomplishment of the main projects planned at regional and national level; the 'desired future' of this scenario requires good coordination and integration of policies and investments both, public and private.

The GDP defined for both scenarios was considered as a percentage of the baseline GDP: 75% for the pessimistic and 125% for the optimistic scenario.

The most relevant water consumption sectors are, and will be, urban/domestic supply and agriculture, but also livestock, energy, industry, tourism, and golf are taken into account, even if these sectors represent a smaller fraction of the water needs. The future evolution of distributed water for consumption in these sectors is summarized in Table 3. 11 to Table 3. 14. The values shown have no forecast nature, only representing possible evolution patterns of these variables. According to these projections, the level of water consumption for the two most demanding sectors will be maintain or decreased, with the exception of the southern basins (Table 3. 11 and Table 3. 12).

Table 3. 11: *Synthesis of the evolution of the forecasted distributed water for consumption in Urban supply for Portugal mainland. Values for Vouga, Mondego & Lis and Tejo basins include tourism consumption (+t). Data from RBMP (APA & ARH Norte 2012, 2012a, 2012b, APA & ARH Centro 2012, APA & ARH Tejo 2012, 2012a, APA & ARH Alentejo 2012, 2012a, APA & ARH Algarve 2012).*

River basin	Water Consumption (%) - 2009	Baseline scenario			Minimalist scenario			Maximalist scenario		
		2009-15	2009-21	2009-27	2009-15	2009-21	2009-27	2009-15	2009-21	2009-27
Minho & Lima	56.9**	→	→	→	→	→	→	→	→	→
Ave, Cavado & Leça	67.2**	→	→	→	→	→	→	→	→	↗
Douro	41.0**	→	→	→	→	→	→	→	→	→
Vouga, Mondego & Lis	25.8 (+t)	→	→	→	→	→	→	↑	↑	↑
Tejo	27.2(+t)	→	→	→	→	→	→	→	→	→
Sado & Mira	9.5	↗			↗			↗		
Guadiana	12.0	↗			↑			↗		
Algarve	27.8	↗			↗			↑		

Change rate: ↓: lower than - 50%; ↓: between -50% and - 25%; ↘: between -25% and -5%; →: between -5% and 5%; ↗: between 5% and 25%; ↑: between 25% and 50%; ↑*: higher than 50%. ** share of distributed water for consumption calculated without agriculture & livestock data*

Table 3. 12: *Synthesis of the evolution of the forecasted water distributed for consumption in Agriculture in Portugal. No data were available (NA) for the northern basins. Data from RBMP (see Table 3. 11).*

River Basin	Water consumption (%) - 2009	Baseline scenario			Minimalist scenario			Maximalist scenario		
		2009-15	2009-21	2009-27	2009-15	2009-21	2009-27	2009-15	2009-21	2009-27
Minho & Lima	NA	↘	↓	↓	↓	↓	↓	↘	↓	↓
Ave, Cavado & Leça	NA	↘	↓	↓	↘	↓	↓	↘	↓	↓
Douro	NA	↘	↓	↓	↓	↓*	↓*	↘	↘	↓
Vouga, Mondego & Lis	55.3	→	↘	↘	↘	↘	↘	→	→	→
Tejo	65.4	↘	↘	↘	↘	↘	↘	↗	→	→
Sado & Mira	81.7	↑*			→			↑*		
Guadiana	84.7	↑*			↑			↑*		
Algarve	57.0	→			↘			↗		

The large increase in water consumption in the Sado-Mira and Guadiana basins are linked with the recent implementation of the Alqueva reservoir and its subsidiaries infrastructures. The water distribution system will reach long distances and will be fully operational in a short term allowing a significant expansion of irrigated crop area. The Alqueva reservoir also contributes to bust the tourism sector in Alentejo, however for the other regions, the development of this sector (and its water consumption), is instead linked to expectations about GDP and to general projections for Europe, mainly for the coastline (Table 3. 13 and Table 3. 14). According to the RBMPs, estimated increases in consumption above 25% imply the adoption of measures avoiding degradation and over exploitation of water resources. This situation is evident for tourism in all regions and in agriculture in the south. However this indicator does not account with an increase in water efficiency and a shift in society concerns towards environmental sustainability, depicted in “what comes around goes around” scenario.

Table 3. 13: *Synthesis of the evolution of the forecasted water consumption in the Tourism sector in Portugal. Values for southern basins (Sado & Mira, Guadiana and Algarve) include golf consumption (+g). Data from RBMPs (see Table 3. 11).*

River Basins	Water Consumption (%) - 2009	Baseline scenario			Minimalist scenario			Maximalist scenario		
		2009-15	2009-21	2009-27	2009-15	2009-21	2009-27	2009-15	2009-21	2009-27
Minho & Lima	0.6**	↗	↑	↑	→	↗	↗	↑	↑	↑*
Ave, Cavado & Leça	0.6**	↗	↑	↑*	→	↗	↑	↑	↑	↑*
Douro	4.0**	↗	↑	↑*	→	↗	↑	↑	↑*	↑*
Vouga, Mondego & Lis	NA									
Tejo	NA									
Sado & Mira	0.7(+g)	↑*			↑*			↑*		
Guadiana	1.4(+g)	↑*			↑*			↑*		
Algarve	11.2(+g)	↗			↗			↑		

Change rate: ↓: lower than - 50%; ↓: between -50% and - 25%; ↘: between -25% and -5%; →: between -5% and 5%; ↗: between 5% and 25%; ↑: between 25% and 50%; ↑*: higher than 50%. ** share of distributed water for consumption calculated without agriculture & livestock data*

Table 3. 14: *Synthesis of the evolution of the forecasted water consumption in the Golf sector in Portugal. Data from RBMPs (references as in Table 3. 11).*

River Basin	Water consumption (%) - 2009	Baseline scenario			Minimalist scenario			Maximalist scenario		
		2009-15	2009-21	2009-27	2009-15	2009-21	2009-27	2009-15	2009-21	2009-27
Minho & Lima	0.6**	→	→	→	→	→	→	→	↗	↑
Ave, Cavado & Leça	0.3**	→	→	→	→	→	→	→	→	↗
Douro	2.5**	→	→	→	→	→	→	→	→	↗
Vouga, Mondego & Lis	0.2	→	→	→	→	→	→	→	→	→
Tejo	0.4	↑	↗	↗	↗	↑	↗	↗	↓	↑
Sado & Mira	NA									
Guadiana	NA									
Algarve	NA									

3.5 Switzerland

Two types of scenarios were examined for the Case Study of Switzerland. One scientific and Swiss-wide, developed by dozens of scientists and integrating new modelling and scenarios of the past. The second – a small one - is derived from a questionnaire survey of fruit-growers in the Northeast and Northwest of Switzerland, carried out in early 2013 (Kruse & Seidl, accepted). It concerns the expectations of fruit-growers regarding their cultivations given the prospect of climate change and increasing droughts. These expectations concern solely the domain of fruit-growing agriculture and may be valid for agriculture as a whole.

3.5.1 Swiss-wide socio-economic scenarios

To date the climate in Switzerland is dominated by a reasonably warm summer and a moderate winter, with a relatively even distribution of precipitation throughout the year. Through its humid conditions Switzerland is to date not suffering from water scarcity, but the extreme conditions in summer 2003 have highlighted that some parts of the country are susceptible to drought impacts. In this context, questions related to the nation's vulnerability to anthropogenic climate change, including future droughts, arise (e.g. Seneviratne et al. 2013).

In a series of national studies, selected aspects of anthropogenic climate change related to Switzerland's vulnerability have been investigated [OcCC/ProClim, 2007, C2SM et al., 2011, CH2014-Impacts, 2014].

The latest scenarios, the CH2014-Impacts Initiative, links the Swiss Climate Change Scenarios CH2011 that investigate scenarios for the 21st century. In the CH2014-Impacts Initiative three greenhouse gas scenarios, three future time periods in the 21st century, and three climate uncertainty levels are used (CH2014-Impacts, 2014, p. 9). The aim of this initiative is to "stimulate an on-going process toward the consolidation of scenarios that depict potential impacts of climate change … "Hence, the so called "impact scenarios" do not yet exist but a common basis has been developed. These "impact scenarios" shall "serve the interests of stakeholders, and aid politicians and decision makers in developing effective Swiss mitigation and adaptation strategies" (p. 16).

Model simulations suggest that a warming climate will alter the seasonality of terrestrial water variables, especially runoff. To date a considerable amount of winter precipitation is temporarily stored as snow and released in spring and summer through snow melt which feeds the rivers. In a warming climate, less winter precipitation will be stored as snow and consequently river flows are expected to decrease accordingly. This, paired with model simulations indicating decreasing summer precipitation as well as increasing temperatures suggests that droughts might occur more frequently in the future.

3.5.2 Expectations and scenarios of fruit-growers of Northeast and Northwest Switzerland

In early 2013, a questionnaire survey was organised and addressed to 1420 fruit-growers of Northeast and Northwest Switzerland. A total of 801 questionnaires were received filled out (return rate of 56,5 %). The questionnaire consisted of 5 parts, one of which concerned the farmers' damages so far due to droughts and their expectations regarding this topic. Most questions required ticking predefined choices, only few questions were open. The questions regarding their expectations for the future covered the topics whether droughts will be more frequent or longer in the future, whether and how they would change their practice in such a case, and whether they expect conflicts about water availability.

3.6 The Netherlands

3.6.1 Methodology

The related scenario development was taken up by three national institutions, i.e. Netherlands Environmental Assessment Agency (MNP); Netherlands Bureau for Economic Policy Analysis (CPB); National Institute for Spatial Research (RPB)[5]. Its purpose is to visualise the challenges that the Dutch government may expect when continuing with 'business as usual'. Structural measures in the physical environment usually take a long time to be realised, may be costly and have long-term consequences. Therefore, the government has to balance short term costs, benefits and risks with possible developments in the future. As well, there is a need to compare effects for different generations, social groups and regions.

It is well-understood that long-term trends such as a decreasing household size, an ageing population, international migration, economic growth, and increasing personal welfare, will change the Dutch natural and built environment significantly. Therefore, the scenario development analyses the combined impact

[5] Welvaart en Leefomgeving, een scenariostudie voor Nederland in 2040. L.H.J.M. Janssen, V.R. Okker, J. Schuur, 2006. Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau. (Available in Dutch only).

of these trends on various aspects of the Dutch urban and rural landscape, including residential and industrial land use, traffic & transport, energy, agriculture, nature & landscape, water safety, and environment & health.

The scenario development assessed the long-term effects of current policy, given the international economic and demographic context of The Netherlands. Its qualitative and quantitative results should serve as a reference for policy-makers involved in spatial planning, housing, natural resources, infrastructure, and the environment. By exploring how land use and various aspects of the living environment may develop on the long run (2040), the study shows when current policy objectives may come under pressure, and which new issues may emerge.

3.6.1.1 Scenarios and extensive integrated modelling

The long-term future of the Dutch population and economic development and, consequently, of its natural and built environment is highly dependent on international factors. Two critical factors of uncertainty stand out: (1) to which extent will nations and international trade blocks cooperate and exchange, giving up some of their cultural identity and sovereignty?, and (2) how will governments balance between market forces and a strong public sector? These international political choices determine four possible scenarios for the Netherlands:

- Global Economy: emphasis on international cooperation and private responsibilities.
- Strong Europe: emphasis on international cooperation and public responsibilities.
- Transatlantic Markets: emphasis on national sovereignty and private responsibilities.
- Regional Communities: emphasis on national sovereignty and public responsibilities.

The scenario analysis built on earlier work by the involved institutes, in which these scenarios were translated into four development paths for the Dutch economy and demography. For this application, the earlier economic and population scenarios, including their international contexts, were elaborated for application to the built and natural environment. This required both conceptual thought and extensive integrated modelling. Scenarios should include national policy to be realistic. To allow for statements on the future effects of current government policy and to compare these with alternative policies, trend-based policy is assumed in all scenarios.

Many factors determine the development of the Dutch physical environment, of which many are uncertain. Often these factors cannot be influenced by the Dutch government. The Netherlands is dependent on international developments in economy, politics and population. To be able to deal with these uncertainties, four scenarios were investigated , with an horizon until 2040, and they have been modelled around two key uncertainties, the ability and willingness of countries to cooperate internationally and the distribution of public and private responsibilities (more or less government control).

It needs to be remarked that, in the overall socio-economic scenario development, the issue of drought is not included in the thematic “results” (listed as housing; industrial land use; traffic and transport; energy; agriculture; nature and landscape; water safety; environment) the. The safety of the country, with about 50% of the land area below Mean Sea Level or prone to flooding from rivers, tops the water agenda in The Netherlands.

3.6.2 Final scenarios developed for The Netherlands

General findings of the socio-economic scenarios:

- Some problems will be less prominent after 2020
    - Increasing pressure on the physical environment due to the ever increasing need for housing, work and mobility, will get less mainly due to less population growth. Less population also leads to a decreasing demand for housing with a related decrease in spatial demand.

    - The ‘congestion’ in most scenarios will not grow after 2020
    - Changes in the growth of the workforce and changes in the economy will result in less need for offices and business areas: after 2020 there will be less spatial demand for this in three of the four scenarios
- Some problems will get more urgent after 2020
    - In certain parts of the large cities social and livelihood issues may increase because of restricted participation of certain groups. Education levels, emancipation and integration determine chances on the labour market
    - Climate change remains a persistent environmental problem, with flooding risks.
    - The landscape may become less attractive due to mono-functional scale increase in agriculture, ancillary agrarian activities, recreational facilities and further urbanisation.

In all scenarios, the population will age and can eventually decrease. This increase will occur earliest in the scenario with limited immigration. In most scenarios, the supply of labour and employment will decrease after 2020. A shrinking population can lead to long-term problems (empty housing, villages, business areas, etc.). But it also offers opportunities to improve quality through re-development and spatial planning. In all scenarios, the income per head of the population increases. Prosperity can increase because there is less pressure on collective goods as environment, safety and landscape.

With a continuation of current trends, there is a real chance that after 2020 the congestion in the traffic system will decrease and that there will be a surplus of infrastructure and business areas. This leads to a risk of ‘over-investment’ due to the long preparation time and long lifespan of investments in infrastructure and business areas.

Thematic results:

- International migration determines demand for housing
- Decreasing need for business area; need for re-structuring
- Traffic congestions will become less
- EU policy determines agriculture and dairy farming (with reducing land use for agriculture)
- The Netherlands will be more dependent on energy from coal and oil (renewable energy, contributing about 10% to the energy demand, will remain expensive for the near future)
- The risks for climate change will increase; water quality will remain influenced by earlier intensive application of nutrients; emissions from sewage will decrease due to investment programmes; air quality will improve.
- The bio-diversity in the rural area will deteriorate (not in the least with the more intensive and large-scale agriculture). Nature may suffer from desiccation (maintaining low groundwater levels for agriculture)
- Higher occurrence of flooding and excess water (higher river flow, more intense rainfall, rising sea level).
- Lower population growth leads to less pressure on land use. Demand for housing and business areas will decrease after 2020 (and the more so in areas where the population shrinks). The west of the country (Randstad) will experience demand for space.
- Size and composition of migrants determine the development of the large cities. The environment, the safety and the socio-economic conditions of these large cities remain under pressure.
- Liberalisation of agriculture will lead to less and larger farms, larger farm buildings and more greenhouses (although developments will occur less fast than in the previous 40 years). Advancing city limits will interfere with the openness of the rural area. City inhabitants will more and more visit the rural area for recreation and other secondary agrarian activities.

3.6.2.1 The scenarios linked to water

The scenarios[6] developed within the national Delta programme: two extreme climate scenarios, “Moderate” and “Warm” (i.e. without and with changed air-circulation over Europe) were combined with two ‘extreme’ socio-economic scenarios (one with high socio-economic growth and one with some socio-economic decline). These combined lead to a broad width of conditions between “the worst that can happen” and “the least that can happen”.

The following delta-scenarios are distinguished (Figure 3. 12):

- Quiet: moderate climate change “with less pressure on space”
- Full: moderate climate change “with more pressure on space”
- Warm: fast climate change “with less pressure on space”
- Steam: fast climate change "with more pressure on space"

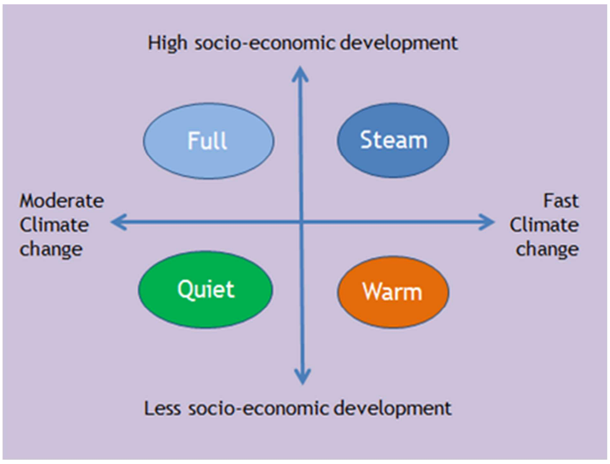


Figure 3. 12: *Scenario matrix for The Netherlands.*

In “Full” and “Steam”, the population increases considerably until 2050, there is considerable economic growth and the urban areas expand at the cost of land for agriculture and horticulture. These driving forces continue after the year 2050. In combination with higher temperatures, this also implies a larger per capita demand for drinking and industrial water. As well, the need for cooling water for energy production increases and water quality in urban areas will need to fulfil higher quality standards.

For “Quiet” and “Warm”, the increase in population is less and the population will eventually shrink! The economic growth is limited, resulting in less demand for drinking and industrial water, but the water demand for agriculture and nature will increase, especially with higher temperatures.

The issues in the national socio-economic scenario development include trends in individualisation, aging (increasing average age), migration, economic development. This had been investigated for a number of themes: housing, work, mobility, agriculture, environment, nature and water. As well, regional differences are weighed, and the spatial needs and future of both the ‘large’ cities and rural area have been taken into account.

[6] Ref. Synthesis of the national and regional analysis of bottlenecks. Under the auspices of the Delta programme, sub-programme Fresh water. May 2011 (available in Dutch only).

4 Future drought impacts in the Case Studies

4.1 Syros island, Greece

The most important drought impacts in Syros Island are: (i) yield reduction in agriculture, and (ii) water deficit in the agglomerations that are mainly supplied with water from groundwater bodies. Future impact assessment is focusing on these two sectors, by estimating impacts and the associated economic losses. A risk-based approach is followed, as illustrated in Figure 4. 1, and has the following Steps:

1. Step 1: Future drought characterisation in terms of severity, duration and frequency. Future SPI values have been estimated using climate projections from the FP7 WASSERMed project and analysed to develop Severity-Duration-Frequency curves. Future climate projections concern temperature and precipitation data for the 2011-2050 period from the HIRHAM5 Regional Climate Model, forced by the ECHAM5 GCM for the A1B IPCC scenario.
2. Step 2: Risk assessment on the basis of water shortages in the domestic and agricultural sectors. Water balance modelling for Syros Island was developed using the WEAP software and water deficits were estimated for the baseline conditions (2010) and for the future for three cases (baseline, best case scenario and worst case scenario). The economic losses were estimated using Eq. 3. Losses for domestic use correspond to the substitution cost (for alternative water supply of adequate quality) while for crop irrigation to the reduction in crop yield and income (no change in market prices assumed). The risk of economic losses is estimated as in Eq. 4.

$$Drought\ Economic\ Impact_s = f(DI_{T,D}.Q_s.I_s) \quad \text{(Eq. 3)}$$

$$Risk\ of\ economic\ losses_s = p_{T,D}.DEI_s \quad \text{(Eq. 4)}$$

Where:

$DI_{T,D}$:	Drought intensity for a return period T & duration D
$p_{T,D}$:	Probability of occurrence of a drought event for a return period T & duration D
Q_s:	Water availability (or deficit) for the specific sector (s)
I_s:	Parameters that specify the economic impacts in the specific sector (s)
DEI_s:	Drought Economic Impact for the specific sector (s)

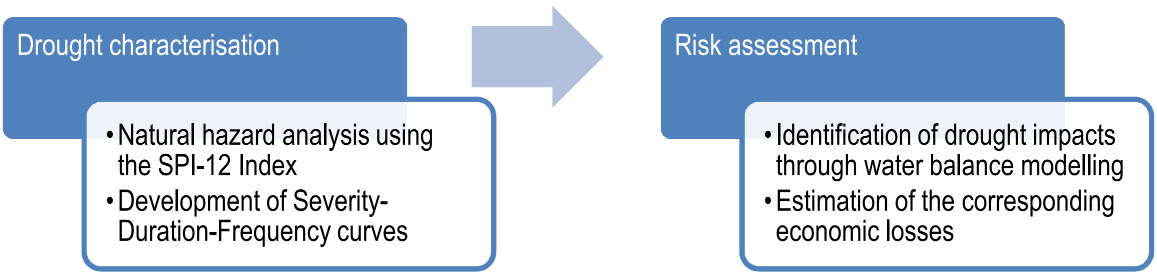


Figure 4. 1: *Future drought risk assessment in Syros Island.*

The schematic representation of the Syros water system (Figure 4.2) was based on the initial work within the framework of a study by the Ministry of Development (2008) which was updated (i.e. groundwater bodies, other water sources, links between demand sides and sources, desalination plants) using input from stakeholders. The system comprises of:

1. Fifteen (15) water demand nodes: Nine nodes of domestic and urban demand (population, cattle breeding, industrial demand) and six nodes of water demand for agriculture. The distinction is made according to the source of water (desalinated, groundwater or both).
2. Four (4) groundwater bodies: Four hydrogeological units have been defined according to the geological features of the region.
3. Nineteen (12) nodes for other types of water sources: five desalination plants, six nodes corresponding to water stored in cisterns, and one private network.
4. One (1) wastewater treatment plant, operating in the capital of the island, Hermoupolis.

The data, rules and assumptions used for the water balance modelling are listed in Table 4. 1.

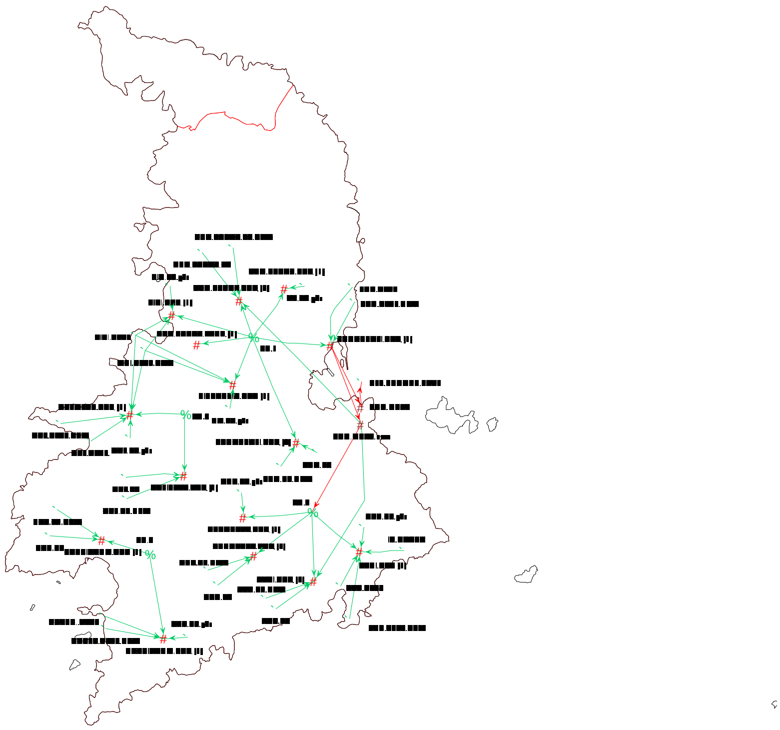


Figure 4. 2: *The schematization of the Syros water system in the WEAP software (red nodes: demand sites, green nodes: water sources).*

Table 4. 1: *Data sources for the Syros water balance model.*

Category	Description	Data sources
Priorities		
Water demand	Domestic, industrial and livestock breeding demands have a higher priority than crop irrigation	• Input from stakeholders & Ministry of Development (2008)
Water supply	Primary source of water supply for domestic and urban use is desalination, followed by groundwater and cisterns	• Input from stakeholders & Ministry of Development (2008)
	Agriculture is supplied mainly by groundwater, and secondary by cisterns	• Input from stakeholders & Ministry of Development (2008)
Restrictions		
Water supply from cisterns	Irrigation: accounting for about 15% of irrigation water supply	• Local Farmer Associations
Deficit irrigation	Only 80% in the water supply/water demand ratio is defined for the individual irrigation needs to account for the current practice of deficit irrigation	• Ministry of Development (2008)
Water demand		
Urban water demand	Calculated based on permanent population, seasonal population (summer housing), overnight stays and room occupancy, per capita consumption for all categories, and losses in water distribution networks	• Hellenic Statistical Authority, (Population census for 2001 and 2011) • Hellenic Statistical Authority and "CYCLADES" Tourist Apartments Federation (Arrivals, overnight stays, room occupancy, number of beds) • Hellenic Ministry of Development, 2008 (per capita consumption) • Municipal Enterprise of Water Supply and Sewerage of Syros (network losses)
Crop irrigation	Calculated according to cropping patterns (a distinction is made between arable crops, vegetables, olive trees, vineyards and orchards), effective precipitation, evapotranspiration, areas equipped for irrigation and irrigation efficiency.	• Hellenic Statistical Authority (2007 Agricultural Census) • Hellenic Ministry of Development, 2008 (irrigation efficiency)
Cattle breeding	Calculated using the number of animals per type and demand per head	• Hellenic Statistical Authority (2007 Agricultural Census)
Industry (secondary sector activities)	Default value	• Municipal Enterprise for Water Supply and Sewerage of Syros & Ministry of Development (2008)
Water sources		
Desalination plants	Capacity of existing desalination plants	• Municipal Enterprise of Water Supply and Sewerage of Syros
Groundwater	Calculation of natural recharge using climate data and a groundwater model, adapted from Kumar, 2002 and Kumar, 2004, and information by the Water Directorate of the Region of South Aegean	• Water Management Study for the Cyclades Complex, Prefecture of Cyclades, 2001 (capacity)
Cisterns	Capacity & volume of rainwater harvested; Estimates based on information on current demand coverage and precipitation pattern	• Local Farmer Associations
Private network	Percentage of demand coverage by the public network	• Water Directorate of the Region of South Aegean & Municipal Enterprise of Water Supply and Sewerage of Syros
Other data		
Wastewater treatment plant	Capacity	• Municipal Enterprise for Water Supply and Sewerage of Syros
Climate data	Precipitation & temperature	• FP7 WASSERMed project (HIRHAM5, REGCM3,RACMO2,RCA models driven by ECHAM5 for the A1 IPCC scenario)

4.1.1 Future drought characterisation

The future values of the SPI-12 index for the 2011-2050 period were statistically analysed (Table 4. 3; Table 4. 4) in order to develop the Severity-Duration-Frequency curves (Figure 4. 3), using the Gumbel Max probability function that best fits the SPI-12 data. Short drought events (with 1 to 3 months duration) are the most frequent (44-50%), while prolonged events (duration higher equal or more than 2 years) are calculated to be 15% to 33% of total drought events.

Table 4. 2: *Future drought events in Syros Island (SPI-12 calculated using the climate dataset from the HIRHAM5 Regional Climate Model, forced by the ECHAM5 GCM for the A1B IPCC scenario).*

Drought event	Drought duration (months)	Magnitude (-ΣSPI-12)	Drought event	Drought duration (months)	Magnitude (-ΣSPI-12)
Ιαν-11	1	-0.07	Φεβ 26 - Ιαν 27	12	-4.65
Απρ-11	1	-0.02	Δεκ 30 - Δεκ 32	25	-14.7
Οκτ-Νοε 11	2	-0.15	Νοε-34	1	-0.13
Φεβ-12	1	-0.02	Ιαν 36 - Οκτ 37	22	-23.11
Ιουλ-Αυγ 12	2	-0.04	Δεκ-37	1	-0.19
Οκτ-Νοε 12	2	-0.59	Δεκ 40 - Νοε 42	24	-20.62
Μαρ 16- Οκτ 17	20	-12.51	Νοε 43 - Οκτ 45	24	-18.47
Οκτ 20 - Οκτ 21	13	-17.33	Νοε 46 - Οκτ 47	12	-3.78
Φεβ 23 - Δεκ 23	11	-10.03	Δεκ 47 - Δεκ 50	37	-55.48

Table 4. 3: *Future drought characteristics in Syros island (SPI-12 calculated using the climate dataset from the HIRHAM5 Regional Climate Model, forced by the ECHAM5 GCM for the A1B IPCC scenario).*

Drought duration (months)	Probability of occurrence ($p_{T,D}$)	Number of events	Magnitude (-ΣSPI-12; ranked events according to severity)
1	28%	5	0.19; 0.13; 0.07; 0.02; 0.02
2	17%	3	0.59; 0.15; 0.04
11-13	22%	4	17.33; 10.03; 4.65; 3.78
20-24	22%	4	23.11; 20.62; 18.47; 12.51
>24	11%	2	55.48; 14.7

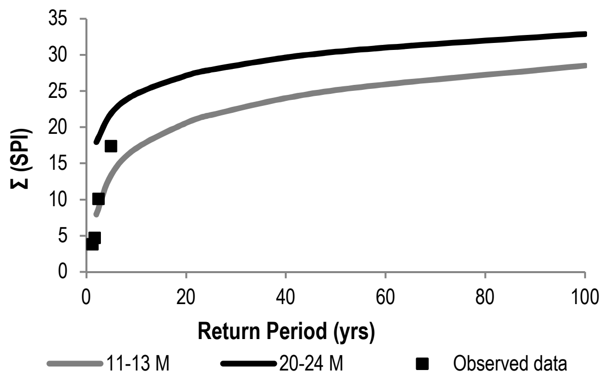


Figure 4. 3: *Severity-Duration-Frequency curves of future drought events for events of one and two years duration.*

Table 4. 4: *Future drought characteristics in Syros island (climate datasets from top and bottom values of the model ensemble.*

Ensembles top			Ensembles bottom		
Drought duration (months)	Probability of occurrence	Number of events	Drought duration (months)	Probability of occurrence	Number of events
1-3	50%	10	1-3	45%	9
6	10%	2	6-7	10%	2
9-15	25%	5	10-16	25%	5
>22	15%	3	>26	20%	4

4.1.2 Risk assessment on the basis of water shortages

Water deficits in the different water demand nodes were summed to estimate the total water deficit in the urban and agricultural sectors in Syros Island for the baseline conditions and for the best and worst case scenarios (Table 4. 5; Table 4. 6). As expected, water shortages increase as drought duration increases. An important note is that water shortages in the agricultural sector for the worst case scenario are less than the baseline conditions, as the total agricultural land that should be irrigated is reduced by 30% in this scenario.

Table 4. 5: *Future water shortage (million cubic meters) in the urban sector for drought events of different duration.*

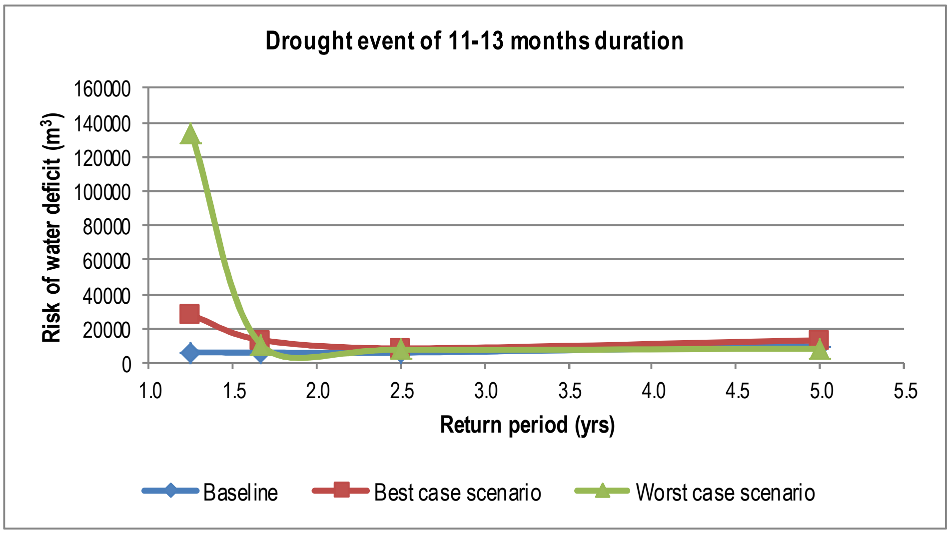
	Baseline conditions		Best case scenario		Worst case scenario	
Drought duration (months)	min	max	min	max	min	max
1	0.000	0.000	0.000	0.000	0.000	0.000
2	0.001	0.002	0.001	0.003	0.001	0.003
11-13	0.021	0.035	0.030	0.099	0.027	0.479
20-24	0.046	0.069	0.049	0.201	0.035	0.814
>24	0.053	0.123	0.103	0.504	0.218	2.083

Table 4. 6: *Future water shortage (million cubic meters) in the agricultural sector for drought events of different duration.*

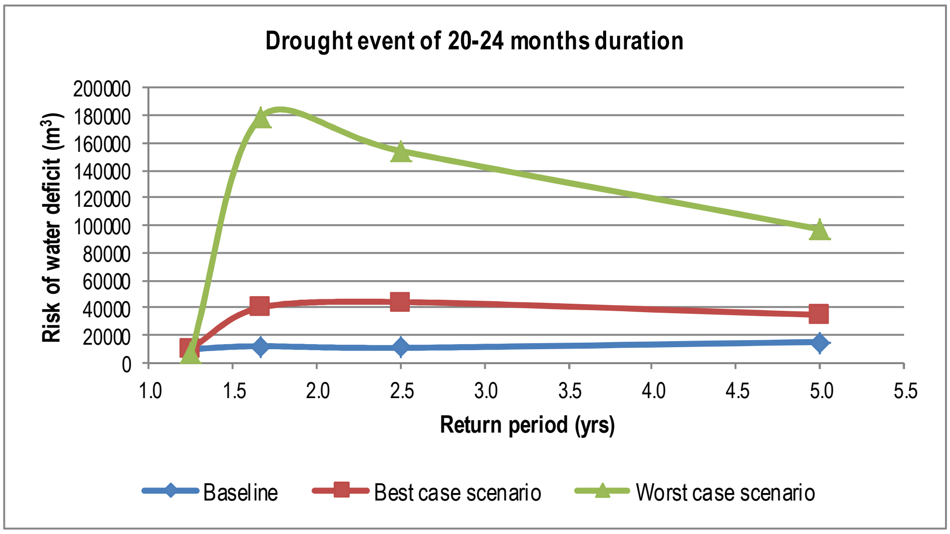
	Baseline conditions		Best case scenario		Worst case scenario	
Drought duration (months)	min	max	min	max	min	max
1	0.000	0.129	0.000	0.150	0.000	0.118
2	0.092	0.455	0.092	0.455	0.091	0.444
11-13	1.085	1.373	1.216	1.495	0.698	1.265
20-24	2.142	2.581	2.284	2.893	1.607	2.075
>24	2.347	4.486	2.605	4.162	1.928	3.054

Another critical point is that water shortages are a result of limited groundwater availability. Therefore, even if a drought event of relative low intensity follows a long period of low groundwater recharge, impacts may be higher than an event of higher intensity that follows a period of high groundwater recharge. This is particularly shown in Figure 4. 4a. The drought event of lower return period corresponds to the period November 2046 to October 2047, following a prolonged drought event in the period November 2043 to October 2045. Groundwater recharge in the period in between is insufficient to cover demand and thus high water shortages are estimated.

The risk of water deficit in the agricultural sector is shown in Figure 4. 5.

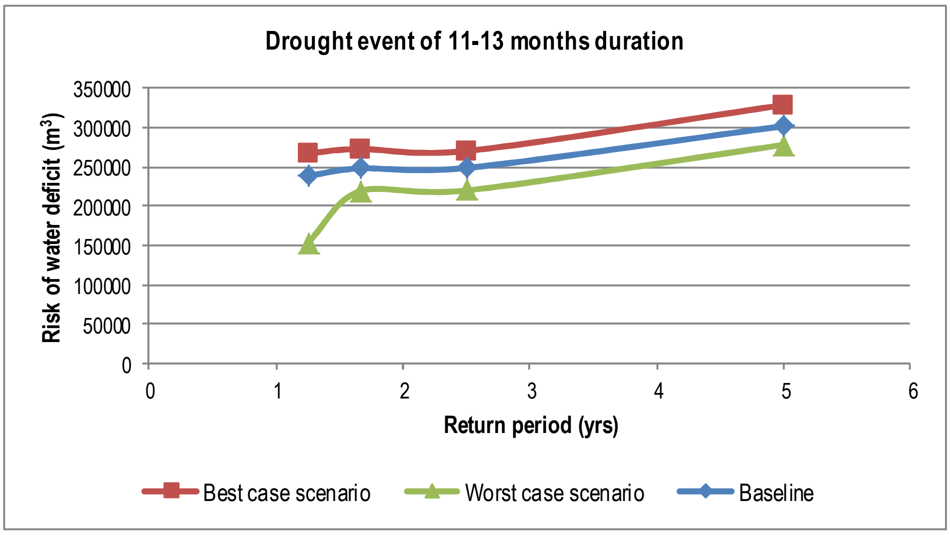


(a)

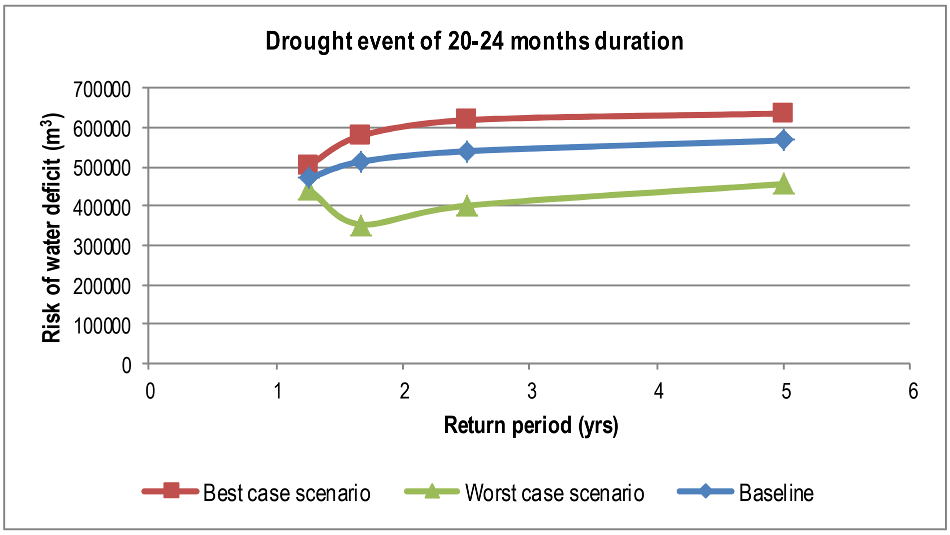


(b)

Figure 4. 4: *Risk of water deficit – domestic sector.*



(a)



(b)

Figure 4. 5: *Risk of water deficit – agriculture.*

The risk of economic losses is estimated on the basis of Eq. 4. Economic losses for the domestic sector are calculated assuming a substitution cost, i.e. cost of using an alternative water resource to cover the water deficit as in Eq. 5. For agriculture, economic losses are estimated using Eq.6 on the basis of crop yield reduction compared to the long-term average of crop yield. The estimation of the yield of irrigated crops is based on the equation of Smith and Steduto (2012).

$$DEI_{urban} = Price\ of\ alternative\ source.Water\ deficit \quad \text{(Eq. 5)}$$

$$DEI_{agriculture} = Crop\ area.Product\ price.Crop\ yield\ reduction \quad \text{(Eq. 6)}$$

Figure 4. 6 presents the total risk of economic losses in Syros island for a drought event of 20-24 months duration. Risk increases in both scenarios, being higher for the agricultural than the domestic sector. Groundwater availability defines the magnitude of drought-related impacts and thus groundwater should be preserved as a strategic reserve in the island.

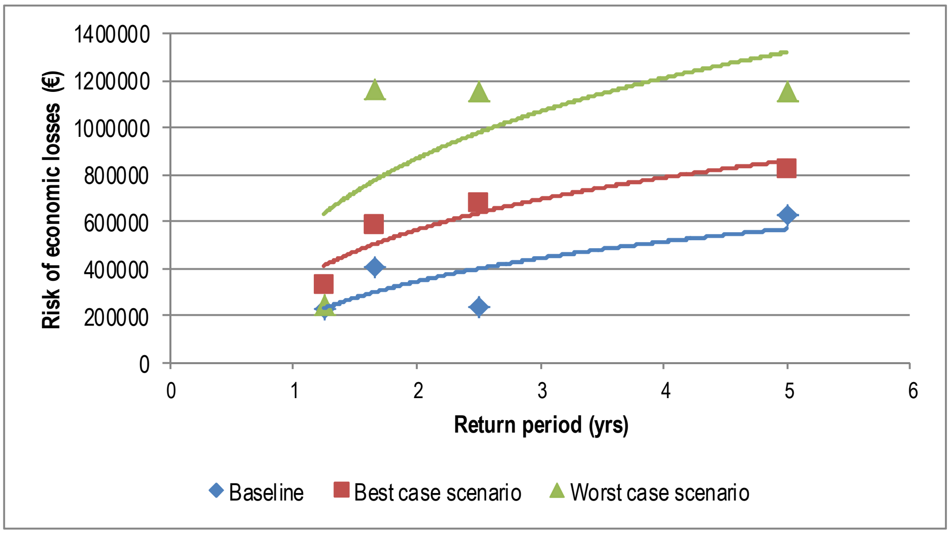


Figure 4. 6: *Risk of economic losses in Syros island (sum of losses in the domestic and agricultural sectors, drought events of 20-24 months duration).*

4.2 Jucar River Basin, Spain

The methodology for the integrated evaluation of climate change impacts on complex water resources systems requires the use of various simulation models in a nested sequence. This is due to the high level of complexity and interaction of the various elements of water systems, both in its quantitative aspects and aspects of chemical and ecological water quality and its socio- economic impact.

In any research study, the available information is very important, and in climate change studies climate information is especially relevant. Thus, it is necessary to have a climate database as complete as possible for a greater reliability of the results obtained. Once we have the weather data in the study area, the sequential impact evaluation process starts with the selection of the outcomes of the various climate scenarios existing for Spain. These scenarios are provided by General Circulation Models and by regional climate models so the results contain a greater spatial detail. The climatic variables resulting from these models are generally forecasts of temperature and precipitation variation.

An important part in assessing the impacts of climate change on water resources systems is the proper selection of scenarios, which generally must be made based on the experience of experts in the field. One can choose or propose different scenarios, among which are the incremental or synthetic, which can provide valuable assistance about system sensitivity to future climate. Sometimes, the increases in these scenarios may take as a guide the results of GCMs outputs given by the IPCC in its section on global regionalization, and selecting the corresponding to Spain. Another way to evaluate water resources scenarios is to use regional models so there is a wide range of scenarios that allow, in turn, evaluating the results for each one and analyzing the results for different seasonal periods, in order to know both global effects and those due to seasonal variations in rainfall and temperature and their possible effects on water resources.

Once the set of climate scenarios is selected, the next step involves simulating the hydrological cycle through a distributed rainfall-runoff model covering the entire watershed in a monthly time scale. This rainfall-runoff model will allow knowing where and in what proportion water resources will be reduced, and how this affects the various hydrologic cycle components and storages, such as the aquifer groundwater levels or soil moisture in upper layers (closely related to rainfed agriculture). Moreover, if these models include the transport of some chemical components dissolved in water, it would be possible to assess changes in water chemistry due to climate change, although this later aspect is not covered in the present study.

This first part of the methodology described above can be found in DROUGHT-R&SPI Deliverable 2.4 on the effects of climate change in future drought characteristics.

Once quantitative and, to a certain extent, qualitative impacts on watersheds are analysed, the next step is the evaluation of the management of water resources systems and particularly the assessment of any changes in reliability and number of shortages that may occur in the demands and environmental flows and reserves of the system, using models of water management as SIMGES, included in the Decision Support System Shell AQUATOOL (Andreu et al., 1996). This way the future implications of declining water resources in the operation system can be analysed.

At the Jucar River Basin Case Study, impacts are described as water deficits, or lacks in supply, that the different demands may suffer in case of drought. These shortages can be translated into economic values by using economic functions to assign an economic value to the water supplied (or to the unsupplied water) like was done in Collazos (2004) or Alvarez-Mendiola (2010). However, stakeholders in the basin agree that the values of supply shortages are enough to evaluate the severity of the drought episode, and so it is done in the meetings of the Permanent Drought Commission where the tools for decision making show possible storage levels and shortages.

Therefore, the future drought impact evaluation is done obtaining the shortages that occur in the system in each of the different scenarios defined in 3.2.5. The historic streamflow series were modified by the streamflow reduction factors obtained from the GCM models.

4.2.1 Water resources simulation model (SIMGES-AQUATOOL)

AQUATOOL (Andreu et al., 1996) is a Decision Support System Shell (DSSS) that includes a number of modules for the development of simulation and optimization models of water resources systems at the basin scale. It is developed by the Group of Water Resources Engineering, at the Department of Hydraulic Engineering and Environment, in the Universitat Politècnica de València.

The simulation model of water resources system of the Jucar River system used in this research has been developed with the SIMGES module (Figure 4. 7). It is a general model for the simulation of complex water resources systems that allows considering: regulatory elements of both surface and groundwater storage in the form of reservoirs and aquifers respectively; collection and transportation structures, either natural river streams or manmade channels and other facilities; areas of use and/or consumption of resources; and artificial recharge. Using SIMGES allows modeling the hydrographic system considered with extreme flexibility. The successive simulation provides supply values for each demand, flow values in transportation facilities, and storage values in reservoirs and aquifers. The model supports any configuration within limits imposed only by hardware capabilities, and thus is usable for any scheme of water resources.

The simulation is performed on a monthly basis and reproduces the spatial scale detail that the user wants for the flow of water through the system. Surface subsystems flow is simply calculated by continuity or balance, while for underground subsystems, or aquifers, flow is simulated using uni or multicellular models, as convenient, or even by distributed linear flow models. It also takes into account in the simulation filtration and evaporation losses in reservoirs and channels, as well as the relationship between surface water and groundwater.

The management of water resources is done by operating rules that allow reproducing any management rule in the system using reservoirs zone curves. These curves are the operating rules themselves and are user-supplied to the model. The definition of ecological minimum flow is allowed as well as different user priorities for water use.

The simulation of the surface system is performed at once by using a network flow optimization algorithm that solves the minimum cost problem. This algorithm is responsible for determining the flow in the system trying to satisfy to the maximum multiple objectives such as: minimizing deficits; maximum adaptation to reservoir target volume; and hydropower production target volumes.

Model results include the evolution of all variables of interest at the monthly and annual scale, average monthly values, and demands reliability. This allows the model to be used, among other purposes for:

- Determining the reliability obtained for different scenarios of infrastructure and evolving demands, as well with different rules for basin operation.
- Establish the most appropriate operation rules to meet required reliability levels.
- Estimate the profits or losses resulting from the alteration of water use priorities.
- Determine capacity of reservoirs, pipelines and pumping facilities for different demand levels and reliability.

The scheme of the Jucar River basin (Figure 4. 7) contains the most important elements of the system, both infrastructures and demands. It is not meant to be an exact representation of the reality but it is a good approximation of how the system behaves. Additionally, the construction of this model with all the included elements is the result of a participative joint development of the model in a commission in which most stakeholders were represented (Andreu et al., 2009), so it can be considered as a common vision of the water resources system, which results are trusted by the stakeholders.

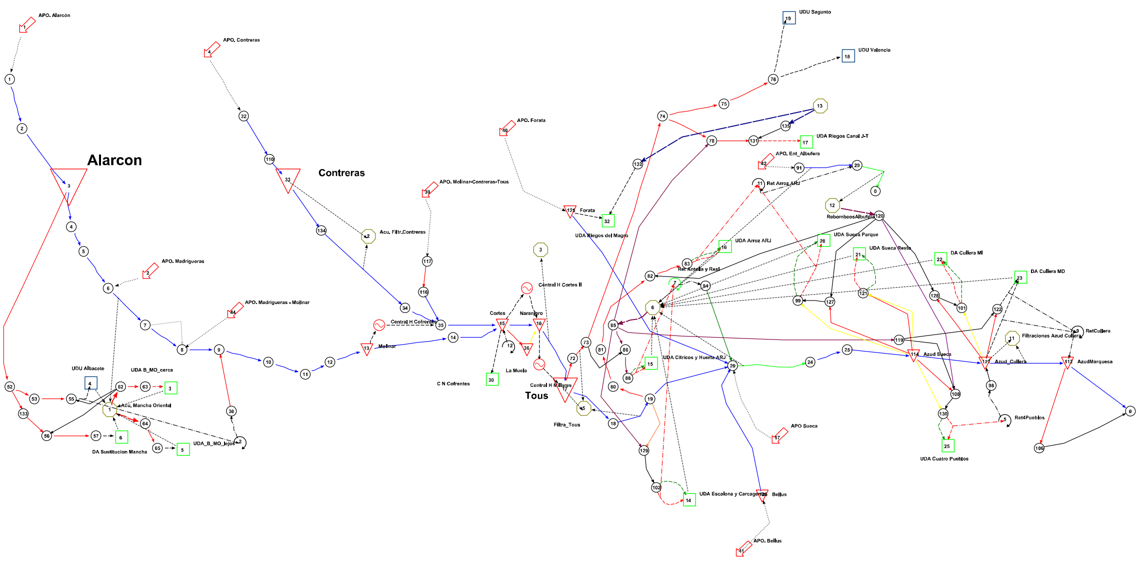


Figure 4. 7: *Scheme of the Jucar River Basin water resources system created with AQUATOOL.*

The demands included in the system can be divided into four groups, with different priorities: urban demands, corresponding to the cities of Albacete, Valencia and Sagunto, and with the higher supply priority; traditional irrigation demands in the lower course of the river (Ribera Alta and Ribera Baja); the irrigation demands of the Jucar-Turia Canal; and the mixed irrigation demands of Mancha Oriental.

The simulation model incorporates mechanisms to perform water allocation taking into account the priority criteria between demands set out in the Jucar River District Water Plan from the perspective of resource sustainability.

Thus, in the simulation of the system, we take into account the order of preference for each demand unit established in the hydrological plan. The model was calibrated so that, in the use of surface water, urban demands have priority over irrigation. And, in the latter, traditional irrigation has a higher priority than mixed irrigation.

Also, there is an order of preference for water withdrawals from the different regulation reservoirs included in the model. Water storage is prioritized in the reservoir of Alarcon, second in Contreras, and finally, in Tous. Therefore, if possible, water withdrawals will be first from Tous, after Contreras, and finally, Alarcon.

Similarly, the methodology developed in the Drought Plan for the determination of the various states - normal, pre-alert, alert and emergency - depending on the stored volume in the three main reservoirs (Alarcon, Contreras and Tous) was taken into account. This, together with the curve defined in the "Alarcon Agreement", allows establishing, within the range of possible reservoir volumes, five areas to apply different management strategies to minimize deficits and ensure urban supply.

In essence, the system management is performed by evaluating the level of resources stored in the system at the beginning of the irrigation season (April 1st) as follows:

- If the volume stored in the system exceeds the 570 hm^3, it is considered that the system is in normal situation so that urban demands are fully met, and the three irrigation demand groups receive maximum surface water supply, according with their maximum surface water assignment. From this point, irrigation demands from Mancha Oriental and from Jucar-Turia Canal complete their needs with groundwater.
- If the stored volume is between 570 and 420 million cubic meters, it is considered the system has entered in the pre-alert state, so it would be necessary to implement small austerity measures to protect surface resources available without compromising the supply to the demands. With this objective, urban demands still receive their normal supply and the supply level to all agricultural demands is restricted by 4%. In order to increase the surface resources saving, surface supply is restricted in Mancha Oriental and Jucar-Turia Canal by 15%, completing their needs with groundwater.
- If the stored volume is between 420 and 360 million cubic meters, it is considered that the system has entered the alert scenario. In this situation, the stored resources start to be scarce and, therefore, it is necessary to implement more restrictive measures than those applied in the previous situation. In this situation, urban demands continue to receive their normal supply while all agricultural demands suffer reductions in their total supply by 7%. Besides, the surface supply to Mancha Oriental and Jucar-Turia Canal is limited by 35%, completing their needs with groundwater and activating the drought wells that at the Jucar-Turia Canal area.
- If, at the start of the irrigation season, the stored volume is less than 360 and above 300 million cubic meters, these values correspond to an exiguous reserves situation in the system. Urban demands continue to receive their normal supply, and the level of supply to all agricultural demands is reduced by 10%. In this case, the extraordinary resources available in the system enter into operation. Surface water supply to irrigation demands at Mancha Oriental and the Jucar-Turia Canal is restricted by 55%, and these complete their requirements with groundwater. Being below the curve defined in the "Alarcon agreement" requires the activation of drought wells and the so-called "rebombeos" (reuse of irrigation returns), in addition to the drought wells to supply Jucar-Turia Canal irrigation demands, to release surface resources for their allocation among users
- Finally, if the stored volume is less than 300 million cubic meters, the use of extra resources is at its maximum, as well as the restriction levels to irrigation demands. Urban demands continue to receive their normal supply (although it may be necessary to activate wells to ensure the supply of the demand of Albacete), and the level of supply to all irrigation demands is restricted by 13%, but to Mancha Oriental and Jucar-Turia Canal that are restricted by 67 %. Being reserves below the USUJ (traditional irrigation and hydroelectricity) curve, all surface supply to urban and agricultural demands not belonging to USUJ must come from a trade with traditional irrigation,

which will draw the same amount from drought wells at Southern Valencia Plain, and from "rebombeos" in the rice field areas.

Complementary to the previous management rule, another rule is articulated under the provisions of the "Alarcon Agreement". This rule would operate as follows:

- The first day of every month must be checked whether the volume stored in Alarcon is below the curve defined by the agreement, in which case it would only be allowed to supply with surface resources to demands integrated into USUJ.

4.2.2 Main results from drought impact assessment

Impacts obtained from the different runs of the simulation model for each of the scenarios can be measured at several levels: individual, sectorial and the whole system. Table 4. 7 shows the deficits occurred in the system in the baseline scenario (or scenario 0). In this scenario, one can study what would the behavior of the system be with the existing management rules up to date and the complete observed streamflow series. Results indicate that the impacts in the system would be low under the current operation, if the flows were the same as the observed. Impacts occur precisely during the 2005-2008 period which, as commented in previous documents corresponds to the worse drought episode in terms of availability of resources.

Table 4. 7: *Deficit values for the baseline scenario.*

Scenario 0	Av. Deficit (Hm^3)	Max. Deficit (Hm^3)	Total Deficit (Hm^3)	Volumetric Reliability (Supply/Demand)
Urban Demand	0.00	0.00	0.00	100.00%
Albacete	0.00	0.00	0.00	100.00%
Valencia	0.00	0.00	0.00	100.00%
Sagunto	0.00	0.00	0.00	100.00%
Irrigation Demand	4.39	106.85	302.67	99.56%
Mancha Oriental	1.00	39.04	68.95	99.70%
Jucar-Turia Canal	0.32	10.93	21.74	99.67%
Ribera Alta	0.82	28.76	56.91	99.66%
Ribera Baja	0.69	25.80	47.63	99.75%
Jucar WRS	4.39	106.85	302.67	99.61%

Results can be shown too in the form of graphics to see their temporal distribution. Figure 4. 8 shows the evolution of the impacts for the period 1980-2008 at different scales (individual, sectorial and complete system). It must be noted that these graphs show the results of drought impacts as if the system had been managed in the way explained above during the whole period. This is why the impacts corresponding to the drought episodes of 1992-1995 and 2005-2008 appear to be so low or even inexistent.

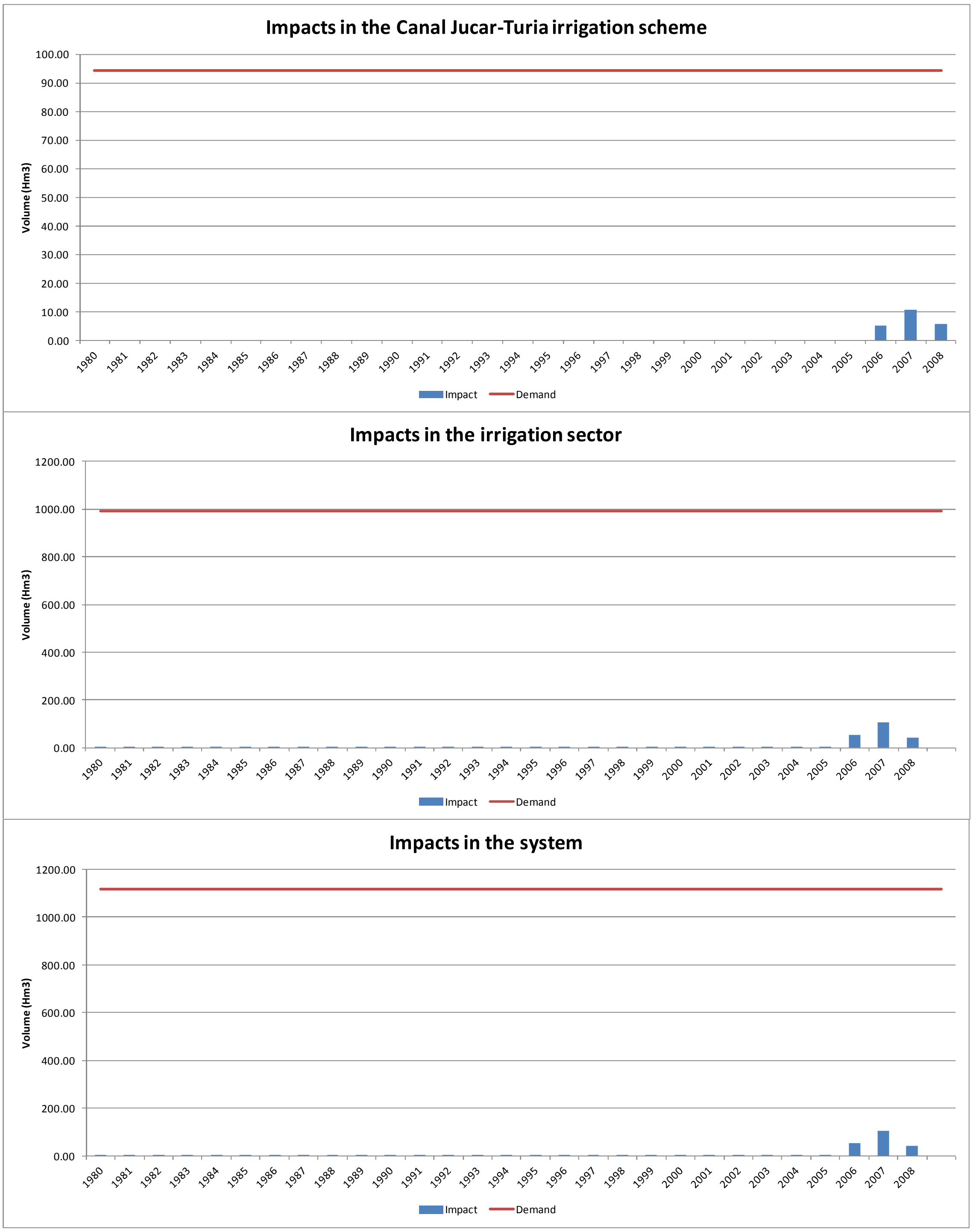


Figure 4. 8: *Evolution of impacts at different scales for the 1980-2009 period.*

Table 4. 8 to Table 4. 13 show the impacts, in terms of deficit in demands supply, of future streamflow situations. The results are obtained for streamflow series with the same length than the historic series used for the baseline scenario so comparison is possible.

Table 4. 8: *Deficit values for scenario 1: near future situation (2015).*

Scenario 1	Av. Deficit (Hm³)	Max. Deficit (Hm³)	Total Deficit (Hm³)	Volumetric Reliability (Supply/Demand)
Urban Demand	0.00	0.00	0.00	100.00%
Albacete	0.00	0.00	0.00	100.00%
Valencia	0.00	0.00	0.00	100.00%
Sagunto	0.00	0.00	0.00	100.00%
Irrigation Demand	15.67	253.01	1081.01	98.42%
Mancha Oriental	3.53	43.22	243.73	98.94%
Jucar-Turia Canal	1.41	23.50	97.39	98.50%
Ribera Alta	5.25	100.82	362.52	97.87%
Ribera Baja	3.90	83.62	268.88	98.58%
Jucar WRS	15.75	255.08	1086.69	98.64%

.

Table 4. 9: *Deficit values for scenario 2: medium future situation (2027).*

Scenario 2	Av. Deficit (Hm³)	Max. Deficit (Hm³)	Total Deficit (Hm³)	Volumetric Reliability (Supply/Demand)
Urban Demand	0.38	19.28	26.08	99.80%
Albacete	0.00	0.00	0.00	100.00%
Valencia	0.35	17.78	24.00	99.75%
Sagunto	0.03	1.51	2.08	99.75%
Irrigation Demand	39.28	387.91	2710.37	95.79%
Mancha Oriental	9.30	43.22	641.55	97.20%
Jucar-Turia Canal	4.28	37.69	295.46	95.46%
Ribera Alta	11.92	157.84	822.70	94.09%
Ribera Baja	11.88	145.98	819.89	95.49%
Jucar WRS	41.34	433.89	2852.44	96.43%

Table 4. 10: *Deficit values for scenario 3: 2040-2070 HadCM2.*

Scenario 3	Av. Deficit (Hm³)	Max. Deficit (Hm³)	Total Deficit (Hm³)	Volumetric Reliability (Supply/Demand)
Urban Demand	17.78	48.12	1226.87	91.41%
Albacete	15.69	15.69	1082.28	51.94%
Valencia	1.97	30.28	136.06	98.76%
Sagunto	0.12	2.16	8.53	99.19%
Irrigation Demand	138.60	505.22	9563.09	86.60%
Mancha Oriental	16.36	42.61	1128.69	95.18%
Jucar-Turia Canal	10.59	33.88	730.95	89.50%
Ribera Alta	65.98	254.41	4552.52	74.95%
Ribera Baja	43.38	170.83	2992.90	85.00%
Jucar WRS	158.90	565.55	10963.99	87.40%

Table 4. 11: *Deficit values for scenario 4: 2070-2100 HadCM2.*

Scenario 4	Av. Deficit (Hm^3)	Max. Deficit (Hm^3)	Total Deficit (Hm^3)	Volumetric Reliability (Supply/Demand)
Urban Demand	32.19	91.47	2221.25	86.97%
Albacete	21.99	21.99	1517.35	43.53%
Valencia	9.61	64.54	663.26	94.94%
Sagunto	0.59	4.94	40.65	96.75%
Irrigation Demand	218.55	521.27	15079.69	79.51%
Mancha Oriental	28.12	48.84	1940.28	92.45%
Jucar-Turia Canal	17.94	35.76	1237.78	82.54%
Ribera Alta	101.90	260.87	7030.82	60.94%
Ribera Baja	67.85	171.04	4681.93	76.53%
Jucar WRS	256.19	627.93	17677.11	80.79%

Table 4. 12: *Deficit values for scenario 5: 2070-2100 HadCM3 B2.*

Scenario 5	Av. Deficit (Hm^3)	Max. Deficit (Hm^3)	Total Deficit (Hm^3)	Volumetric Reliability (Supply/Demand)
Urban Demand	42.11	124.36	2905.33	82.95%
Albacete	22.00	22.32	1517.79	43.51%
Valencia	18.84	96.12	1300.15	90.08%
Sagunto	1.27	6.67	87.39	93.01%
Irrigation Demand	452.72	657.22	31237.59	63.39%
Mancha Oriental	47.83	56.31	3299.93	88.40%
Jucar-Turia Canal	63.56	73.48	4385.57	54.76%
Ribera Alta	206.42	319.94	14242.67	35.48%
Ribera Baja	131.66	202.72	9084.21	59.13%
Jucar WRS	503.08	801.34	34712.71	66.54%

Table 4. 13: *Deficit values for scenario 6: 2070-2100 A2.*

Scenario 6	Av. Deficit (Hm^3)	Max. Deficit (Hm^3)	Total Deficit (Hm^3)	Volumetric Reliability (Supply/Demand)
Urban Demand	64.19	170.06	4429.26	75.91%
Albacete	25.06	25.07	1729.44	40.34%
Valencia	36.77	134.96	2536.91	82.06%
Sagunto	2.36	10.03	162.91	87.92%
Irrigation Demand	607.24	734.62	41899.28	54.56%
Mancha Oriental	57.90	61.29	3995.03	86.81%
Jucar-Turia Canal	90.00	95.16	6209.67	44.50%
Ribera Alta	276.61	349.47	19086.34	20.85%
Ribera Baja	179.28	223.94	12370.50	47.91%
Jucar WRS	683.03	924.63	47128.89	57.91%

It is possible to observe that there is a generalized increase of the deficit as the horizon analyzed increases.

Drought affects more severely demands that rely mostly in surface supply, while those capable of receiving some groundwater supply suffer less. However, it is important to note that pumping from aquifers has important technical and environmental consequences that are not completely reflected in this study. Under the important streamflow reductions of the climate change scenarios, the amount of water that could be pumped from aquifers would very likely decrease in order to safeguard environmental flows and probably other uses with higher priority than the irrigation demands at Mancha Oriental. Thus, the impacts in that particular region would be probably higher than reflected in the tables, and would maybe decrease in other demands.

Anyway, the main conclusion to this point is that drought impacts are very likely to increase in the future and thus it will be necessary to pay special attention to system management. The improvement of indicators systems and the need of advanced prevention and mitigation measures should become a priority. In the same way, it will be necessary to define new adaptation and/or mitigation measures and strategies to cope with these negative effects.

4.3 Portugal

4.3.1 Methodology followed for future impact assessment

In this section we select two of the major impacts perceived during the last drought events (MAMAOT 2013a) and which are expected to maintain or increase in magnitude in the future: agricultural losses and wildfire extent (Amatulli et al., 2013; Bedia et al., 2014; Parrya et al., 2004).

Agricultural loss, namely a reduction in rain-fed crop production is a recurrent significant drought impact, particularly in the southern regions, where urban systems supply as the first priority, subtracts water resources from agriculture. An impact in crop production was assumed to reveal a reduction in both, cultivated area and crop fitness. We centred our attention on the identification of specific periods where the shortage of water is crucial to maximise the referred impacts, by exploring the links between variables having available long-term data series and meteorological drought indicators, as SPI.

Monthly SPIs were used as candidate explanatory variables to model wildfire extent and crop production change, using their anomaly (proportional change), in relation to a multi-year moving average which length was determined by the structure of the time series data as detected by autocorrelation analyses:

$$Yanomaly = Yproportional\ change = (Yobserved - Ymov.average)\ /Ymov.average$$

The approach of using moving averages for continuous variables (as crops or fires) is justified because these data do not typically fluctuate around a constant mean, but show multi-annual trends that can reflect the influence of socio-economic factors (e.g. political changes, wars, technological developments). Therefore, in order to detect the possible signal of drought in annual crop production and fire extent it is important to remove these multi-annual trends. SPI values were calculated on the basis of long-term series of monthly precipitation (1979-2009) based on the WFDEI (Watch Forcing Data ERA-Interim). Annual Crop production (wheat, rye, rice, corn, potato, olives and vineyard) were extracted from Eurostat database (1986-2009). Data for annual burned area in Portugal by wildfires (1985-2010) from the European Fire Database (compiled by the EU JRC) were used after log transformed.

Once defined the moving average period, we performed a correlation analysis (Pearson r) to detect the most significant links between monthly SPIs (of the current year and the last 3 months of the previous year) and the proportional change in several crop productions and in log-transformed annual burned area. These later variables were in turn modelled using a multiple regression model (stepwise method) with all possible linear combinations of SPI1, SPI2, SPI3, SPI6, and SPI9 as candidate independent variables. Correlation values and regression coefficients were considered statistically significant for $p<0.05$.

The equations obtained were solved in order to access the change (in %) for crop production and area burned by wildfires in mainland Portugal induced by droughts of different intensity Severe and Extreme corresponding to SPI-1 and SPI-2 respectively (Paulo & Pereira 2006).

4.3.2 Main results from impact assessment

The analyses of long term series of wheat and corn production in Portugal indicate that statistically significant partial autocorrelations of these data exist for lags 1 and 2 years. Similar results were obtained for area burned by wildfires (log transformed) and other crops. Accordingly we considered that a 4 year moving average (2 previous years and 2 following years) were adequate to smooth these data in order to better detect the annual anomaly (in crop production or fire) that could be related to a drought indicator such as SPI. Significant correlations between SPIs and impact variables were found, although they varied markedly according to crop type. For example, rainfed winter cereals were negatively affected by winter precipitation and positively by spring rain (Figure 4. 9). An inverse pattern regarding winter rain was observed for area burned by wildfires (SPI 1, Figure 4. 10). In a Mediterranean country such as Portugal, a water surplus by the end of winter benefits fuel accumulation, namely the biomass of the herbaceous layer, which easily burns during the summer (Pellizzaro et al. 2007, Gouveia et al. 2009).

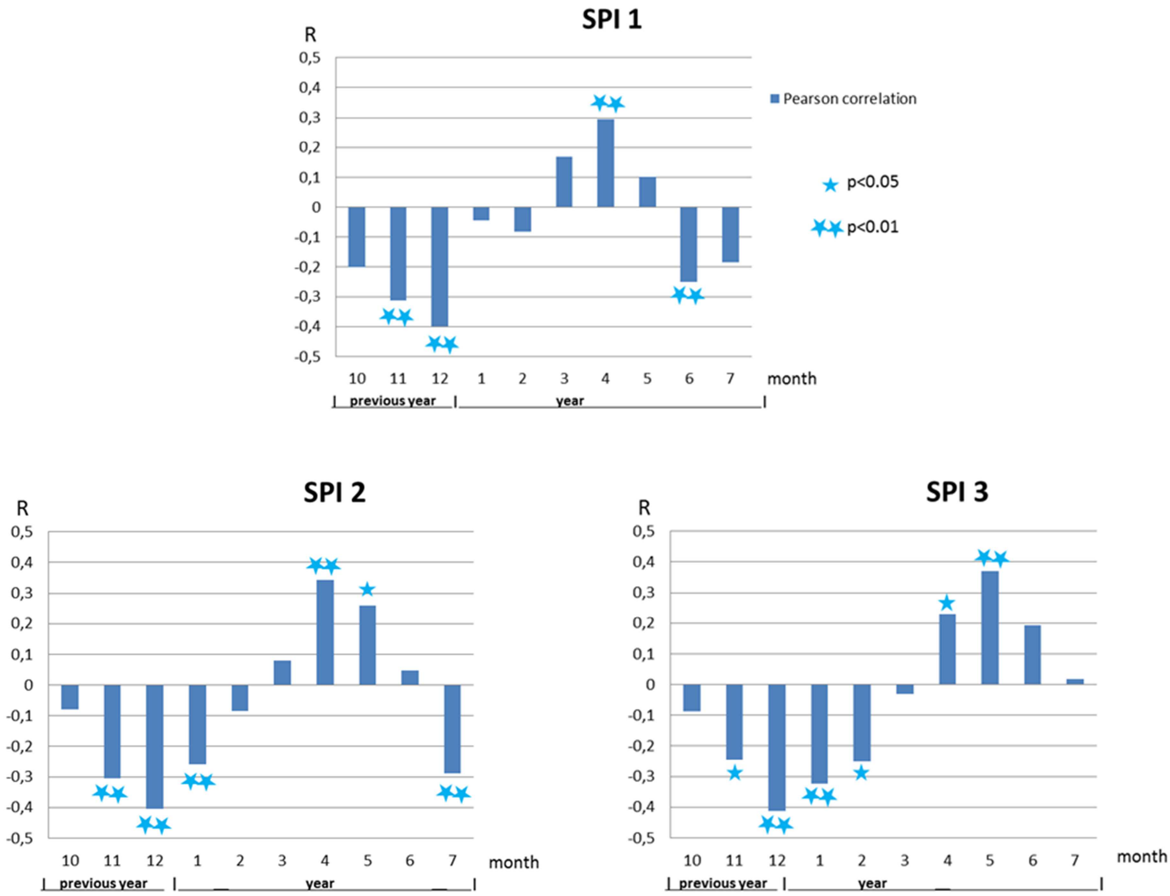


Figure 4. 9: *Correlations between SPI1 SPI2 and SPI3 and Wheat crop changes (1986-2009) in Portugal.*

According to our results, accumulated deficit of precipitation from May to July is a good candidate for predicting larger annual wildfire area (Figure 4. 10, SPI3). A significant positive effect of summer drought (especially when evaluated by SPEI) in wildfire extent, was also found by Stagge et al. (2014) for several European regions. Medium-term SPI (6), commonly used to indicate drought impacts occurring in rainfed agriculture, was also significantly correlated with anomaly in the burned area. In fact SPI6, from September was the variable selected by the model that best explain the yearly anomaly in the area burned in Portugal (Table 4. 14). Accumulated precipitation deficits from April to September results in low moisture content in forest fuels and therefore in larger areas burned due to more intense wildfires. SPIs of shorter period were select by modelling the drought impacts on annual crop production change (Table 4. 14).

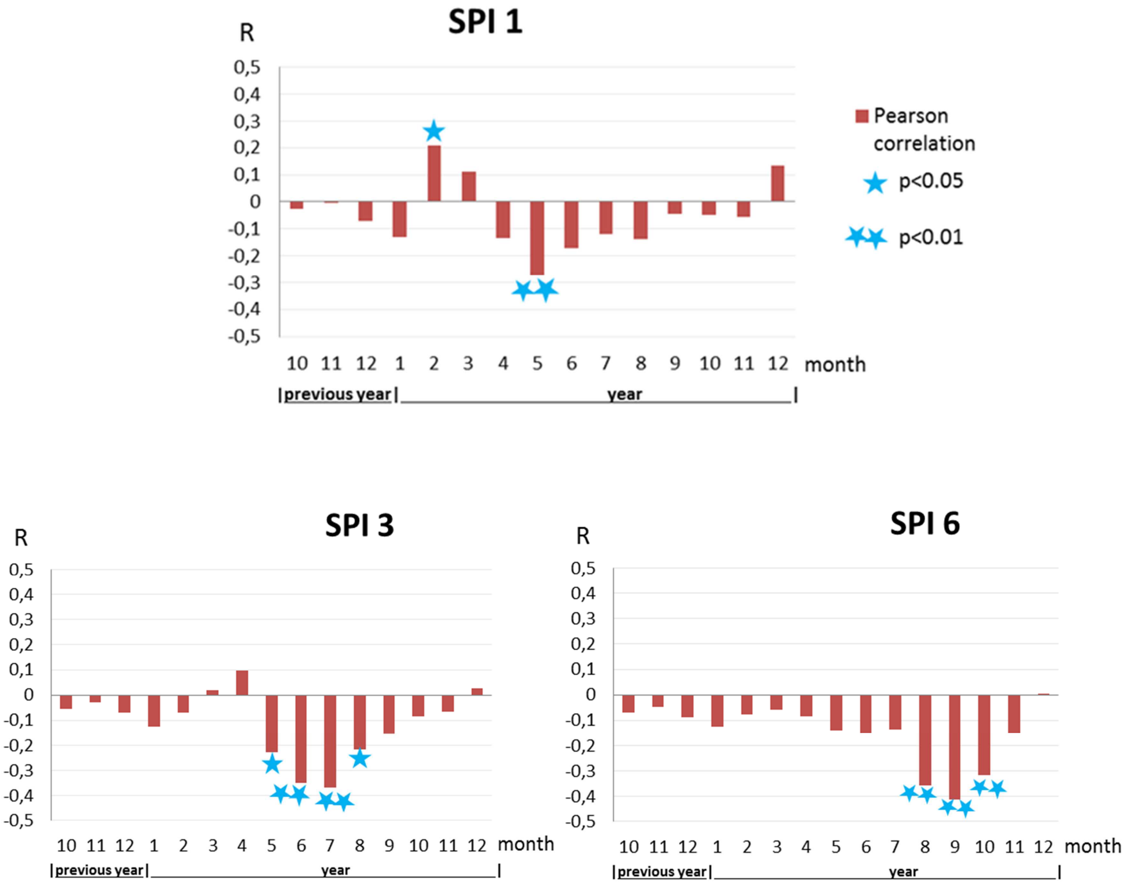


Figure 4. 10: *Correlations between SPI1, SPI3 and SPI6 and Log Forest Fires change (1986-2009) in Portugal..*

Table 4. 14: *Model results of the linear regression (through the axis origin) obtain for log fire Change and several crop production changes in Mainland Portugal.*

Model equation	R
$Y_{LogFire\_Change}$= - 0,047 × SPI_6_Sep;	0,412
Y_{Wheat_Change} = - 0,179 × *SPI_3_Dec* + 0,161 × *SPI_3_May*	0,592
Y_{Rye_Change} = -0,075 × *SPI_3_Mar*	0,121
$Y_{Grain\_maize\_Change}$ = 0,032 × *SPI_2_May*	0,292
Y_{Potato_Change} = 0,078 × *SPI_1_Aug*	0,385
Y_{Rice_Change} = 0,071 × *SPI_3_Aug*	0,361
$Y_{Olive\_trees\_Change}$= -0,223 × *SPI_6_Nov_Year_Before* + 0,143 × *SPI_1_Aug*	0,529
$Y_{Vineyards\_Change}$ = 0,055 × *SPI_2_Aug* - 0,062 × *SPI_2_Jun*	0,392

The outcome of our approach for the quantification of drought impacts from mainland Portugal is summarized in Table 4. 15. When in the equation included two significant SPIs, the changes were computed twice, with the other SPI having value zero.

The burned areas change equation was estimated using natural logarithmic transformations. Therefore the relative change is in log scale and it can only be seen as an exponent coefficient. We can thus transform the equation developed in log scale:

$$Y_{LogFire\_Change} = -\ 0{,}047 \times SPI\_6\_Sep$$

Where $Y_{LogFire\_Change}$ was defined as $(Y_{LogFireobserved} - Y_{LogFiremov.average}) / Y_{LogFiremov.average}$

It is possible re-transforming the previous equations, where the dependent variable is not the $Y_{observed}$ but the predicted area burned, $Y_{predicted}$, that can be estimated as a function of the reference value of the area burned for that spatial and temporal unit $Y_{reference}$, already defined as $Y_{moving\ average}$:

$$Y_{predicted} = Y_{reference}\ \ (1 - 0.047 \times SPI\_6\_Sep\ )$$

Of course we have for average conditions, SPI=0, $Y_{predicted}=Y_{reference}$.

For positive SPI values $Y_{predicted} < Y_{reference}$, and for negative SPI values (drought conditions) $Y_{predicted} > Y_{reference}$. For instance:

for SPI = -1 $\quad Y_{predicted} = Y_{reference}\ ^{1,047}$

and for SPI = -2 $\quad Y_{predicted} = Y_{reference}\ ^{1,094}$

Table 4. 15: *Changes in crop production for values of SPI -1 and -2.*

Crop Change	SPI assumed as independent variable	SPI= -1	SPI= -2
Wheat	SPI 3 Dec (SPI 3 May=0)	18%	36%
Wheat	SPI 3 May (SPI 3 Dec=0)	-16%	-32%
Rye	SPI 3 Mar	8%	15%
Grain maize	SPI 2 May	-3%	-6%
Potato	SPI 1 Aug	-8%	-16%
Rice	SPI 3 Aug	-7%	-14%
Olive trees	SPI 6 Nov Year Before (SPI 1 Aug =0)	22%	45%
Olive trees	SPI 1 Aug (SPI 6 Nov Year Before=0)	-14%	-29%
Vineyards	SPI 2 Aug (SPI 2 Jun=0)	-6%	-11%
Vineyards	SPI 2 Jun (SPI 2 Aug=0)	6%	12%

According to our approach wheat and olives will experience the largest changes in production due to drought. These crops are mainly concentrated in the south of the country and currently subject to external drivers such as CAP subsidies.

4.4 Switzerland

Switzerland has a complex geography where both temperate and cold high altitude climates can be found in close proximity. Therefore, future climate change is likely to have contrasting impacts depending on the geographic location. Consequently, general predictions cannot be made. Overall, negative drought impacts are most likely to occur on the Swiss Plateau where future decrease in summer stream flow implies increasing water scarcity but also in classical dry regions within the Alps (e.g. Valais). This in turn suggests an increasing vulnerability to extremely dry conditions.

4.4.1 Implications for forest ecosystems

Ecosystem response to climate change is complex and depends largely on the current system characteristics. Factors including species composition, current climate and management practice do influence the response. Generally, the increasing temperatures paired with the tendency for drying summers implies that forests in Switzerland will change in species composition (disappearance of spruce and beech), that the trees get under increased stress and more vulnerable to drought, pests, fire etc. in the future. Actually, some reports do already indicate that drought impacts on forest ecosystems are already evident in the driest parts of Switzerland and at low elevations (e.g. Valais). On the other hand, moderate temperature rise will increase forest growth in areas with presently low temperatures – provided that there is enough water. Overall, the implications are quite different regionally, yet can be profound in affected and vulnerable areas.

4.4.2 Implications for agriculture

Increasing temperatures imply an extending growing season, in some places higher productivity, higher water demand, heat stress for dairy cows, and both increased and decreased pest pressure (p. ex. more codling moth – an apple pest -, but also less fungi on fruits). Vine production will be favored due to a wider array of species and better growth. Overall current production systems might become more dependent (a) on regular precipitation and/or (b) on irrigation. As precipitation is projected to decrease in the summer months this implies that long periods with low precipitation in the growing season might increase. As river flow is also projected to decrease in the growing season, this water source might not be sufficient to satisfy the emerging water demand in extreme conditions. Conflicts over water use may come up. Consequently, Swiss agriculture is likely to become more vulnerable to drought in a warming climate, although the report found – in line with earlier assessments - that “on balance, beneficial impacts on agriculture under the moderate degree of climate change projected for the first half of the century.” It goes on stating that “negative effects are, however, expected to dominate in the long term as climate change progresses, except for the case of effective mitigation [scenario RCP3PD])” (CH2014-Impacts, 2014, p. 8).

When it comes to fruit-growing in Northeast and Northwest Switzerland, 79% of the farmers expect (rather) more frequent droughts, 50% believe their farm will be more often concerned of droughts and 46 % expect that they will be more often involved in conflicts over withdrawal of water. Yet, only 32% believe that their cultivation will depend on fixed irrigation, and their readiness to invest in it will depend on the future frequency of droughts. Overall, many farmers are willing to implement countermeasures in the future if droughts will increase.

Although an increase in droughts is expected for the whole Switzerland, climate modelling and scenarios focusing agriculture in the Northeast and Northwest Switzerland do not expect important deficits in water availability in the relevant pluvial catchment areas by 2065 (Fuhrer / Calanca 2014) although in principle, scarcities are possible. In the same vain, the Swiss government does not consider this area as particularly vulnerable to droughts (Schweizer Eidgenossenschaft 2012, p. 24). Hence, there will be more droughts but there may not be widespread lack of water in the area of Northeast and

Northwest Switzerland – hence irrigation facilities and drought-adapted cultivation will suffice to face potential droughts.

4.4.3 Implications for public water supply

The general pattern of decreasing river runoff in the summer months (yet higher winter runoff – and little change in total annual volume) implies that some water reservoirs might be depleted in extremely dry summers. In addition, significant amounts of drinking water are extracted through bank infiltration, which taps ground water adjacent to rivers. As ground water levels in the vicinity of rivers do largely depend on the rivers water level, this water resource is likely to also become more vulnerable to droughts in a changing climate. Yet, as in most regions the public water supply is linked between municipalities, the danger of shortages is limited (– if agriculture is not tapping public water supply).

4.4.4 Implications for other industries

Due to the changes in seasonal water availability hydropower production is projected to change accordingly. Overall, there is a tendency for increased production in winter (about 10%) and decreased production in summer (4-6%), and overall a slight increase of 0.9-1.9% is projected (CH2014-Impacts, 2014, p. 64). Still, in the mid- (2060) and long term (2085) production loss for single hydropower stations may not be excluded. Beside the production quantity, hydropower producers are interested in the value of electricity produced: interviews revealed that price fluctuations and developments on the energy markets may be more important for hydropower producers than physical impacts by climate change (Staehli et al. 2013). Winter tourism will be affected – by higher temperatures, less snow, in particular in lower altitudes, and less reliable snow coverage. Yet, winter tourism in high altitudes may be favored due to concentration to these places.

4.5 The Netherlands

The Netherlands owes much of its prosperity and welfare to its water supply. There is a large variety of special water-dependent nature as well as landscapes that depend on the availability of water. A considerable part of the economy depends on fresh water, namely agriculture & horticulture, the food and chemical industry, the energy sector, the recreation sector, the inland fisheries and navigation. About 8.5% of the working population works in a water-related job. Water is an important factor in the national economy, with a total production value of about € 183.5 Bn (i.e. 16% of direct production value).

A drought impact is the change caused by a projected change in drought, measured relative to a continuation of present drought conditions. While seemingly simple, this concept embeds difficulties that limited the power and utility of impact assessments. Three difficulties are especially prominent: complex causal linkages between impacts, vulnerability, and adaptation; linkages between multiple domains of drought impact at various spatial scales; and multiple stresses, environmental and other, that are occurring with drought.

4.5.1 Methodology followed for the future impact assessment

The study of “future drought impact and vulnerability” in The Netherlands is embodied in the national Delta Programme. The ultimate aim of this Programme is to develop water management in the Netherlands in such a way that the water system is resilient and can face the overall climate scenarios, and that only in very extreme situations crisis management will be needed. Many aspects play a role, in the field of the living environment and economy, as well as in the field of nature, agriculture, and recreation. The Delta Programme is in the process of developing an integrated strategy to prepare The Netherlands for changes in the environment, like higher ánd lower river flows, sea-level rise, soil-subsidence and salinisation. Integrated here means connecting environmental factors with socio-economic developments.

In The Netherlands, sufficient availability of fresh water has always been taken for granted as there is practically always an annual precipitation excess. Even in dry years, there is discharge of fresh water to the sea. Only because of a ‘mismatch’ between demand and availability there will be ‘bottlenecks’ in the future, with bottlenecks already occurring in the occasional dry years now. So far, the occurrence of bottlenecks is accepted and that is the reason that there is no policy to deal with structural water shortage, but only policy to deal with (occasional) drought events.

4.5.2 Main results from impact assessments

Future drought impacts can be summarised as, per sector:

- Agriculture: Water shortage leads to a sub-optimal production and in areas affected by salinity, yields will be affected. Despite damages, this is not (yet) a major problem in The Netherlands.
- Nature: There are different impacts to drought, for the main water management system, the regional system and the terrestrial nature: respectively (i) water shortage and heat; (ii) loss of biodiversity in aquatic ecosystems; and (iii) irrecoverable loss of nature value due to drought-related water shortage. In drought years, the goals for Natura 2000 and the Water Framework Directive may not be achievable.
- Urban area: Drought has impact on the ability to maintain water levels required for safety or to prevent damage to real estate. Safety is an issue in areas that are defended against flooding with peat dikes (that can fail during drought, at least it happened once, during the last major drought in The Netherlands, in 2003). Impact on real estate is mostly an issue in peat and clay areas, where soil subsidence and soil settlement may result in problems. Damage to foundation of houses (when on wooden piles) can happen when the groundwater level is so low that it will expose the wood. Another issue in the urban can be the lack of the possibility to flush urban waters in order to prevent bad air quality.
- Drinking water supply: Although most of the drinking water used in The Netherlands is from deep groundwater, some inlet points (from the main river system) for drinking water production are threatened by salt-intrusion from the sea (mainly in the low-lying western part of the country, where land elevation is below Mean Sea Level). Also high water temperatures (norm is 25° Celsius) can become a bottleneck.
- Industrial water supply: The supply of water for industry will suffer either from an increase of salinity (in the south-west of the country) or due to a too low water level of the Lake Ijsselmeer water storage reservoir (bottlenecks at less than 10 locations in an average or dry year.

  Energy: The energy sector suffers from drought every 2-5 years, mainly due to reduced production capacity due to shortage of cooling water. In certain instances, industry also suffers from lack of cooling water and production will be reduced (2003 drought). This happens mostly in an extremely dry year.
- Navigation: Ships can take fewer loads due to lower water levels during drought, which also leads to more operation cost and longer waiting times at locks, etc. Limitations start when the Rhine inflow to the country (the main determining factor) is less than 1250 m^3/s.

  Tourism/ recreation: Generally weather conditions typical for drought are appreciated by the public, but there are conditions that result in damage, such as algae blooms or low water levels. Sometimes low water levels during drought result in problems for recreational navigation (especially in the north of the country).
- Inland fisheries: For inland fisheries, mostly positive results are expected from climate change, including drought. Possibly negative impacts will be partly counteracted by measures contemplated for the future in relation to salt intrusion.

5 Future impacts based on large-scale assessments: Areas burned by wildfires

5.1 The Relative Wildfire Index proposed

In a previous DROUGHT R &SPI report regarding the analysis of historic events in terms of socio-economic and environmental impacts, we developed a study on the correlation of areas burned in various territorial units (NUT3) with the corresponding weather variables. Details on the data used are provided in the corresponding technical report (van Lanen et al. 2013).

From the former analysis it was concluded that a simple model using monthly average temperature and accumulated precipitation of two months provided similar explanation of the area burned than the monthly average of the Canadian Fire Weather Index (FWI), commonly used in many European countries and by the Joint Research Centre of the EU (Amatulli et al. 2013, Bedia et al. 2014).

It was also concluded that the predictions of area burned based on weather variables (FWI or the proposed model) were quite variable in their prediction ability, with higher correlations obtained in territorial units where areas burned are larger, as in Portugal and Spain.

The simplification of the model would result in the equation of the form:

$$\ln(A) = C0 + C1\ (1 - T/40)\ \ln(P2 + 1)$$

where:

A is the area burned in hectares,

C0 is a coefficient, interpreted as the natural logarithm of the maximum possible area burned (hectares), of the territorial unit considered during that month,

C1 is a coefficient, that can be considered to be around 2.0 when weather variables are significant,

T is the average monthly temperature (°C),

P2 is the accumulated precipitation of the current and the previous month (mm).

Rearranging and simplifying this equation to have a Relative Wildfire Index (RWI) relating the predicted area burned (A) to the maximum possible area burned (Amax) we have:

$$RWI = A / Amax = \exp[-2\ (1 - T/40)\ \ln(P2 + 1)] = 1 / (P2 + 1)\ 2\ (1 - T/40)$$

This equation can be easily interpreted: the value of the index RWI approaches 1 for the extreme conditions of a two month period without rain and/or average monthly temperatures approaching 40°C. On the other hand, high precipitation and low temperatures will decrease RWI to values close to zero. For average temperatures, around 20°C, the index is inversely proportional to precipitation.

This simple index is therefore adequate to be used for comparing different territorial units, different months, or in the evaluation of scenarios of climate change at a large scale. In the following sections we will apply it to the six case-studies of the project, using the same data set as before (van Lanen et al. 2013).

5.2 Climate patterns in the different case studies

The six areas considered for this study-case have very different climates, as well expressed by the diagrams below (Figure 5. 1), based on the current climate (CP-CNRM).

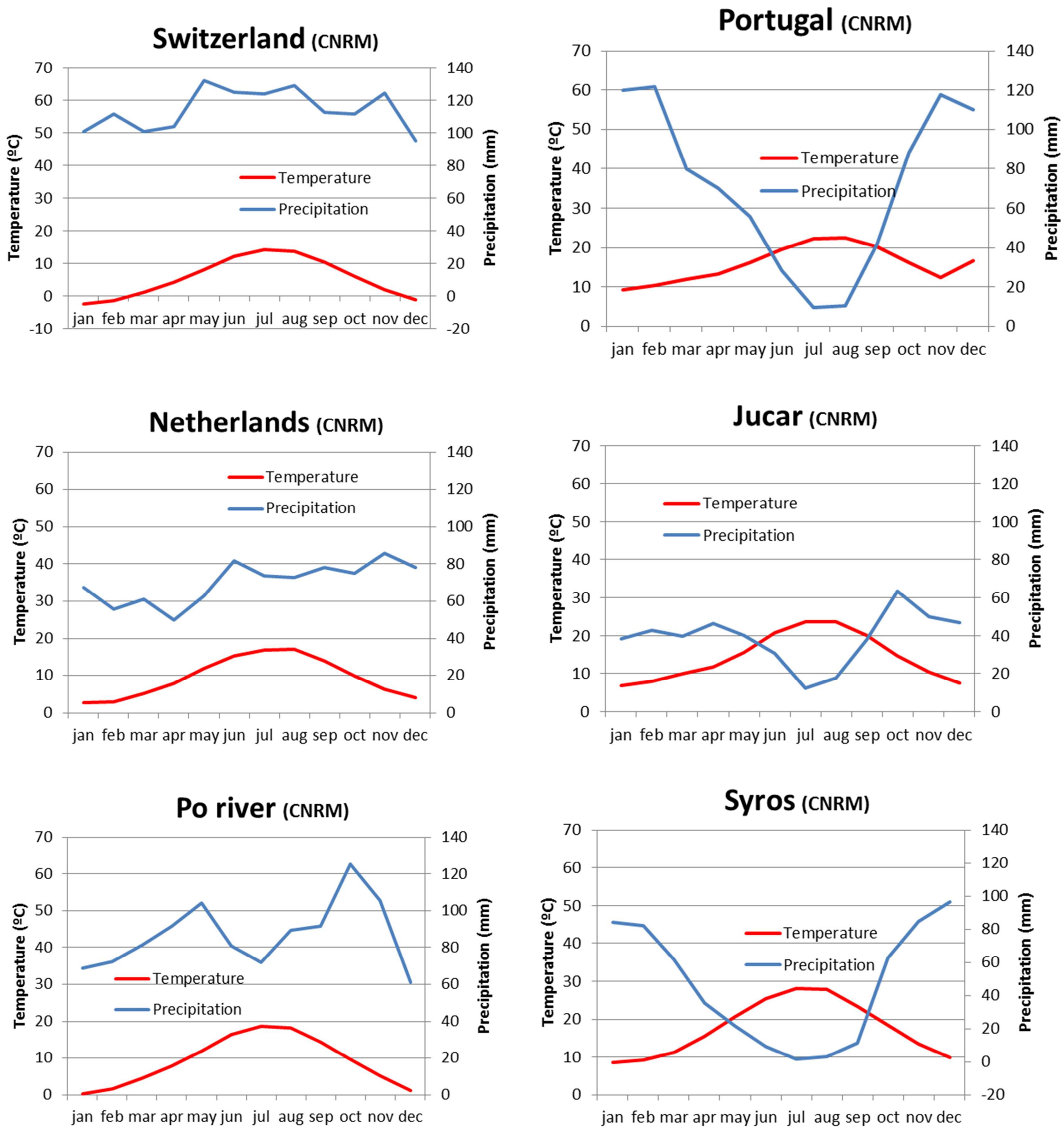


Figure 5. 1: *Monthly variation in precipitation and temperature (Ombrothermic Diagram) for the six case-study within the DROUGHT R&SPI project.*

It can be easily seen that Switzerland, Netherlands, and the Po river do not have months where precipitation (in mm) is below twice the average temperature (ºC), a simple system to understand the presence of the Mediterranean climate with its typical conditions for wildfires.

5.3 The Relative Wildfire Index for the six case studies under current situations

Because of the referred differences in climate, it is not a surprise that the Relative Wildfire Index, comparing the evolution of the index through an average year for the six areas, shows some drastic differences. The graph (in decimal log scale to allow for comparisons) in Figure 5. 2 shows that Syros has by far the highest values, above 10% for several months, due to the combination of low precipitation in two months and high temperatures in the month, followed by Jucar and Portugal, with summer months where the index is still relatively high, above 1%, the Po river and the Netherlands with low values, but still above 0.1% in the summer, and Switzerland with very low values, always below 0.1%.

It is also noticeable that the higher values correspond to August, for Syros, Jucar, and Portugal, indicating the importance of the lack of accumulated precipitation in that month, whereas for the Po river and Switzerland the highest values occur in July, corresponding to the month with higher temperatures.

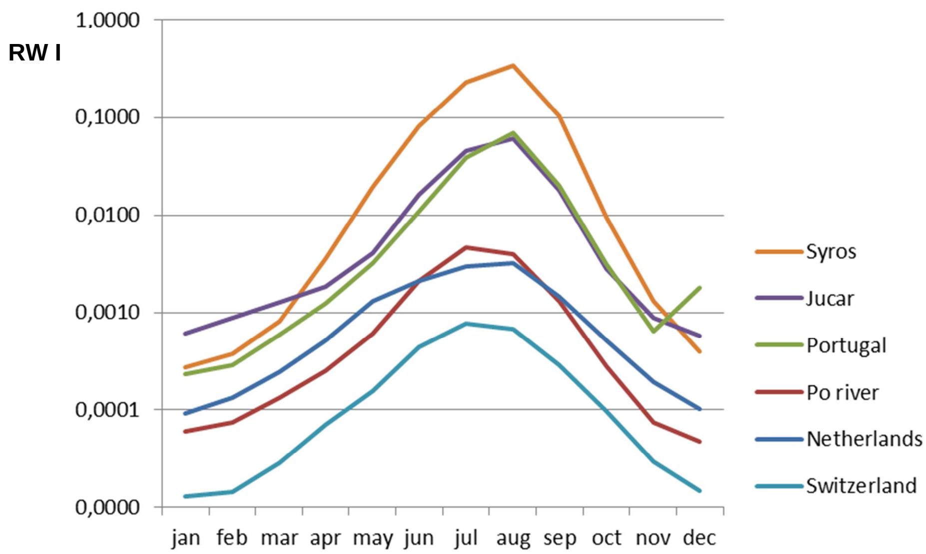


Figure 5. 2: *Reference values for monthly RWI in log scale, showing the differences between case studies.*

From this analysis we can now compare the results obtained with different models and with different climate scenarios.

5.4 Comparing different climate scenarios for the impact on wildfires

Using the CNRM model, we compared the predictions for monthly temperature and precipitation for two time frames (2021-2050 and 2071-2100) and for two scenarios (SRES A2 and B1). Figure 5. 3 shows the inputs in our model (left) and the resulting values of RWI (right) for three case-studies. From the analysis of the figure it is possible to see that, under scenario A2 for 2071-2100 the combinations of lower precipitation and higher temperatures already result in RWI values well above 1% for summer months for Netherlands and the Po basin. For Switzerland the maximum value is close to 1% but only for July. For the scenario B1 the values of RWI are lower than those obtained with scenario A2 because of a lower decrease in precipitation.

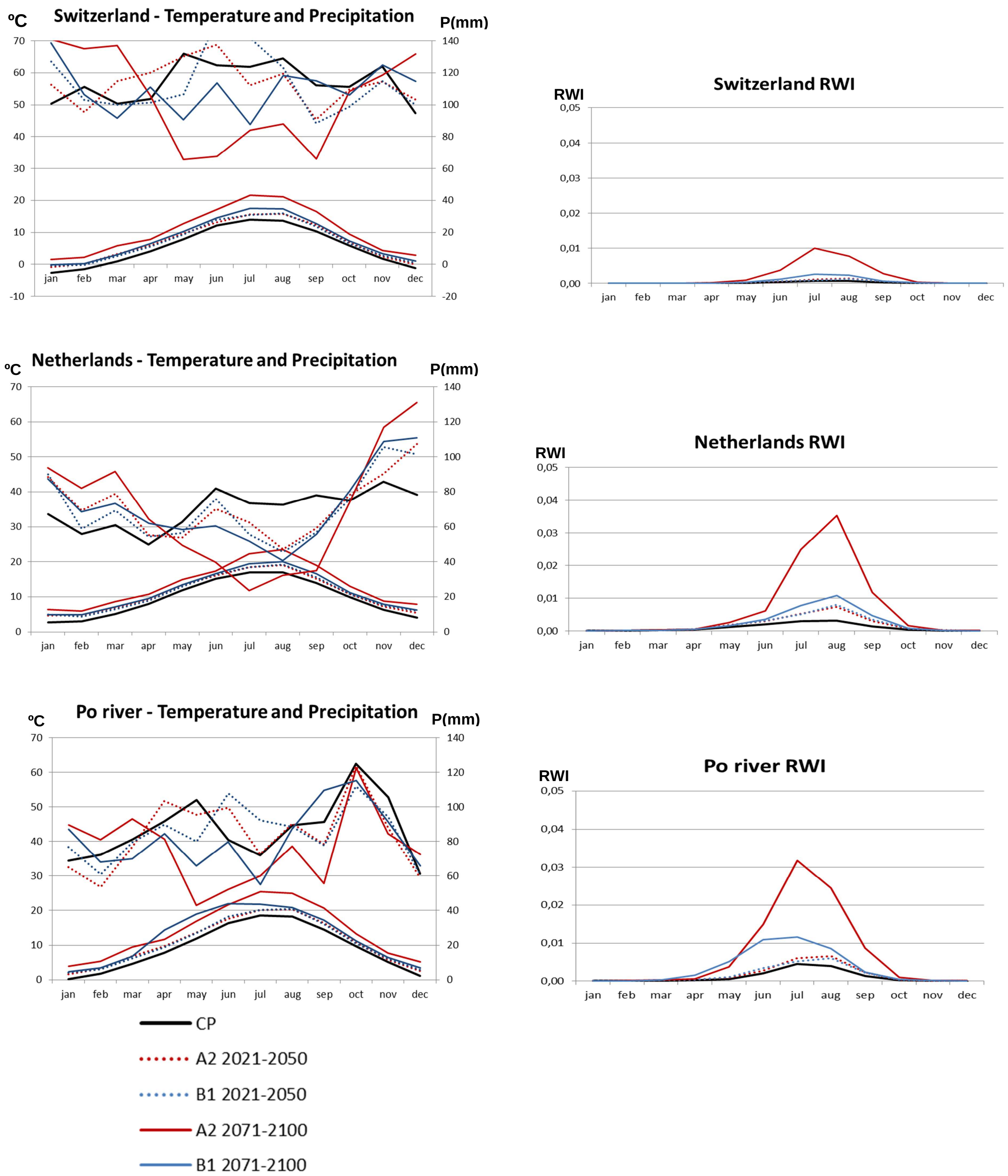


Figure 5. 3: *Predictions for monthly temperature (ºC) and precipitation (P in mmm) for two time frames (2021-2050 and 2071-2100) and for two scenarios (SRES A2 and B1), regarding the three case-studies with higher precipitation: Netherlands, Po river basin, and Switzerland. Inputs in our model (left) and the resulting values of RWI (right).*

For the case studies with lower precipitations and higher temperatures the same analysis was performed and results shown below (Figure 5. 4). For the case studies of Portugal and Jucar the current situation (CP) already reaches values of the RWI around 5%, and with scenario A2 it will reach values around 20-25% in 2071-2100. For Syros, with RWI values represented in a different scale, the maximum values were already above 30% and duplicate with the worst scenario A2 for 2071-2100.

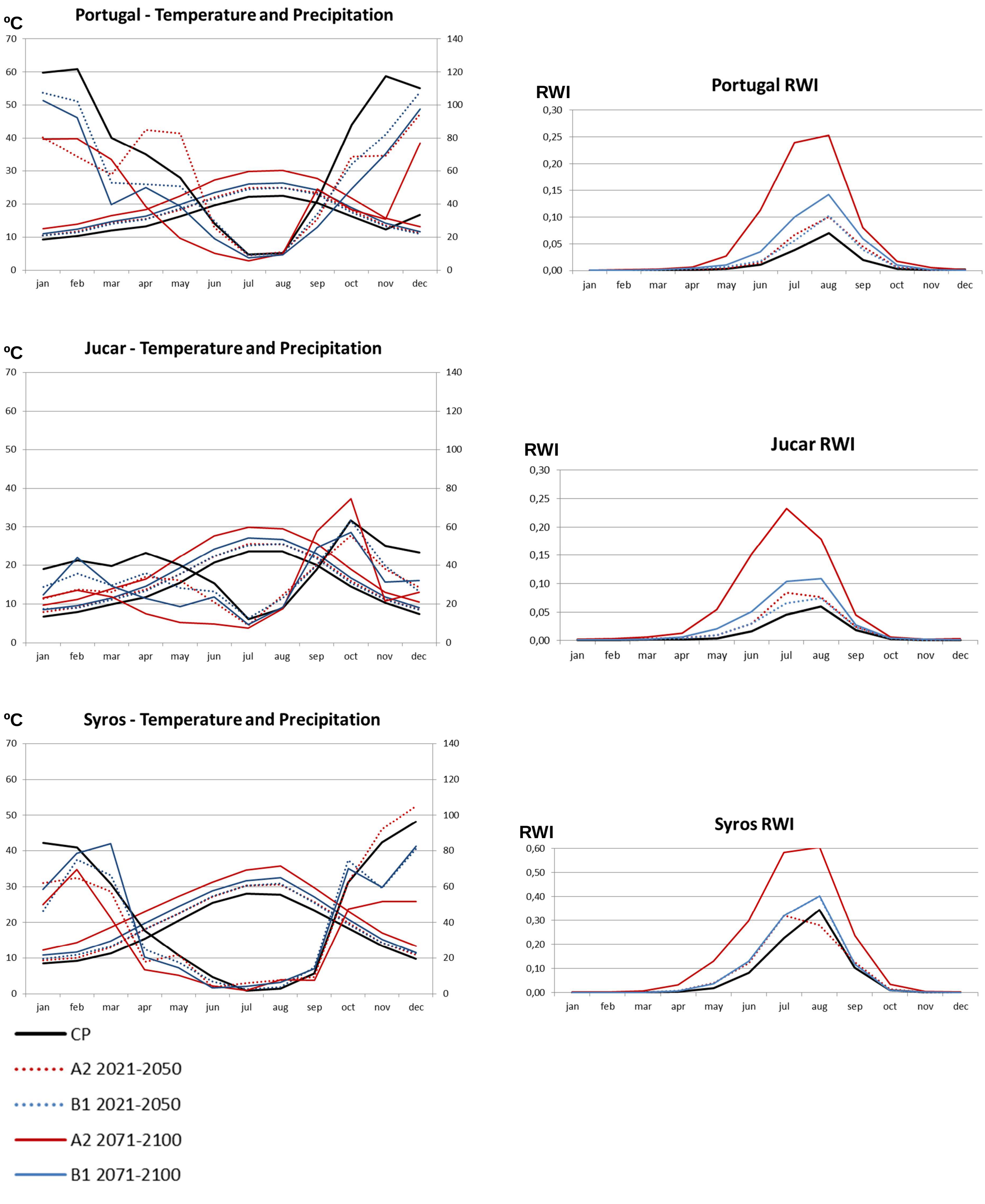


Figure 5. 4: *Predictions for monthly temperature (ºC) and precipitation (P, in mm) for two time frames (2021-2050 and 2071-2100) and for two scenarios (SRES A2 and B1), regarding the remaining case-studies: Portugal, Jucar and Syros. Inputs in our model (left) and the resulting values of RWI (right).*

5.5 Calculating predicted increases in area burned

As our RWI is developed to be directly proportional to the area burned, we can estimate the percentage increase of area burned with the different scenarios and time frames by using the sum of the individual RWI values computed for each month for each of those combinations. The sum of the individual RWI values for the various scenarios and reference time periods is shown in Table 5. 1.

Table 5. 1: *Sum of the individual RWI values for the various scenarios and reference time periods.*

Case-study	CP	A2		B1	
		2021-2050	2071-2100	2021-2050	2071-2100
Switzerland	0.003	0.004	0.026	0.004	0.008
Netherlands	0.013	0.023	0.084	0.024	0.031
Po river	0.013	0.023	0.086	0.019	0.041
Portugal	0.150	0.244	0.748	0.235	0.367
Jucar	0.152	0.242	0.698	0.217	0.332
Syros	0.791	0.916	1.935	1.029	1.234

These values indicate that it is likely that the areas burned will increase substantially in the future, considering that other factors are kept constant. There is a general agreement in the predictions from both scenarios for the period 2021-2050. In fact, they both predict the smallest increases in area burned for the Syros (16-30%), indicating that the conditions for wildfire were already very high and cannot increase indefinitely. On the other side is the Netherlands, with predicted increases of area burned by 77-85%, indicating that the weather conditions for wildfires may be arriving soon. All the other case studies show intermediate results, with Portugal being the area where these increases are highest, between 57% and 63%.

For the period 2071-2100 the two scenarios show quite distinct results. Again, Syros has the smaller increases, ranging from 56% (B1) to 145% (A2). In all other situations scenario B1 predicts large increases of area burned (ranging from 118% for Jucar to 215% for the Po river). However, these large predictions are still considerably smaller than the extreme predictions of scenario A2. Under this scenario, areas like Jucar or Portugal, already with significant conditions for wildfires would still face an important increase in the areas burned, 359% and 399% respectively. But the most striking prediction is that of areas currently with small impacts of wildfires that would face very significant problems because the currently small areas burned will tend to increase dramatically, with estimated increases of 546% (Netherlands), 562% (Po river) or 767% (Switzerland).

5.6 Conclusions and lessons learned

From the analysis above it can be concluded that, maintaining the same conditions as in the current situation in what concerns vegetation (fuel) accumulation, prevention and firefighting practices, and landscape characteristics the areas burned by wildfires will increase very substantially in the near future due to predicted climate change scenarios.

The simulations made used average conditions for precipitation and temperature, and the model proposed for this evaluation was developed based on existing data of monthly burned area in many territorial units of Europe. Therefore, the simulation compares an average year in current situations (CP) with an average year in two different time periods (2021-2050 and 2071-2100) for two different climate scenarios. And the results indicate that, already for the first time period, the two scenarios predict very large increases in the burned area and therefore in the various impacts of wildfires.

We know that the results of these simulations should be seen with attention. In the first place, it is known that vegetation adapts to its fire regime. If the changes in climate result in the very substantial increase in area burned, forest vegetation is likely to be replaced by more fire resilient shrubs. This is clearly the case of Syros, where shrubs dominate. In Portugal and Spain, it is likely that increased area burned and therefore increased fire frequency will change some of the more vulnerable forests to fire adapted shrublands. And fire management has to be changed accordingly. But the main impacts are in the areas with higher precipitation. For the northern Italy (the Po river), but also for Netherlands and Switzerland, an average year in 2071-2100 will, most likely (especially under scenario A2), have already some wildfire problems. And, of course, large wildfire events can occur with some probability, for the "surprise" of vegetation, that is not adapted to any fire regime, and to humans that, if not starting appropriate actions, can be also taken "by surprise" with all the impacts on environment but also on people lives.

6 Future vulnerability to drought in the Case Studies

6.1 Syros island, Greece

The results from future impact assessment indicate that Syros Island will remain vulnerable to drought if no measures are taken to ensure water supply, particularly for agriculture, and awareness and cooperation among actors (water users and managers) is not improved. Table 6. 1 summarises the future state of underlying causes of vulnerability to drought for the best and worst case scenario.

Table 6. 1: *Scenarios on the future state of underlying causes of vulnerability to drought.*

Underlying causes of vulnerability	Best case scenario	Effect on vulnerability	Worst case scenario	Effect on vulnerability
Intensive use of groundwater sources	Protection of groundwater bodies through the development of alternative water supply sources	↓	Over-exploitation of groundwater to meet irrigation demand	↑
Limited use of alternative water sources	Decentralised wastewater management & implementation of local solutions	↓	Centralised wastewater management	-
Limited/ no use of insurance/ compensation schemes	Use of insurance schemes	↓	No use of insurance schemes	-
Competition over groundwater sources	Desalination capacity expansion to meet increasing urban water demands & Increase of water stored in cisterns	↓	No further investments in desalination plants & Abandonment of traditional practices to store water	↑
Competing land uses (namely with tourism sector)	Controlled tourism development	-	Expansion of tourism infrastructure	↑

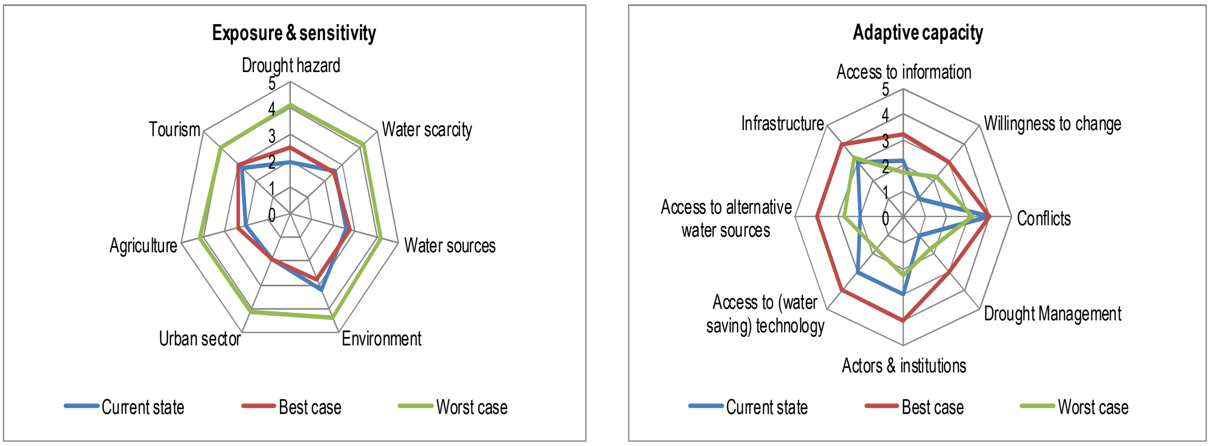
Future vulnerability to drought has been assessed using the Vulnerability Index (VI) described in Section 2.3. A survey was organised, in which stakeholders were asked to: (i) cross-compare in terms of importance the components that form the VI for Syros Island (Table 6. 2), and (ii) assign a score to the proxy variables of each component in the scale 1 to 5 (for Exposure & Sensitivity: 1-low vulnerability, 5-high vulnerability; for Adaptive Capacity: 1-low adaptive capacity, 5-high adaptive capacity) for the current state, as well as for the best and worst case scenario.

Even though only five (5) questionnaires were received, the survey input and results are important, as the questionnaires were filled-in by key stakeholders of the island. The AHP process was applied for calculating the weights for each Component (Table 6. 2), while it was assumed for the proxy variables that these have equal weight in each Component.

Figure 6. 1 shows the vulnerability profile for Syros Island on the basis of the stakeholders' perceptions of the future. Water scarcity, groundwater quality and tourism intensity are the factors that mostly determine vulnerability to drought. On the other hand, low adaptive capacity is mainly attributed to the lack of drought management and the limited willingness of local society to change (water use) habits.

Table 6. 2: *The vulnerability matrix for Syros Island.*

Dimension	Component	Component's Weight	Variable	Variable's Weight
Exposure (E)	Drought Hazard	0.30	Number of drought event	0.100
			Drought duration	0.100
			Drought intensity	0.100
	Water scarcity	0.14	Water Exploitation Index	0.140
Sensitivity (S)	Water sources	0.19	Groundwater level	0.190
	Environment	0.08	Water quality	0.080
	Urban sector	0.11	Population density	0.055
			Demand coverage	0.055
	Agriculture	0.10	Demand coverage	0.025
			% irrigated land	0.025
			Share of agricultural GDP	0.025
			Crop pattern/ diversity	0.025
	Tourism	0.08	Tourism intensity	0.080
Adaptive Capacity (A)	Social	0.41	Access to information	0.136
			Willingness to change	0.137
			Conflicts	0.137
	Policy	0.30	Existence of drought management policies	0.150
			Actors & institutions (jurisdictions, availability to resources)	0.150
	Technology/ economic	0.30	Access to (water saving) technology	0.100
			Access to alternative water sources	0.100
			Infrastructure	0.100



(a) (b)

Figure 6. 1: *Profile of vulnerability to drought in Syros island (a: Average scores for Exposure & Sensitivity: 1-low vulnerability, 5-high vulnerability; b: Average scores for Adaptive Capacity: 1-low adaptive capacity, 5-high adaptive capacity).*

The estimated composite VI values are given in Figure 6. 2. The blue bar corresponds to the VI calculated using the average score assigned to the variables (Table 6. 3). The red bar refers to the VI in case of using the minimum score assigned from the stakeholders, while the green bar to the case of the maximum score assigned from the stakeholders (see Annex E).

A low vulnerability (~1) is estimated for the current state for Syros Island. This is in line with the results from the assessment of past responses to drought (Deliverable 2.3), as the majority of stakeholders think that water scarcity is the main problem in the island and the urban sector is not so vulnerable due to the increased water availability from desalination plants. For the best case scenario, vulnerability slightly decreases (~0.7), where a significant increase is noticed for the worst case scenario. This increase in value is noticed due to the high score of the Exposure & Sensitivity dimension, which is almost double from that in the current state.

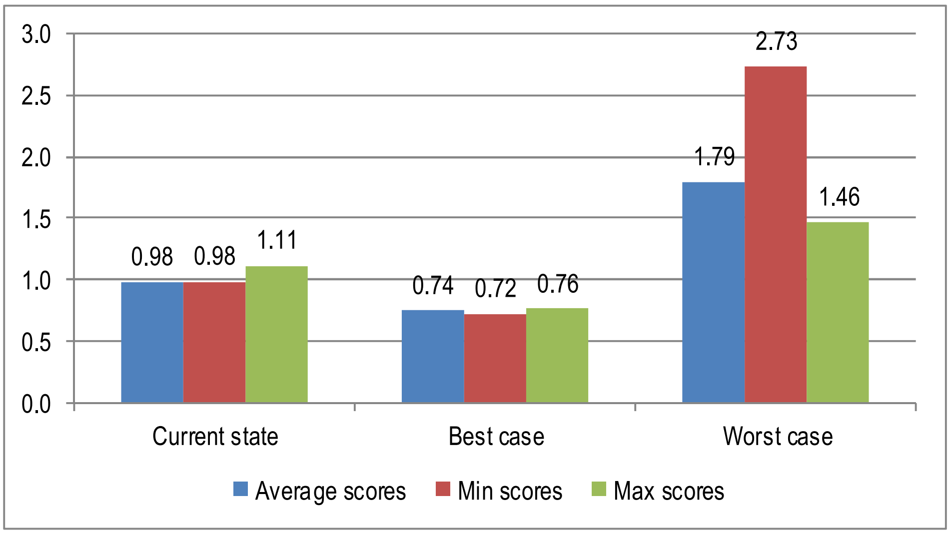


Figure 6. 2: *VI values for Syros Island.*

Table 6. 3: *Average scores assigned to the proxy variables of the VI for Syros Island.*

Dimension	Component	Variable	Current state	Best case scenario	Worst case scenario
Exposure (E)	Drought Hazard	Number of drought event	2	3	4
		Drought duration	2	3	4
		Drought intensity	2	3	4
	Water scarcity	Water Exploitation Index	3	3	4
Sensitivity (S)	Water sources	Groundwater level	3	3	4
	Environment	Water quality	3	3	4
	Urban sector	Population density	2	2	4
		Demand coverage	2	2	4
	Agriculture	Demand coverage	2	3	5
		% irrigated land	2	3	4
		Share of agricultural GDP	2	2	4
		Crop pattern/ diversity	2	2	4
	Tourism	Tourism intensity	3	3	4
Adaptive Capacity (A)	Social	Access to information	2	3	2
		Willingness to change	2	3	2
		Conflicts	3	3	3
	Policy	Existence of drought management policies	2	4	2
		Actors & institutions (jurisdictions, availability to resources)	3	3	2
	Technology/ economic	Access to (water saving) technology	3	4	2
		Access to alternative water sources	3	4	3
		Infrastructure	3	3	3

Results are summarised in Table 6. 4 for three alternative cases of VI Calculation:

1. Use of average scores assigned in each variable of the Vulnerability Index.
2. Use of the minimum score assigned by the stakeholders to the variables of exposure & sensitivity and the maximum score to the adaptive capacity variables. This case represents a ‘low vulnerability’ image of the system with ‘low exposure &sensitivity’ and ‘high adaptive capacity’.
3. Use of the maximum score assigned by the stakeholders to the variables of exposure & sensitivity and the minimum score to the adaptive capacity variables. This case represents a ‘high vulnerability’ image of the system with ‘high exposure &sensitivity’ and ‘low adaptive capacity’.

Table 6. 4: *VI values for different cases of scores assigned to the proxy variables.*

	Exposure & sensitivity	Adaptive capacity	VI
Case 1: VI calculation using the average scores assigned to the variables			
Current state	2.33	2.38	0.98
Best case	2.53	3.40	0.74
Worst case	4.17	2.33	1.79
Case 2: VI calculation using the minimum score assigned to the variables of exposure & sensitivity and the maximum score to the adaptive capacity variables			
	Exposure & sensitivity	**Adaptive capacity**	**VI**
Current state	1.64	2.92	0.56
Best case	1.84	4.45	0.41
Worst case	3.67	3.36	1.09
Case 3: VI calculation using the maximum score assigned to the variables of exposure & sensitivity and the minimum scores to the adaptive capacity variables			
	Exposure & sensitivity	**Adaptive capacity**	**VI**
Current state	3.25	1.67	1.95
Best case	3.37	2.55	1.32
Worst case	4.92	1.35	3.65

VI values were also calculated using equal weights for: (i) the VI components, and (ii) the variables, to examine the effect on VI of alternative weighting schemes (Table 6. 7); results do not significantly change.

Table 6. 5: *VI values for different weighting schemes.*

	Weights calculated using the AHP	Equal weight among components	Equal weight among variables
Current state	0.98	1.02	0.92
Best case	0.74	0.74	0.71
Worst case	1.79	1.80	1.76

Overall, future vulnerability to drought in Syros Island is mainly defined by the socio-economic development pattern and the intensive water use requirements particularly during summer (tourism). Agriculture is the most vulnerable sector and measures should be taken to ensure sufficient water supply.

6.2 Jucar River Basin, Spain

In the case of the Jucar River Basin Case Study, vulnerability is defined as: “The degree to which a water resources system is unable to cope with the impacts suffered due to a drought episode”. Under this assumption, the term reliability comes to hand to determine the vulnerability of the system.

In the making of River Basin Plans, the Jucar RB stakeholders have agreed to consider that a particular demand has a LOW (Acceptable) or HIGH (Unacceptable) vulnerability to drought if it meets the reliability criteria.

In the case of urban demands, the criterion defines the vulnerability as **HIGH** if:

1. The expected maximum deficit in one month exceeds 10% of the monthly demand

2. The expected maximum deficit accumulated in 10 years exceeds 8% of the annual demand

On the other hand, for agricultural demands, the criterion to determine their vulnerability is defined as:

1. The expected maximum deficit in one year cannot exceed 50 % of annual demand
2. The expected maximum deficit in 2 consecutive years cannot exceed 75 % of annual demand
3. The expected maximum deficit of 10 consecutive years cannot exceed 100 % of annual demand

Finally, for the entire water resource system, vulnerability is defined as LOW (Acceptable) if all the demands meet the vulnerability criteria, and HIGH (Unacceptable) if any demand fails at meeting the vulnerability criteria.

The same simulation process as described in Section 4.2 was used to evaluate the vulnerability criteria on the basis of the expected maximum deficits (in terms of percentages). It must be noted that even though vulnerability has a close relationship with deficit and thus with the definition of impact, it does include the temporary dimension allowing to disregard small or punctual impacts and giving more importance to the duration and magnitude of the deficits. Table 6. 6 to Table 6. 12 show the evolution of the vulnerability of the system for the different scenarios.

Table 6. 6: *Vulnerability results for the baseline scenario.*

Scenario 0	**1 month**		**10 years**	**Vulnerability**
Urban Demand				**LOW**
Albacete	0.00%	-	0.00%	**LOW**
Valencia	0.00%	-	0.00%	**LOW**
Sagunto	0.00%	-	0.00%	**LOW**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**LOW**
Mancha Oriental	11.74%	17.00%	20.68%	**LOW**
Jucar-Turia Canal	11.59%	17.71%	23.06%	**LOW**
Ribera Alta	11.68%	17.66%	23.12%	**LOW**
Ribera Baja	9.37%	14.42%	17.30%	**LOW**
Jucar WRS				**LOW**

Table 6. 7: *Vulnerability results for scenario 1: near future situation (2015).*

Scenario 1	**1 month**		**10 years**	**Vulnerability**
Urban Demand				**LOW**
Albacete	0.00%	-	0.00%	**LOW**
Valencia	0.00%	-	0.00%	**LOW**
Sagunto	0.00%	-	0.00%	**LOW**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	13.00%	25.68%	53.25%	**LOW**
Jucar-Turia Canal	24.92%	45.16%	75.67%	**LOW**
Ribera Alta	40.97%	65.02%	103.94%	**HIGH**
Ribera Baja	30.37%	46.34%	71.12%	**LOW**
Jucar WRS				**HIGH**

Table 6. 8: *Vulnerability results for scenario 2: medium future situation (2027).*

Scenario 2	1 month		10 years	Vulnerability
Urban Demand				**HIGH**
Albacete	0.00%	-	0.00%	**HIGH**
Valencia	51.27%	-	12.99%	**HIGH**
Sagunto	51.32%	-	13.18%	**HIGH**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	13.00%	26.00%	99.35%	**LOW**
Jucar-Turia Canal	38.86%	69.78%	167.43%	**HIGH**
Ribera Alta	70.44%	118.84%	216.48%	**HIGH**
Ribera Baja	54.04%	96.90%	164.79%	**HIGH**
Jucar WRS				**HIGH**

Table 6. 9: *Vulnerability results for scenario 3: 2040-2070 HadCM2.*

Scenario 3	1 month		10 years	Vulnerability
Urban Demand				**HIGH**
Albacete	51.48%	-	480.69%	**HIGH**
Valencia	85.80%	-	56.92%	**HIGH**
Sagunto	85.88%	-	39.03%	**HIGH**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	12.57%	25.13%	122.84%	**HIGH**
Jucar-Turia Canal	33.58%	66.70%	280.90%	**HIGH**
Ribera Alta	96.61%	186.45%	640.09%	**HIGH**
Ribera Baja	59.09%	117.48%	367.62%	**HIGH**
Jucar WRS				**HIGH**

Table 6. 10: *Vulnerability results for scenario 4: 2070-2100 HadCM2.*

Scenario 4	1 month		10 years	Vulnerability
Urban Demand				**HIGH**
Albacete	60.53%	-	564.82%	**HIGH**
Valencia	96.38%	-	148.35%	**HIGH**
Sagunto	96.42%	-	102.59%	**HIGH**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	13.12%	26.23%	131.16%	**HIGH**
Jucar-Turia Canal	34.80%	69.60%	327.03%	**HIGH**
Ribera Alta	100.00%	198.91%	827.59%	**HIGH**
Ribera Baja	59.16%	118.05%	460.54%	**HIGH**
Jucar WRS				**HIGH**

Table 6. 11: *Vulnerability results for scenario 5: 2070-2100 HadCM3 B2.*

Scenario 5	1 month		10 years	Vulnerability
Urban Demand				**HIGH**
Albacete	60.99%	-	565.69%	**HIGH**
Valencia	103.33%	-	256.45%	**HIGH**
Sagunto	103.29%	-	184.19%	**HIGH**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	13.66%	27.32%	136.59%	**HIGH**
Jucar-Turia Canal	52.30%	104.61%	518.57%	**HIGH**
Ribera Alta	100.00%	200.00%	939.61%	**HIGH**
Ribera Baja	62.93%	125.84%	582.91%	**HIGH**
Jucar WRS				**HIGH**

Table 6. 12: *Vulnerability results for scenario 6: Deficit values for scenario 6: 2070-2100 A2.*

Scenario 6	1 month		10 years	Vulnerability
Urban Demand				**HIGH**
Albacete	63.92%	-	596.65%	**HIGH**
Valencia	103.33%	-	385.84%	**HIGH**
Sagunto	103.36%	-	288.44%	**HIGH**
	1 year	**2 years**	**10 years**	**Vulnerability**
Irrigation Demand				**HIGH**
Mancha Oriental	13.96%	27.93%	139.65%	**HIGH**
Jucar-Turia Canal	58.68%	117.36%	585.39%	**HIGH**
Ribera Alta	100.00%	200.00%	974.72%	**HIGH**
Ribera Baja	65.07%	130.12%	629.84%	**HIGH**
Jucar WRS				**HIGH**

The results of the simulations of the system management indicate that the reductions in streamflows and increases in agricultural demand significantly reduce system reliability regarding the current situation and thus increasing the system vulnerability. It will be no longer possible to fulfill the guarantees of the agricultural demands in almost any climate scenarios. Urban demands meet more easily the reliability criteria due to their higher priority, although in the worst case scenario (scenario 6) they also fail.

Although the results of the effects of climate change in the CHJ indicate alarming situations facing the availability of water resources in the coming years, these not only depend on the yields of the hydrological cycle, conditioned by the soil, temperature and the temporal structure of precipitation, but it is the system of water resources available and how to handle who ultimately determines the capacity to meet the needs.

Finally, the results obtained with this work can be used to identify and establish where and in what proportion could be climate change effects on water resources and, on that basis, to define new adaptation and/or mitigation measures and strategies to cope with these effects.

6.3 Po River Basin, Italy

6.3.1. Methodology followed in the Po river basin case study for assessing future vulnerability to drought

Similarly to what done in the case of the definition of the narrative scenario, the process of assessment of the future vulnerability was undertaken following a qualitative approach, and involving the experts and stakeholders participating to the 3rd Case Study Dialogue Forum, held in Parma on the 13th of May 2014.

Making again basis on the impact tree diagram previously developed for each sector (agriculture and energy), the objective was then to qualitatively measure the importance and the future trend of the key vulnerability factors. Doing that, there was the chance to order these vulnerability factors in terms of importance ad to make clear hypotheses about their future trend.

The technique for assessing such factors was designed in the context of the typical Delphi logics, although with some changes[7]. In the second stage of the CSDF, after the open discussion, experts and stakeholders were infact asked to rate each vulnerability factors indicated in the impact tree diagrams, according to two criteria:

- Level of importance (ordinal scale on five levels / choices, from unimportant to very important)
- Future trend (3 choices: increasing, stable, decreasing)

Experts were given a document containing a table where they had to rate each factor (see Annex G, the vulnerability factors placed in the column on the right, as well as the cells where they had to rate each of them). The data obtained and collected, were then analysed and the results are presented in the following sections. It is important to underline that also in this case the time horizon proposed to experts and stakeholders was 2030.

[7] For example, according to the Delphi approach, there is an interactive process where the questionnaire is sent several times to the experts respondent. In this case, experts were asked to answer only when they were present in the CSDF.

6.3.2 Importance of the vulnerability factors in agriculture

Table 6. 13: *Average importance assigned to vulnerability factors (1: unimportant; 5: very important).*

Issue	Vulnerability factors	Mean
Production and markets		
	Predominance of hydro-demanding crops	3,0
	Corn	3,2
	Rice	3,0
	Foraggere	2,4
	Horticulture	2,6
	Fruit	2,4
Infrastructures and technologies		
	Lack of infrastructures for storing surface and ground water	4,6
	Lack of adequate and efficient irrigation systems and technologies	4,4
Representativeness and conflicts		
	Scarce ability of farmers to represent and defend their interests	1,6
	Competition on water uses	2,2
	Hydropower	1,2
	Thermoelectric	1,4
	Environment	3,0
	Tourism	0,8
Policy, regulation and management		
	Legal withdrawals larger than the actual water availability	2,2
	Lack of controls on illegal water withdrawals	2,8
	Lack of controls on the use of wells for irrigation	3,2
	Lack of water pricing policies	2,6

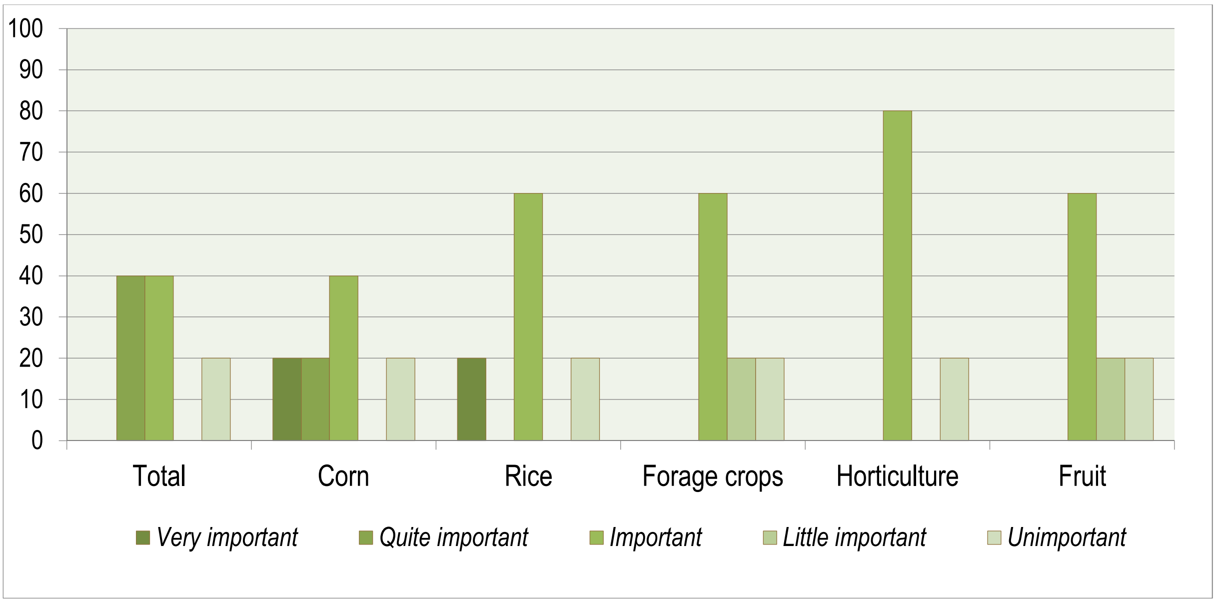


Figure 6. 3: *Importance assigned to the vulnerability factors concerning the issue "Production and markets – predominance of hydro-demanding crops" (% distribution by level of importance).*

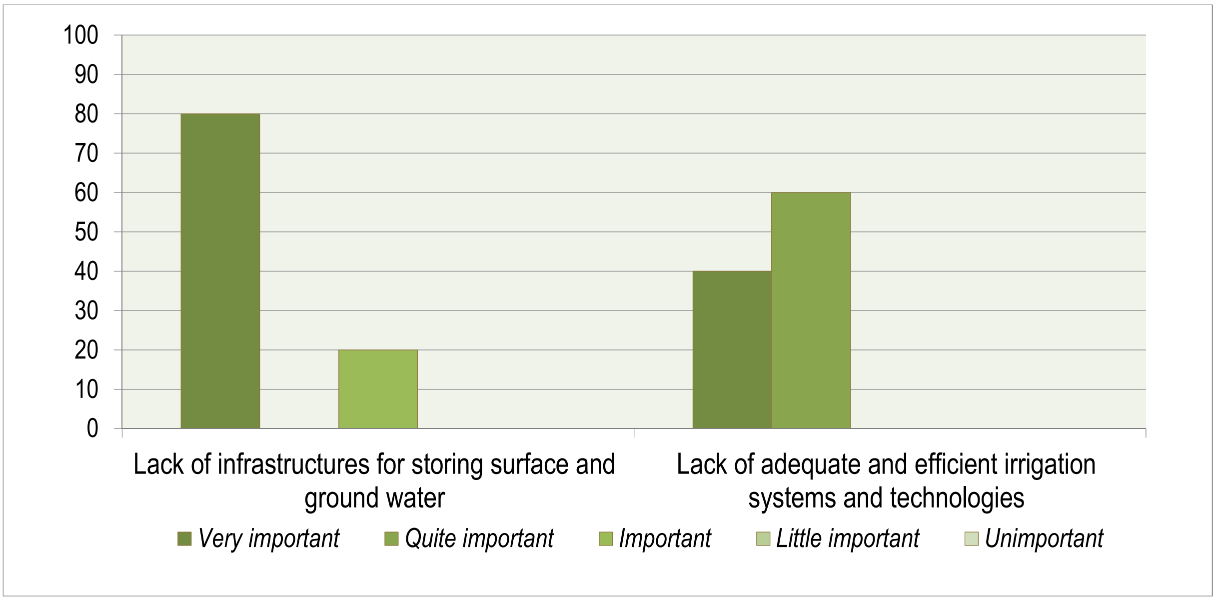


Figure 6. 4: *Importance assigned to the vulnerability factors concerning the issue "Infrastructures and technologies" (% distribution by level of importance).*

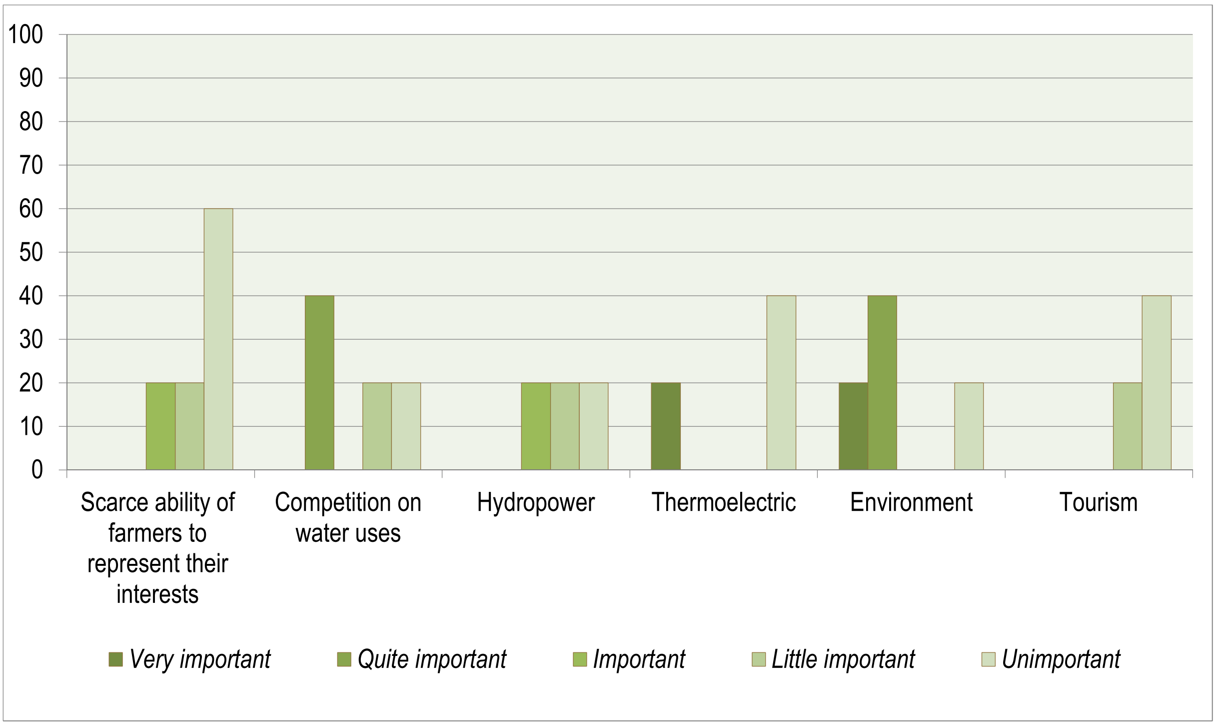


Figure 6. 5: *Importance assigned to the vulnerability factors concerning the issue "Representativeness and conflicts" (% distribution by level of importance).*

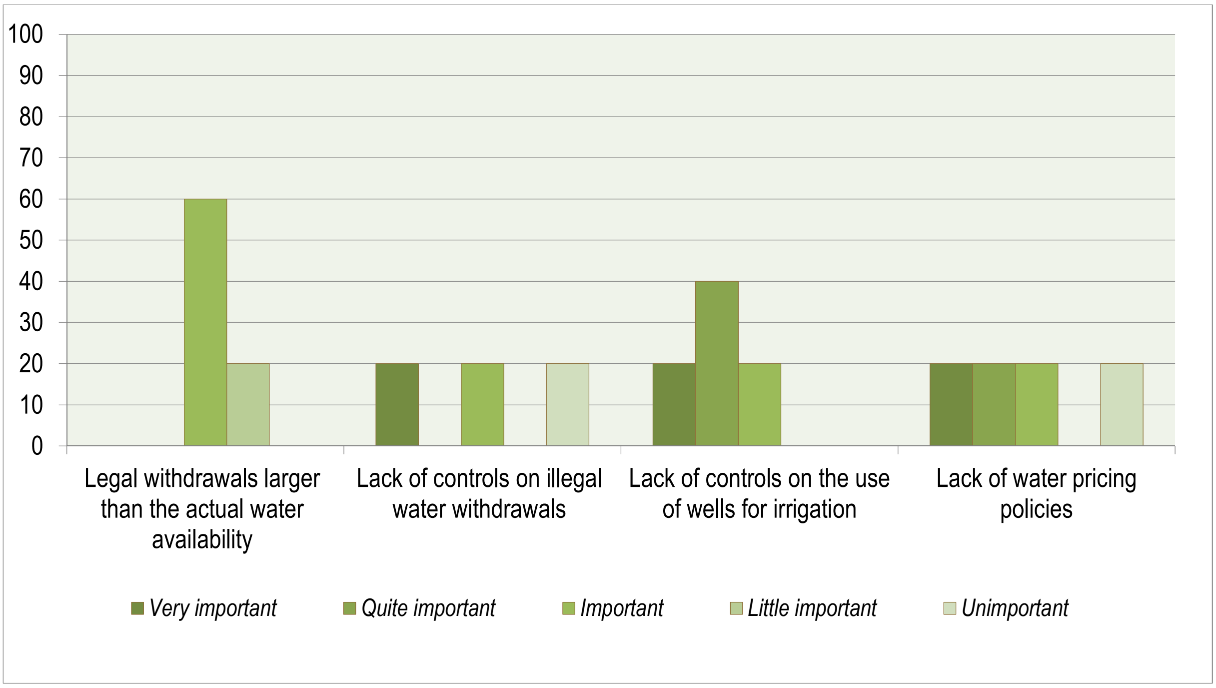


Figure 6. 6: *Importance assigned to the vulnerability factors concerning the issue: "Policy, regulation and management" (% distribution by level of importance).*

6.3.3 Future trends of the vulnerability factors in agriculture

Table 6. 14: *Prevailing trend of the vulnerability factors in agriculture (1: unimportant; 5: very important).*

Issue	Vulnerability factors	Prevailing trend
Production and markets		
	Predominance of hydro-demanding crops	Stable
	Corn	Stable
	Rice	Stable
	Foraggere	Stable
	Horticulture	Stable
	Fruit	Stable
Infrastructures and technologies		
	Lack of infrastructures for storing surface and ground water	Stable
	Lack of adequate and efficient irrigation systems and technologies	Increasing
Representativeness and conflicts		
	Scarce ability of famers to represent and defend their interests	Stable
	Competition on water uses	No prevailing trends
	Hydropower	Stable
	Thermoelectric	Stable
	Environment	Increasing
	Tourism	Increasing - Stable
Policy, regulation and management		
	Legal withdrawals larger than the actual water availability	Decreasing
	Lack of controls on illegal water withdrawals	No prevailing trends
	Lack of controls on the use of wells for irrigation	No prevailing trends
	Lack of water pricing policies	Increasing

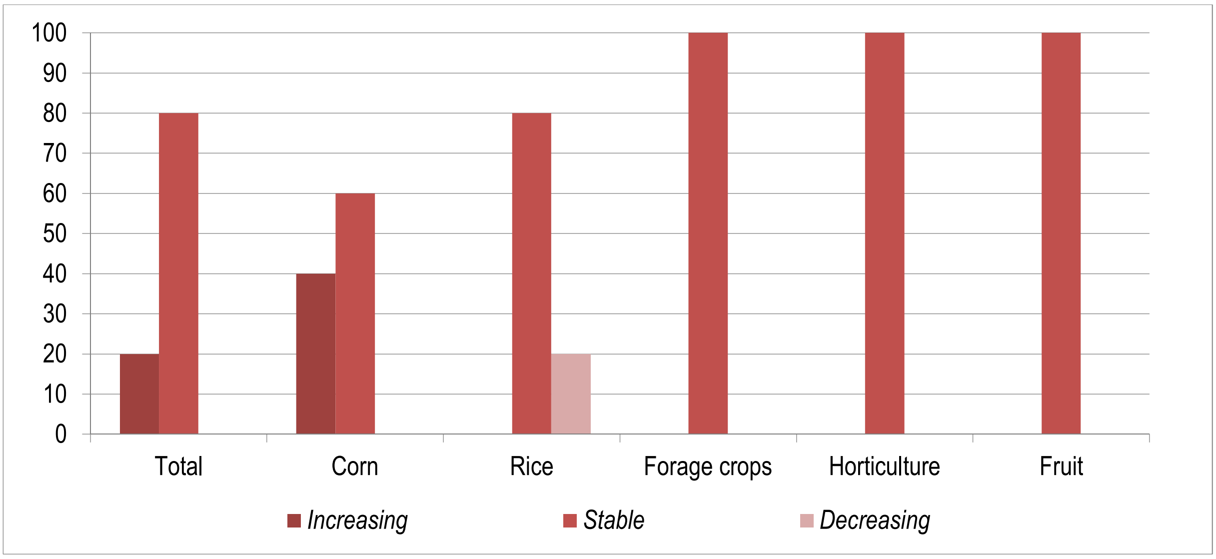


Figure 6. 7: *Future trend of the vulnerability factors concerning the issue "Production and markets – predominance of hydro-demanding crops" (% distribution by prevailing trend).*

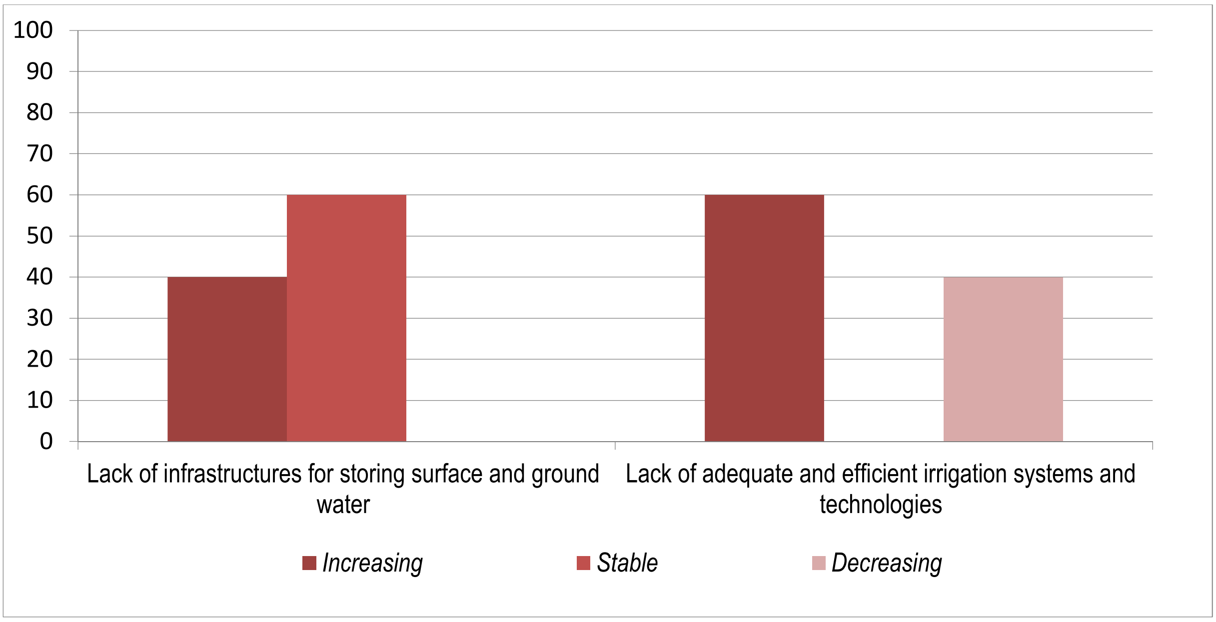


Figure 6. 8: *Future trend of the vulnerability factors concerning the issue: "Infrastructures and technologies" (% distribution by prevailing trend).*

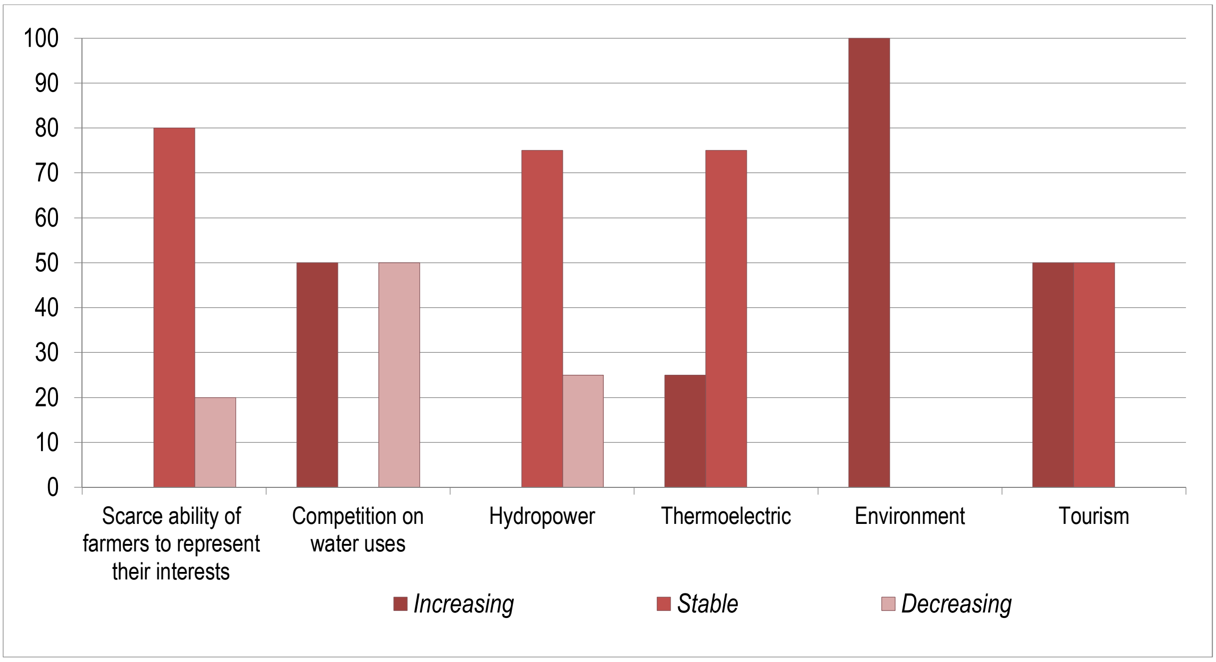


Figure 6. 9: *Future trend of the vulnerability factors concerning the issue: "Representativeness and conflicts" (% distribution by prevailing trend).*

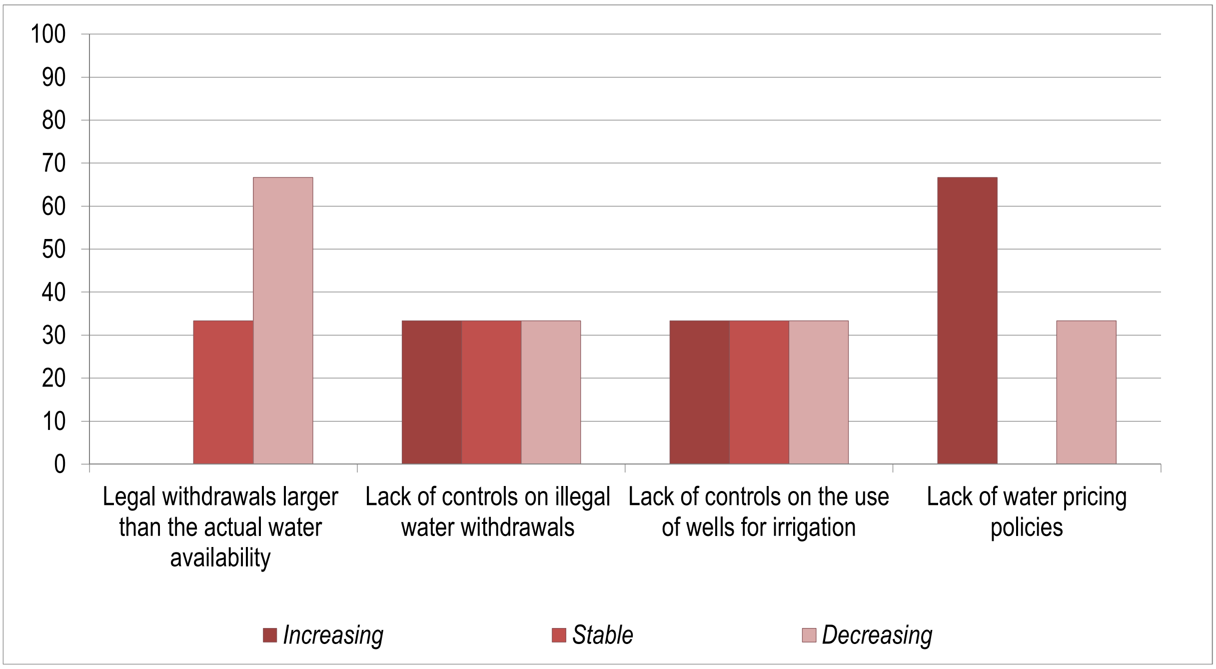


Figure 6. 10: *Future trend of the vulnerability factors concerning the issue: "Policy, regulation and management" (% distribution by prevailing trend).*

6.3.4 Importance of the vulnerability factors in the energy sector

Table 6. 15: *Average importance assigned to vulnerability factors for the energy production sector.*

Issue	Vulnerability factors	Mean
Production and markets		
Decrease of energy consumption	*Priority of production from hydropower for loads modulation*	**4,3**
Increasing production from renewable sources		**4,7**
Infrastructures and technologies		
	Reduction of the capacity of the basins because of the sediments	2,0
Conflicts		
Time concentration of water demand for irrigation	*Agriculture*	3,3
Needs of releasing anticipatedly water for irrigation (in case of heat waves in spring)		**3,7**
	Tourism in basins used for hydropower generation	1,7
	Thermoelectric	2,0
	Energy crops	3,0
	Environment	**3,7**
Policy, regulation and management		
	Unedaquate water resources management for hydropower (and for other uses)	**3,7**

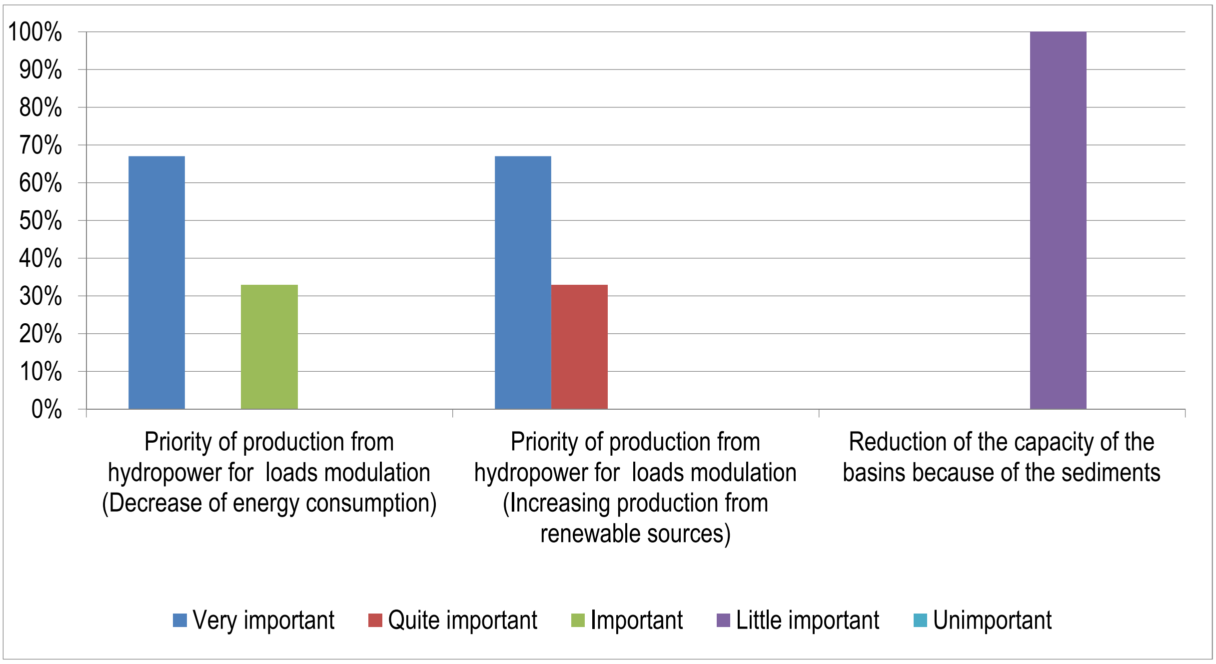


Figure 6. 11: *Importance assigned to the vulnerability factors concerning the issues: "Production and markets" and "Infrastructures and technologies" (% distribution by level of importance).*

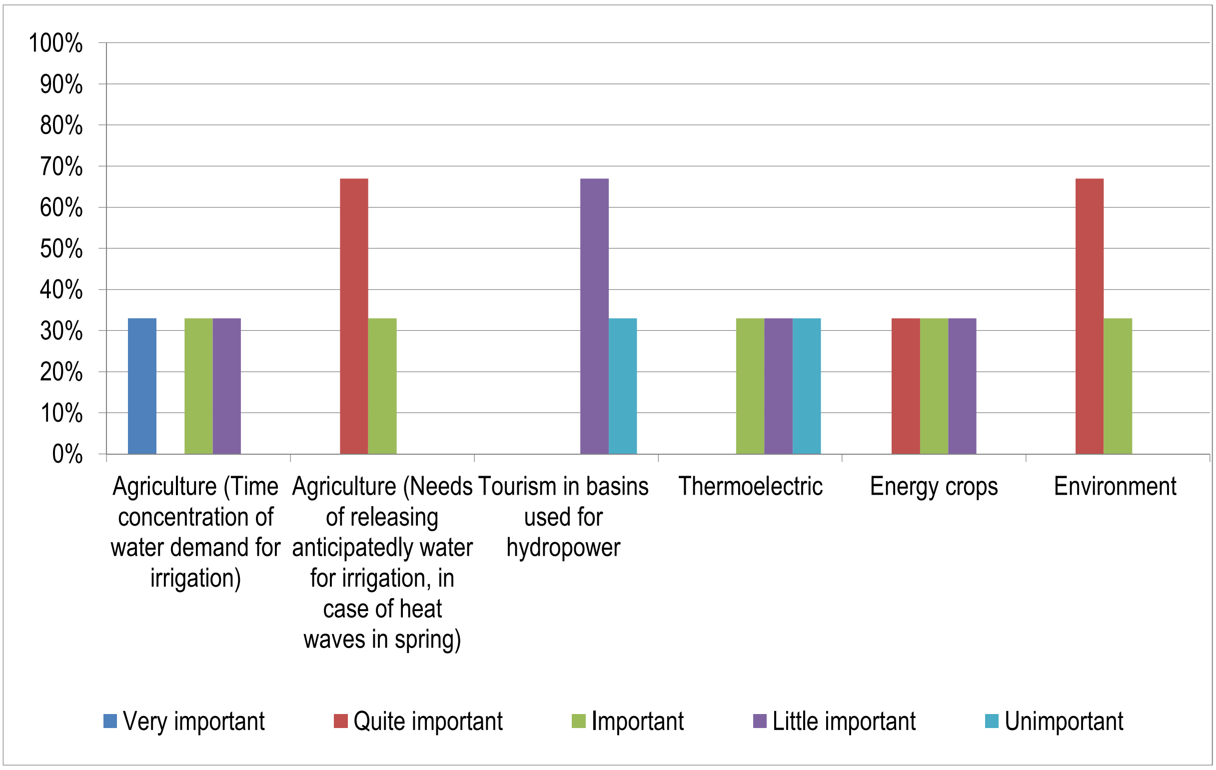


Figure 6. 12: *Importance assigned to the vulnerability factors concerning the issue: "Conflicts" (% distribution by level of importance).*

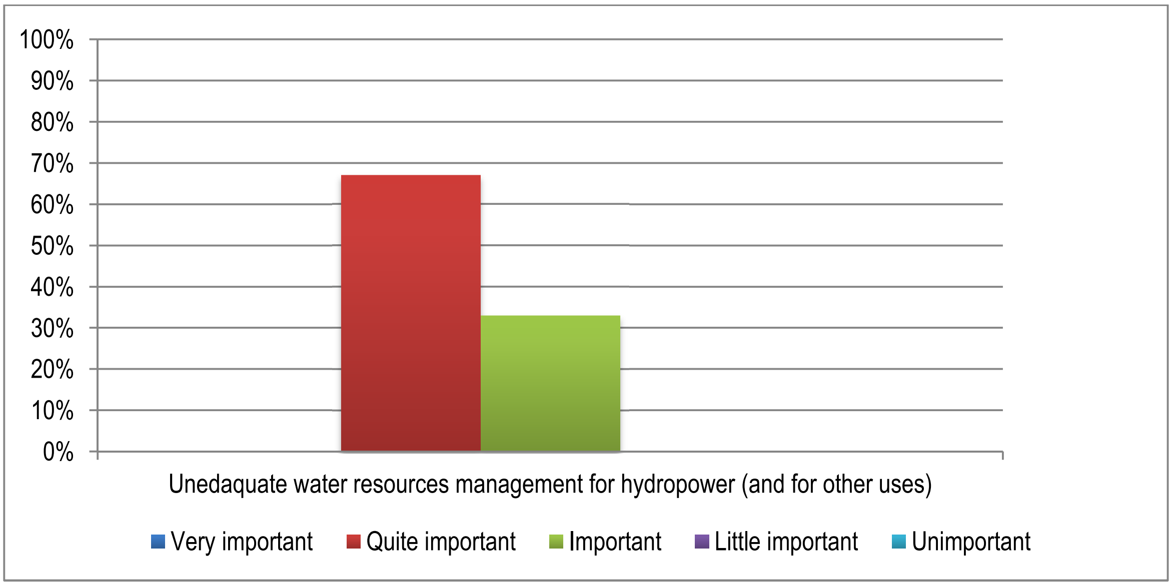


Figure 6. 13: *Importance assigned to the vulnerability factors concerning the issue: "Policy, regulation and management" (% distribution by level of importance).*

6.3.5 Future trends of the vulnerability factors in the energy sector

Table 6. 16: *Prevailing trend of the vulnerability factors in the energy sector.*

Issue	Vulnerability factors	Prevailing trend
Production and markets		
Decrease of energy consumption	*Priority of production from hydropower for loads modulation*	Stable
Increasing production from renewable sources		No prevailing trends
Infrastructures and technologies		
	Reduction of the capacity of the basins because of the sediments	Increasing
Conflicts		
Time concentration of water demand for irrigation	*Agriculture*	Increasing
Needs of releasing anticipatedly water for irrigation (in case of heat waves in spring)		Increasing
	Tourism in basins used for hydropower generation	Stable
	Thermoelectric	Stable
	Energy crops	Increasing
	Environment	Increasing
Policy, regulation and management		
	Unedaquate water resources management for hydropower (and for other uses)	Stable

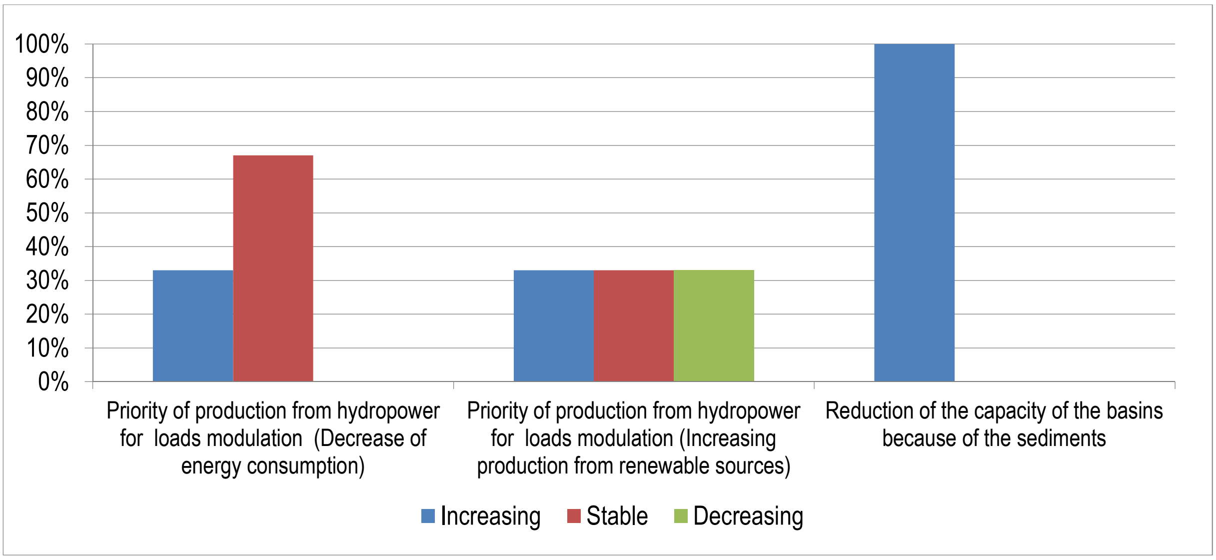


Figure 6. 14: *Future trend of the vulnerability factors concerning the issues: "Production and markets" and "Infrastructures and technologies" (% distribution by prevailing trend).*

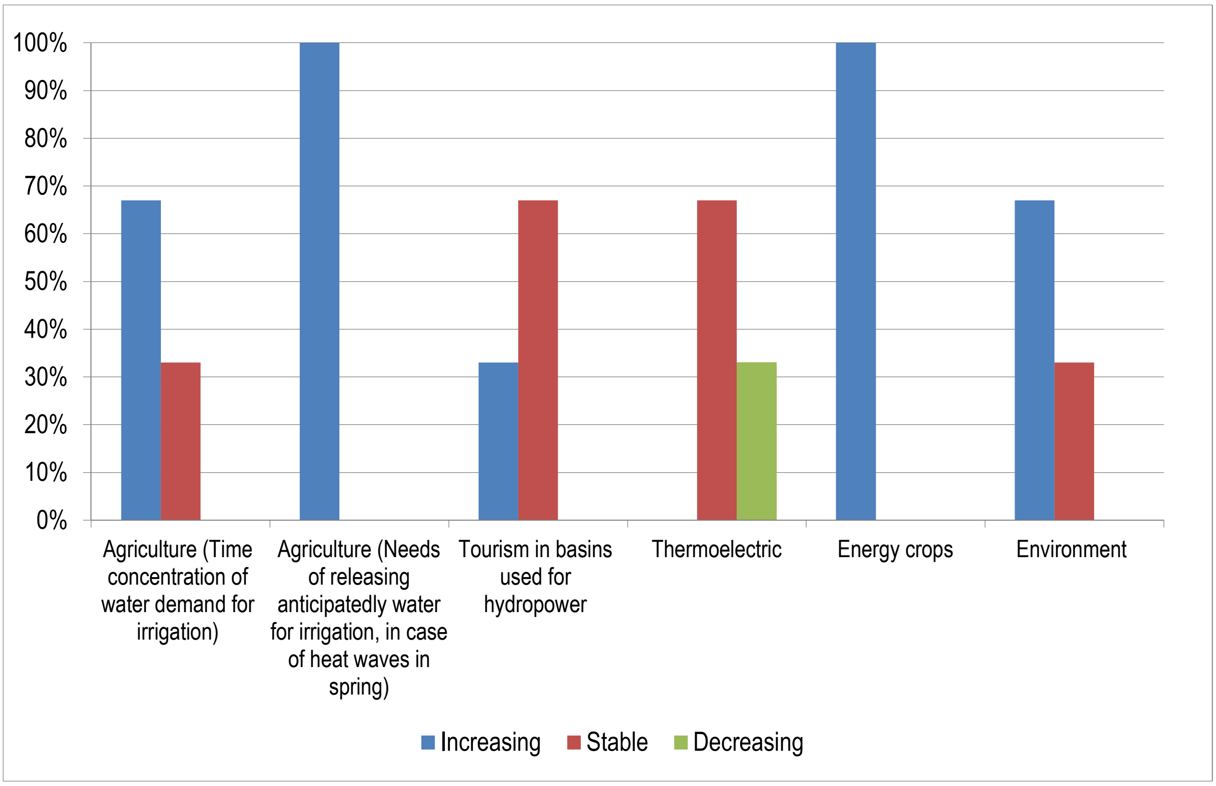


Figure 6. 15: *Future trend of the vulnerability factors concerning the issue: "Conflicts" (%distribution by prevailing trend).*

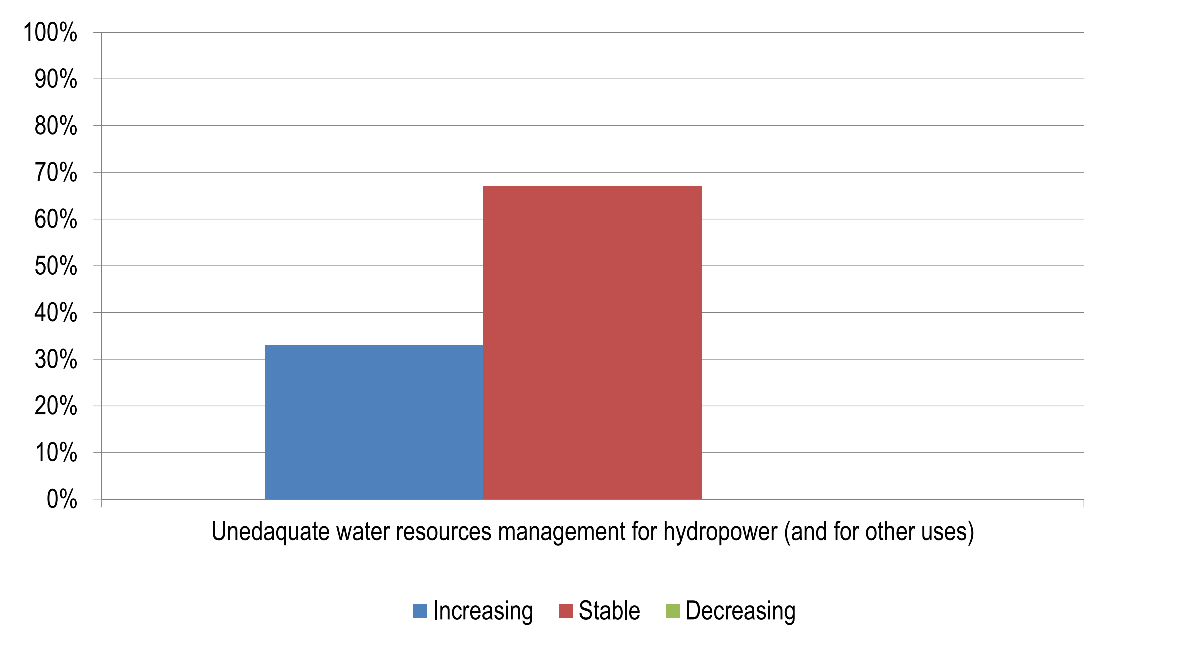


Figure 6. 16: *Future trend of the vulnerability factors concerning the issue: "Policy, regulation and management" (% distribution by prevailing trend).*

6.4 Portugal

6.4.1 Methodology for assessment the future vulnerability to drought

During the second DROUGHT R&SPI workshop, Portuguese stakeholders were consulted about the factors that currently and in the future will shape vulnerability to drought. Those have been chosen by ISA-CEABN team according the outcomes of the previous workshop. The activity done to collect and resume stakeholder's opinion about the most relevant vulnerability factor, for each category (or dimension of analysis) and their perceived trend in a medium term perspective is already described in section 3.4 (and Figure 3. 9). In fact, its outcome was used also for the assessment of critical uncertainties when constructing scenarios.

The stakeholder's view of future state of underlying causes of drought vulnerability in Portugal were presented and discussed during the third CSDF and complemented with views obtain in the scope of other projects focused in southern river basins.

6.4.2 Summary of the main results

Although communities will become more sensitive to drought, they will keep reluctant to change their habits and, therefore, given an increase in water scarcity, an escalation of conflicts in water use is forecasted. A reduction of institutional and policy gaps is foreseen, notably resulting in an increase in shared concern about transboundary water management. In contrast, the lack of incentives to prevent the impacts of drought will continue. Water supply systems for human use and agriculture will be improved along with an increase in strategic water reservoirs (multiyear). All this can be hampered by the increasing lack of resources in the short and medium term. According to stakeholder's perception most of vulnerability factors in societal, technical/economic, institutional/political dimensions will eventually decrease in importance for the futures, whereas others seem to be controlled or affected only by fund availability (Table 6. 17). This can be interpreted as a result of past responses to drought coupled with the implementation of effective policies, demonstrating a positive evolution on drought vulnerability control, regarding those dimensions.

On the other side, vulnerability factors within the environmental dimension are perceived to maintain or increase in importance in the future. This evaluation can be interpreted as both, an external issue not under the control of national or international institutions, like climatic change, and the low impact or sensitivity of the policy implemented, such as control of diffuse pollution or water abstraction.

According to the stakeholders' scenario analysis, agriculture will continue to be the main sector with impacts from future drought events. Socio-economic factors, more than climate change will be the main drivers of drought vulnerability in the next decades, particularly in the southern basins due to their dependence of agriculture and tourism sectors. Irrigated agriculture surface is enlarging (mostly olives, grapes and fresh fruit orchards) at expenses of extensive agriculture and more environmentally friendly and drought-resistant "montado" system production (Jongen et al. 2013; Máñez Costa et al. 2011). The construction of strategic reservoirs such as Alqueva, resulted in substantial irrigation investment and farmer livelihoods gradually dependent on a small number of water intensive crops and EU subsidies. The tourism and urban sprawl near the coast will put an extra pressure on these southern basins, particularly when and where over-exploitation and contamination of groundwater resources is already a reality (Stigter et al., 2013).

Table 6. 17: *Future trends for the underlying causes of vulnerability to drought in Portugal and identification of the most important factor (in blue) in each component of analysis, as perceived by the Case Study platform members (% of response).*

Underlying cause by dimension of analysis	Importance trend (%)		
	Maintain	Increase	Decrease
Societal			
Lack of sensitation/ education in drought	10	10	**80**
Increase of population	25	0	**75**
Water use/ users conflicts (82%)	10	**90**	0
Water use habits/ life styles	**64**	27	9
Preferences (e.g. use of a specific crop)	**73**	27	0
Institutional / Political			
Lack of drought management plans	0	0	**100**
Lack of contingency plans for water use	0	0	**100**
Lack of shared measures for international river basin management	36	9	**55**
Absence/ low use of insurances	**50**	10	40
Lack of incentives for preventing drought impacts (63%)	**80**	0	20
Lack of emergency/aids programmes	10	0	**90**
Inefficient knowledge of reservoir uses	25	0	75
Economic / Technical			
Lack of resources (e.g. financial) for drought management (64%)	8	**92**	0
Inefficient water supply systems	10	0	**90**
Inefficient irrigation systems (9%)	10	0	**90**
Unsuitable crops (9%)	**60**	0	40
Lack of infrastructures	8	0	92
High insurance costs (18%)	**45**	30	25
Water scarcity	8	**92**	0
Lack of knowledge about fish biomass in reservoirs-fish mortality prevention schemes	30	0	**70**
Environmental			

Diffuse pollution	0	**70**	30
Increased river water abstractions (20%)	18	**73**	9
Sand/grit extraction in rivers (10%)	**80**	10	10
Low production of groundwater/ small reservoir capacity	**64**	9	27
Climate Change (70%)	30	**70**	0
Excess of fish biomass in reservoirs	**60**	30	10

6.5 Switzerland

The Swiss Government (Schweizer Eidgenossenschaft 2012, p. 37ff) identifies vulnerabilities of drought and scarcity of water in the following sectors: Protection of ecology and landscape; use of water by agriculture; use of drinking, raw and fire water; use of water for energy production; use of water for sewage; use of water for recreation and tourism (landscape and artificial snow); use of water for navigation, and it identifies particular problems between these different sectors. Table 6. 18 presents these inter-sectoral vulnerabilities and conflict potentials.

Table 6. 18: *Swiss inter-sectoral vulnerabilities and conflict potentials.*

	Protection of Ecology, Landscape	**Agriculture**	**Drinking water / Raw water / Fire water**	**Energy**	**Sewage purification**	**Residual: Navigation, recreation etc.)**
Protection of Ecology, Landscape		Withdrawal: Ground water, streaming water; Prioritization in case of scarcity Risk for sensitive biotopes/biodiversity	Groundwater: Overuse (quality, quantity), Prioritization of multiple use	Security of supply; cooling of thermal power plants, biodiversity, Residual water	Sewage-Waters in small water bodies; dilution/ water quality	Artificial snow; new spring tapping, withdrawal of water
Agriculture		Adapted soil management, crop rotation Irrigation: Efficiency and infrastructures Water for animals: security of supply	Quality and quality of ground water Tariffs Prioritization of multiple uses	No uniform rule regarding tariffs and concessions Prioritization of multiple uses		Prioritization of multiple uses
Drinking water / Raw water / Fire water			Regional/temporal scarcities and problems of quality Safety of supply	No uniform rule regarding tariffs and concessions	Sewage-Waters in small water bodies; dilution/ water quality	Prioritization of multiple uses
Energy				Management of power plants and reservoirs by owners		
Sewage purification					Preservation of infrastructures	
Residual: Navigation, recreation etc.)						Low water, safety of provision

To face these vulnerabilities, the Swiss government has developed a strategy on how to handle local water scarcities (Schweizer Eidgenossenschaft, 2012), the ministry of agriculture drafted a Climate strategy in which drought plays an important role (Bundesamt für Landwirtschaft, 2011), the ministry for the environment drafted a Strategy for climate adaptation (Bundesamt für Umwelt, 2011) and various research projects are financed such as one on early drought information (Stähli et al., 2013).

Yet, although there is political awareness and various measures have been taken (see above), drought vulnerabilities are not seen as that urgent by stakeholders; the reason may be that droughts – so far - are rare, they are mainly local and regional, and there are also beneficial dimensions of droughts and climate change in certain regions and cases.

6.6 The Netherlands

6.6.1 Methodology followed for the future vulnerability assessment

With the present water system, the fresh water situation is actually well arranged in normal situations, and damage due to a limited drought every now and then are accepted at policy level. For instance, the current policy and practice of dividing the Rhine flow over the main branches of the river will remain unchanged as it is until 2050.

Vulnerability assessments are taken care of as part of the national Delta Programme (with 9 components of which the “fresh water programme”, that includes drought, is one). The programme is a broadly supported implementation-programme, to which all water users commit. Parties will take up relevant measures in their plans and will reserve the required financial means in their budgets.

There are various agreements (like the national priority ranking for water supply and desired groundwater and surface water regime) to deal with drought but the present arrangement can be better structured and made transparent. It is realised now that there is a need to make a paradigm shift from “what the user needs” towards “what the user can do and is willing to do”. From stakeholder meetings it has become clear that it is useful to have a transparent overview of what the government (both national and regional) can do and cannot do in times of drought. This is termed “service-levels”: the availability of fresh water in normal and dry conditions in an area. Governments and users jointly specify, in the form of region-specific agreements, which responsibilities and obligations the government has and what are the responsibilities and remaining risks for the users. This concerns in as far as relevant, surface and groundwater, as well as quality and quantity.

Overall, there does not (yet ?) seem to be a real sense of urgency for drought as a policy or water management issue, as might be apparent from the time-lines used for the application of the methodology:

- 2014: Plan of action made –for the main system- for how to define the service-levels (i.e. process, starting point and methodology, relation to other processes).
- End of 2015: Plan of action made – by the regions (provinces and Water Boards) - for the service-levels (which areas first, etc.). Roles: who will lead what, etc.
- End of 2017: Establishing the service-levels for the first group of areas
- 2018: Evaluation of applicability and experiences from reality
- Until end of 2021: continued establishment of service-levels.

As The Netherlands are located at the downstream part of the river basins of Rhine and Meuse, vulnerability to drought is also influenced by water management measures in upstream countries. The national government is working towards putting freshwater issues on the international agenda’s in the river committees (Meuse and Rhine). It is deemed important to create support for joint exploration of the Netherlands freshwater issues. In the Rhine Ministers Conference in 2013 it was agreed to investigate drought as part of a climate adaptation strategy. In the Meuse Committee some model calculations have been started. The Netherlands also actively follows the developments in relevant European guidelines as the Blueprint. The Netherlands actions are twofold, on the one hand exploiting opportunities for a joint EU approach and on the other hand reducing risks of European developments that would not be in agreement with the national preference-strategies.

6.6.2 Summary of the main results for future vulnerability to drought

Table 6. 19 shows the various factors that impact the water use sectors which lead to bottlenecks in the future. They include factors related to land use and factors relating to network functions. Land use related issues include agriculture areas, and urban as well as nature areas. Network related functions concerns uses or sectors depending on the water distribution system. Many of the described factors are location-specific and it appears difficult to make an estimation of the economic effects of future drought conditions.

Table 6. 19: *Vulnerability to drought in The Netherlands[8].*

Sector	Vulnerability factors
Agriculture/Horticulture (70% of the area in NL)	Not enough water available; declining water quality (salinity level too high); low groundwater
Nature	Low groundwater levels; inflow of low quality water (e.g. eutrophic) from outside nature areas
Urban area	Unequal settlement of buildings; land subsidence(clay and peat soils); lower quality for urban waters
Dikes, infrastructure	Peat dikes suffer from drying out; irrecoverable land subsidence
Drinking water	Salt intrusion impacts intake of raw drinking water; low river flows lead to less dilution of pollutants; too high temperature
Water for industry (and fires)	Salt intrusion impacts also industrial water intake; Firewater required for rail-systems (groundwater yet to be studied)
Cooling water for industry	For energy only problems in extreme dry years; for industry problems will increase, also temperature related
Navigation	Extent, severity and frequency of low water levels impacts freight, waiting time at locks, and tourism
Fisheries	In study

The work on the “service levels” is important in dealing with future vulnerability. The current strategy, i.e. trying to answer all water demands, in not tenable. A new strategy is in development: solving bottlenecks and seizing opportunities. The strategy is that then Government and users are responsible together, with a joint commitment to solve bottlenecks and reach the goals. An important question is how to quantify the vulnerability and this will be taken up in 3 pilots (in the west, east and centre of the country), where the involved parties will cooperate.

There is no need for major interventions in the main water system until 2050, but options for the future are open and need to be considered!

[8] Ref. Water voor economie en leefbaarheid, ook in de toekomst. Kansrijke strategieën voor zoet water. September 2013. Bestuurlijke rapportage fase 3. (available in Dutch only).

7 Synthesis of outcomes – Conclusive remarks

Table 7. 1 lists the methods used in the DROUGHT-R&SPI Case Studies for the future impact and vulnerability assessment. Different forms of analysis were undertaken depending on the spatial scale, existing/available information/data and the available models/tools. Agriculture and urban water supply are those mostly analysed, as drought impacts are more pronounced in these sectors. The analysis of environmental impacts concerns only the risk of forest fires.

For the Case Studies where drought management is not yet a priority (i.e. NL, CH), the information originates mainly from existing reports and studies on climate change and water management. On the contrary model-based assessments were undertaken in the Case Studies where droughts are common and somehow incorporated in the water policy agenda. Stakeholder contribution was significant in the development of scenarios for the future and in the vulnerability assessment.

Table 7. 1: *Overview of the methods applied in the Case Studies.*

Case Study	Scenarios		Impact assessment			Vulnerability assessment
	Method / source	***Outcome***	***Method / source***	***Outcome***	***Sectors***	***Method / source***
SY	Stakeholder-driven analysis	Parameters for water system modeling	Water balance modelling	Risk of economic losses due to water shortage	Agriculture; domestic sector	Vulnerability Index
JU	Existing scenarios in water management plans	Future water demand & hydrologic conditions	Water balance modelling	Water deficit	Agriculture; urban sector	Reliability in water supply
PO	Stakeholder-driven analysis	Storylines	-	-	-	Future trend of vulnerability factors
PT	Stakeholder-driven analysis	Storylines & trend	Regression analysis	Change (in %) for crop production & area burned by wildfires	Agriculture; forests	Future trend of vulnerability factors
CH	Survey & review of existing reports		Review of existing reports; survey	Narrative description	Agriculture; forests; urban sector; hydropower production	Review of existing reports
NL	Existing scenarios in policy-related documents	StorylineS	Review of existing reports	Narrative description	All	Review of existing reports

Results indicate the need for enhancing drought preparedness, as drought impacts will remain significant or even increase in the future. Table 7. 2 lists the key messages from the analyses in the Case Studies that could be summarised as follows:

- Besides drought characteristics, the socio-economic development pattern is also an important influencing factor on future drought-related risks as it affects the water balance of the water system.
- Water scarcity is the most important exposure-related factor of vulnerability.
- Agriculture remains the most affected sector, as domestic water supply is ensured in most cases.
- In case of transboundary water bodies, vulnerability to drought is higly influenced by the status in the upstream countries.
- Regional-level or sector-related assessments may enable a more detailed analysis of potential future drought impacts.
- Factors that contribute to a changing vulnerability are: governance, land use changes, increasing population, economic development, water saving technologies and environmental degradation.

It should be noted that drought impact analysis has been undertaken for specific climate projections and socio-economic development scenarios. Therefore, there is uncertainty in results linked to uncertainty in future changes. However, results presented in this report can be considered as indicative of future trends in drought vulnerability and impacts and can support planning for drought impact prevention and mitigation. One way of dealing with uncertainty is by using probabilistic projections of climate change and thus drought characteristics. A risk-based approach for the assessment of impacts will enable the treatment of uncertainty and the adoption of the appropriate mix of measures.

National level assessments are wider in scope and it is thus difficult to represent the regional and sectoral complexities of drought vulnerability and impacts. Even though essential and useful for disseminating drought-related risks and supporting policy development, regional-level assessments are required for the development of drought management plans (drought characterisation, regional vulnerability and impacts, selection of measures, avoiding of overlapping of jurisdictions) and achieving commitment for their implementation.

Vulnerability assessments are a challenging task as the ability of a system to cope with drought cannot be exactly determined in time and space. That is why, different aspects of vulnerability have been analysed in the Case Studies. However, despite the differences in the Case Studies, similar 'aggregated' factors of vulnerability have been identified and the following oucomes can support Pan-EU assessments:

- Drought vulnerability and risk perception differentiates among countries and it is mainly associated with the impacts and management experiences from past droughts. Therefore, the framework can be similar (e.g. same components) but different indicators may be applicable for defining vulnerability, particularly for northern and southern European countries.
- Vulnerability assessments should be linked to drought impacts, in order to better reflect the weaknesses of the system analysed.
- Transboundary water dependencies and management are important when discussing vulnerability to drought.
- Economic development patterns are key determinants of future vulnerability to drought and should be refelected in vulnerability assessments.

Table 7. 2: *Key messages for the future.*

Case Study	Key messages
SY	• Socio-economic development pattern highly influences future vulnerability to drought. • Drought impacts are related to water scarcity problems. • Impacts on agriculture will remain significant, if no measures are taken to ensure water supply.
JU	• Drought impacts are very likely to increase in the future. Drought affects more severely demands that rely mostly in surface water supply, while those capable of receiving some groundwater supply suffer less. • Measures should be taken to ensure water supply for agriculture in almost any climate scenario. • Besides climate change impacts on hydrological components, the operational status of the water system also highly influences vulnerability.
PO	• Vulnerability is mainly defined by sensitivity & adaptive capacity related factors. • Increasing trend is expected in technology-related factors (e.g. efficient irrigation systems; Reduction of the capacity of the basins because of the sediments) and policy-related factors (i.e. lack of water pricing policies).
PT	• Agriculture will continue to be the main sector with impacts from future drought events. Environmental vulnerability to drought will be also a significant concern. • Socio-economic factors, more than climate change will be the main drivers of drought vulnerability in the next decades, particularly in the southern basins due to their dependence of agriculture and tourism sectors. • Adaptive capacity will improve in the future, as institutional and policy gaps are expected to be overcome.
CH	• Climate change is likely to have contrasting impacts depending on the geographic location. • Drought impacts mostly will occur locally/regionally as future water distribution problems, and only sporadically, as water availability problems. • Of all sectors prone to drought, most likely agriculture will become more vulnerable to drought, yet investments in infrastructure and changes in practice will limit vulnerability.
NL	• Regional differences should be taken into account while discussing vulnerability to drought (urban vs. rural regions as well as the low-lying west of the country vs the higher-lying east). • Water users and water-using sectors have their own responsibilities and cannot depend on the government to solve all drought problems. • Vulnerability to drought is also influenced by water management measures in upstream countries.

8 References

Adepetu, A.A., & Berthe, A. (2007): *Vulnerability of Rural Sahelian Households to Drought: Options for Adaptation*, A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 92.

AEMET (2008): *Generación de escenarios regionalizados de cambio climáticos para España*. Ministerio de Medio Ambiente y Medio Rural y Marino.

Aguiar, R. (2008): *Methodologies for downscaling socio-economic, technological and emission scenarios, as well as meteorological scenario data, to country level and smaller regions. Part I: society and technology*, FP6 2-FUN project deliverable 1.2.

Alcamo, J., Henrich, T., Rösch, T. (2000): *World Water in 2025 – Global modelling and scenario analysis for the World Commission on Water for the 21st Century*. Report A0002, Centre for Environmental System Research, University of Kassel, Germany.

Alcamo, J., Acosta-Michlik, L., Carius, A., Eierdanz, F., Klein, R., Krömker, D., & Tänzler, D. (2008): A new approach to quantifying and comparing vulnerability to drought. *Regional Environmental Change*, **8(4)**: 137-149. doi:10.1007/s10113-008-0065-5.

Allen, R., Pereira, L., Raes, D., Smith, M. (2006): *Crop evapotranspiration. Guidelines for computing crop water requirements*. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome.

Alvarenga A., Carvalho P. Lobo Â., Rogado C., Azevedo F., Déjean Guerra M. & Rodrigues S. (2011): Long-term Future of the Portuguese Economy – a Scenario Building Process. Departamento de Prospectiva e Planeamento e Relações Internacionais. Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território.

Álvarez-Mediola, E. (2010): *Diseño de una política eficiente de precios del agua integrando costes de oportunidad del recurso a escala de cuenca. Aplicación a la Directiva Marco del Agua*. PhD thesis, UPV, Valencia, Spain.

Amatulli G., Camia A. & San-Miguel-Ayanz J. (2013): Estimating future burned areas under changing climate in the EU-Mediterranean countries. *Science of the Total Environment*, **450-451C:** 209-222.

Andreu, J., Capilla, J., Sanchís, E. (1996): AQUATOOL: A generalized decision support-system for water-resources planning and operational management. *J Hydrol* **177**, 269-291.

Andreu, J., Pérez, M.A., Paredes, J., Solera, A. (2009): *Participatory analysis of the Jucar-Vinalopo (Spain) water conflict using a Decision Support System*. In R.S. Anderssen et al. (eds), 18th IMACS World Congress - MODSIM09 International Congress on Modelling and Simulation. ISBN: 978-0-9758400-7-8, pp. 3230-3236.

Antwi-Agyei, P., Fraser, E.D.G., Dougill, A.J., Stringer, L.C., Simelton, E. (2012): Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socioeconomic data, Applied Geography, **32**: 324-334, doi:10.1016/j.apgeog.2011.06.010.

APA (2009): Relatório do Estado do Ambiente. Agência Portuguesa do Ambiente. Amadora

APA I.P. & ARH Norte, I.P. (2012): Plano de gestão da região hidrográfica do Minho e Lima (RH1). Relatório base. Parte 4 – Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Norte, I.P. (2012a): Plano de gestão da região hidrográfica do Cávado, Ave e Leça (RH2). Relatório base. Parte 4 - Cenários prospectivos.. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Norte, I.P. (2012b): Plano de gestão das bacias hidrográficas que integram a Região Hidrográfica do Douro (RH3). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Centro, I.P. (2012): Plano de gestão das bacias hidrográficas do Vouga, Mondego e Lis que integram a Região Hidrográfica (RH4). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Tejo, I.P. (2012): Plano das bacias hidrográficas das Ribeiras do Oeste. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Tejo, I.P. (2012a): Plano de gestão Região Hidrográfica (PGRH) do Tejo (RH5). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Alentejo, I.P. (2012): Plano de gestão das bacias hidrográficas integradas na região hidrográfica do Sado e Mira (RH6). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Alentejo, I.P. (2012a): Plano de gestão das bacias hidrográficas integradas na região hidrografica do Guadiana (RH7). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

APA I.P. & ARH Algarve, I.P. (2012): Plano de gestão das bacias hidrográficas que integram a região hidrografica das ribeiras do Algarve (RH8). Relatório base. Parte 4 - Cenários prospectivos. Final technical report. MAMAOT, Ministry of Agriculture, Sea, Environment and Spatial Planning (in portuguese).

Arranja C. (2013): Planos para melhorar a prevenção de secas em Portugal. 3rd Workshop Drought R&SPI. FENAREG, Federação Nacional de Regantes de Portugal. ISA, Lisbon.

Babel, M.S, Pandey, V. P,.Rivas, A. A.. Wahid, S. Md (2011): Indicator-Based Approach for Assessing the Vulnerability of Freshwater Resources in the Bagmati River Basin, Nepal, *Environmental Management* **48**: 1044–1059. doi: 10.1007/s00267-011-9744-y.

Bedia J., Herrera S., Camia A., Moreno J.M. & Gutiérrez J.M. (2014): Forest fire danger projections in the Mediterranean using ENSEMBLES regional climate change scenarios. Climatic Change, **122** (1-2). DOI: 10.1007/s10584-013-1005-z.

Bhattacharya, S., & Das, A. (2007): *Paper 9-Vulnerability to drought, cyclones and floods in India*, European Project: BASIC, http://www.basic-project.net/.

Birkmann, J. (2005): *Danger need not spell disaster—but how vulnerable are we?* Research Brief, Number I, United Nations University, Tokyo.

Birkmann, J. (2007): Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications, *Environmental Hazards* **7**: 20–31.

Blackshear, B., Crocker, T., Drucker, E., Filoon, J., Knelman, J., Skiles, M. (2011): *Hydropower Vulnerability and Climate Change - A Framework for Modeling the Future of Global Hydroelectric Resources*, Middlebury College Environmental Studies Senior Seminar.

Brown, A. & Matlock, M. D. (2011): *A Review of Water Scarcity Indices and Methodologies*, The Sustainability Consortium.

Bundesamt für Umwelt (2011): Anpassung an den Klimawandel in der Schweiz. Ziele, Herausforderungen und Handlungsfelder. Bern.

Bundesamt für Landwirtschaft (2011): Klimastrategie Landwirtschaft. Klimaschutz und Anpassung an den Klimawandel für eine nachhaltige Schweizer Land- und Ernährungswirtschaft, Bern.

C2SM, MeteoSwiss, ETH Zurich, NCCR Climate, and OcCC, editors. Swiss Climate Change Scenarios CH2011. 2011. URL http://www.ch2011.ch/.

CEDEX-DGA (2010): *Evaluación del impacto del cambio climático en los recursos hídricos en régimen natural*.

CESR (Center for Environmental Systems Research), (2010*): Summary of the background document on scenarios for the project Climate Adaptation – modelling water scenarios and sectoral impacts*, Contract N° DG ENV.D.2/SER/2009/0034.

CH2014-Impacts. Toward quantitative scenarios of climate change Impacts in Switzerland. Published by OCCR and FOEN and MeteoSwiss and C2SM and Agroscope and ProClim, 2014. URL: http://www.ch2014-impacts.ch/.

Cheng, J., & Tao, J. (2010): Fuzzy Comprehensive Evaluation of Drought Vulnerability Based on the Analytic Hierarchy Process - An Empirical Study from Xiaogan City in Hubei Province, *International Conference on Agricultural Risk and Food Security 2010*, Agriculture and Agricultural Science Procedia 1:126–135, doi:10.1016/j.aaspro.2010.09.015.

CHJ (2009): *Metodología y resultados de la estimación de demandas*. Documento.

CHJ (2010a): *Informe de evaluación de la demanda urbana de agua en el ámbito territorial de la CHJ*. Confederación Hidrográfica del Júcar.

CHJ (2010b): *Informe de evaluación de la demanda agrícola de agua en el ámbito territorial de la CHJ*. Confederación Hidrográfica del Júcar.

CHJ (2013): *Proyecto del plan hidrológico. Demarcación hidrográfica del Júcar*. Fase de consulta pública. Confederación Hidrográfica del Júcar. http://www.chj.es/es-es/medioambiente/planificacionhidrologica/Paginas/Proyecto-Plan-Hidrologico-cuenca-2009-2015.aspx .

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A., Whetton, P. (2007): *Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Collazos, G. (2004): *Sistema de soporte de decisión para evaluación y optimización económica de sistemas de recursos hídricos*. PhD thesis, UPV, Valencia, Spain.

Colorado Drought Mitigation and Response Plan, (2013): Prepared by the Colorado Water Conservation Board, Department of Natural Resources in Cooperation with The Department of Public Safety Division of Homeland Security and Emergency Management and the Drought Mitigation and Response Planning Committee.

Collins, T.W., & Bolin, B. (2007): Characterizing vulnerability to water scarcity: The case of a groundwater-dependent, rapidly urbanizing region, *Environmental Hazards*, **7**: 399–418.

Cortes R. (2013): River regulation and climate change in Portugal: new challenges to preserve biodiversity. CITAB, Center for Research and technology of Agro-environment and Biological sciences. 3rd workshop DROUGHT R & SPI, ISA, Lisbon.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008): A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, **18(4)**: 598-606. doi:10.1016/j.gloenvcha.2008.07.013.

Diogo V. & Koomen E. (2010): Explaining land-use change in Portugal 1990-2000. 13th AGILE International Conference on Geographic Information Science, 1 -11.Guimarães, Portugal.

Drought Management Centre for South-East Europe – DMCSEE, (2012*): Summary of the result of the project, co-financed by the South East Europe Transnational Cooperation Programme* (contract no. SEE /A/091/2.2/X), Gregor Gregorič (Ed), Slovenian Environmental Agency 2012.

Eakin, H., & Bojórquez-Tapia, L. A. (2008): Insights into the composition of household vulnerability from multicriteria decision analysis. *Global Environmental Change*, **18(1)**: 112-127. doi:10.1016/j.gloenvcha.2007.09.001.

EC (2007a): *Mediterranean Water Scarcity & Drought Report*, Technical Report 009-2007, MED WS&D Working Group.

EC (2007b): Scenar 2020- Scenario study on agriculture and the rural world. European Communities Report, 232pp.

European Environment Agency (EEA). (2006): Land accounts for Europe 1990-2000 – Towards integrated land and ecosystem accounting., EEA Report No. 11 /2006, Copenhagen, Denmark.

EEA glossary, http://glossary.eea.europa.eu/EEAGlossary/

Fontaine, M.M., & Steinemann, A.C. (2009): Assessing Vulnerability to Natural Hazards: Impact-Based Method and Application to Drought in Washington State, *Natural Hazards Review*, February 2009, pp. 11-18.

Fuhrer, J., Calanca, P. (2014): Bewässerungsbedarf und Wasserdargebot unter Klimawandel: eine regionale Defizitanalyse, Agrarforschung Schweiz **5(6):** 256-263.

Gallardo, C., Arribas, A., Prego, J.A., Gaertner, M.A., Castro, M. (2001): Multi-year simulations with a high resolution regional climate modelo ver the Iberian Peninsula. Current climate and 2xCO_2 scenario. *Quarterly Journal of the Royal Meteorological Society* **127**: 1659-1682.

Gallopín, G. C. (2006): Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* **16(3)**: 293-303. doi:10.1016/j.gloenvcha.2006.02.004.

García de Jalón S., Iglesias A., Cunningham R., Pérez & Díaz J. I. (2014): Building resilience to water scarcity in southern Spain: a case study of rice farming in Doñana protected wetlands. *Regional Environmental Change* **14(3):** 1229-1242.

García-Ruiz J.M., López-Moreno J.I., Vicente-Serrano S.M., Lasanta–Martínez T. & Beguería S. (2011): Mediterranean water resources in a global change scenario. *Earth Sci Rev* **105:**121–139

Gbetibouo, G., A. & Ringler, C. (2009): *Mapping South African Farming Sector Vulnerability to Climate Change and Variability*, IFRI.

Gouveia C., Trigo R.M., Da Camara C.C. (2009): Drought and vegetation stress monitoring in Portugal using satellite data. *Nat. Hazards Earth Syst. Sci.* **9**:185-195.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P.,Sibout Nooteboom, s., Bergsma, E. (2010): The Adaptive Capacity Wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society*. Environmental science and policy* **13 (6)**: 459 – 471.

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009): The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change* **19(1)**: 74-88. doi:10.1016/j.gloenvcha.2008.11.002.

Hatzilacou D., Kallis G., Mexa A.,Coccosis H. & Svoronou E. (2007): Scenario workshops: A useful method for participatory water resources planning? *Water Resources Research*, **43 (6)** W06414.

Hellenic Ministry of Development (2008): *Development of Systems and Tools for Water Resources Management in the Hydrological Department of the Aegean Islands*. 2001-2008.

Hurd, B., Leavy N., Jones, R., & Smith, J., (1999): Relative regional vulnerability of water resources to climate change, *Journal of the American Water Resources Association* **35 (6)**: 1399-1409.

Iglesias, A., Moneo, M., Quiroga, S., (2009): *Methods for Evaluating Social Vulnerability to Drought, Chapter 11*, in A. Iglesias et al. (eds.), Coping with Drought Risk in Agriculture and Water Supply Systems, Advances in Natural and Technological Hazards Research 26, doi: 10.1007/978-1-4020-9045-511, Springer Science+Business Media B.V. 2009.

INAG (2001): Plano Nacional da Água, Instituto da Água, Ministério do Ambiente e Ordenamento do Território.

INE (2014): Press release. Projecções da população residente 2012-2060. 18pp.Consulted in 13 August 2014. www.ine.pt

IPCC (2007): *Climate Change 2007: Synthesis Report, 4th Assessment of the Intergovernmental Panel on Climate Change*.

IPCC (2012): *Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Socio-Economic Scenarios* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, V. Barros, C.B. Field, T. Zwickel, S. Schloemer, K. Ebi, M. Mastrandrea, K. Mach, C. von Stechow (eds.)]. IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam Germany, pp. 51.

Jacinto R., Cruz M.J & Santos F.D. (2011): Adaptation of a Portuguese water supply company (EPAL) to climate change: producing socio-economic and water use scenarios for the XXI century. YSW, International Water Week Amsterdam 2011; 31 Oct. - 4 Nov.

Jinno, K. (1995): Risk Assessment of a Water Supply System during Drought, International Journal of *Water Resources Development*, **11(2**): 185-204, doi: 10.1080/07900629550042399.

Jones N., de Graaff J., Rodrigo I. & Duarte F. (2011): Historical review of land use changes in Portugal (before and after EU integration in 1986) and their implications for land degradation and conservation, with a focus on Centro and Alentejo regions. *Applied Geography,* **31(3):** 1036-1048.

Jongen M., Unger S., Fangueiro D., Cerasoli S., Silva J.M.N & Pereira J. S. (2013): Resilience of montado understorey to experimental precipitation variability fails under severe natural drought. Agriculture, *Ecosystems & Environment* **178**: 18-30.

Julião R. & Fernandes J.N. (coord.) (2009): Atlas de Portugal. Instituto Geográfico Português. (http://www.igeo.pt/atlas/Cap1/Cap1d_3.html).

Kaly, U., Pratt, C., and Mitchell, J. (2004): *The Environmental vulnerability Index 2004*. SOPAC Technical Report 384. Available at:http://www.vulnerabilityindex.net/EVI_ Library.htm.

Kok. K., Patelb, M.,. Rothmanc, D.S, Quaranta, G. (2006): Multi-scale narratives from an IA perspective: Part II. Participatory local scenario development, *Futures* **38:** 285–311.

Kossida, M., Kakava, A., Tekidou, A., Iglesias, A., Mimikou, M. (2012): *Vulnerability to Water Scarcity and Drought in Europe*, Thematic assessment for EEA Water 2012 Report, ETC/ICM Technical Report 3/2012.

Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., Wilbanks, T. (2012): The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways, *Global Environmental Change* **22**: 807–822, doi: 10.1016/j.gloenvcha.2012.05.005.

Kriegler E., O'Neill B.C., Hallegatte S., Kram T., Moss R.H., Lempert R., Wilbanks T.J.., (2010): Socio-economic Scenario Development for Climate Change Analysis, Working Paper No 23-2010, C.I.R.E.D.

Kromker, D., Eierdanz, F., Stolberg, A., (2008): Who is susceptible and why? An agent-based approach to assessing vulnerability to drought, *Reg Environ Change* **8**:173–185, doi: 10.1007/s10113-008-0049-5.

Kruse, S., Seidl, I. (accepted) Trockenheit im Obstbau. Befragung von Landwirten in der Nordost- und Nordwestschweiz [Drought in fruit-growing. Survey among farmers in Northeast and Northwest Switzerland]. Agrarforschung.

Kumar, C. P. & Seethapathi, P., V. (2002): Assessment of Natural Ground Water Recharge in Upper Ganga Canal Command Area. *Journal of Applied Hydrology*, XV, 4, pp. 13-20.

Kumar, C. P. (2004): Groundwater Assessment Methodology. Electronic Proceedings (CD), *XXIII Annual Convention of AHI and National Seminar on Water Resources Management & People's Participation*, 10-11 December 2004, Baroda.

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, (2007): *Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

Langeweg, F., & Gutierrez-Espeleta E.E. (2001): *Human Security and Vulnerability in a Scenario Context: Challenges for UNEP's Global Environmental Outlook*. IHDP Update 2:17-19.

Lawrence, P., Meigh, J. & Sullivan, C., (2002): *The Water Poverty Index: an International Comparison, Keele Economics Research Papers*. http://www.keele.ac.uk/kms/

Liu, X., Wang Y., Peng, J., Braimoh, A.K., Yin, H. (2013): Assessing vulnerability to drought based on exposure, sensitivity and adaptive capacity: A case study in middle Inner Mongolia of China. *Chinese Geographical Science*, **23(1)**: 13−25. doi: 10.1007/s11769-012-0583-4.

Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, C.L., and Matson, P.A... (2003): A Method for Quantifying Vulnerability, Applied to the Agricultral System of theYaqui Valley, Mexico. *Global Environmental Change* **13**:255-267.

MAOTDR (2007):Programa Nacional da Política de Ordenamento do Território. Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa.

MAMAOT (2013): Estratégia de adaptação da agricultura e das florestas às alterações climáticas. Portugal Continental. Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território. 88 pp.

MAMAOT (2013a): Seca 2012. Relatório de balanço. Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território. 132 pp.

http://www.portugal.gov.pt/media/916024/Relatorio_Balanco_GTSeca2012_v1.pdf

Máñez Costa, M. A., Moors E. J., & Fraser E. (2011): Socioeconomics, policy, or climate change: what is driving vulnerability in southern Portugal? *Ecology and Society* **16(1):** 28. [online] URL: http://www.ecologyandsociety.org/vol16/iss1/art28/

Massarutto, A., Musolino, D., Pontoni, F., De Carli, A., Senn, L., De Paoli, L., Rego, F.C., Dias, S., Bifulco, C., Acácio, V., Andreu, J., Assimacopoulos, D., Ayala, L.M., Gad, F., Monteagudo, D.H., Kampragkou, E., Kartalides, A., Paredes, J., Soler A. (2013): Analysis of historic events in terms of socio-economic and environmental impacts. DROUGHT-R&SPI Technical Report No 9.

Moss, R.H., Brenkert, A.L., Malone, E.L., (2001): *Vulnerability to climate change: a quantitative approach*. Technical Report PNNL-SA-33642 2001.(PAG 12).

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose S.K. , van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P. & Wilbanks, T.J., (2010): The next generation of scenarios for climate change research and assessment, *Nature* **463**: 747-756, doi:10.1038/nature08823.

Mpezes (2001): *Water Management Study for the Cyclades Complex*, Directorate of Technical Services, Prefecture of Cyclades.

OcCC/ProClim, editor. Climate Change and Switzerland 2050 (2007): Expected Impacts on Environment, Society and Economy. OcCC / ProClim, 2007. URL http://www.proclim.ch/4dcgi/proclim/en/Media?794.

Pandey, R.P., Pandey, A., Galkate, R.V., Byun, H-R, Mal, B.C., (2010): Integrating Hydro-Meteorological and Physiographic Factors for Assessment of Vulnerability to Drought, *Water Resources Management*, **24**:4199–4217 doi: 10.1007/s11269-010-9653-5.

Parrya M.L., Rosenzweig C., Iglesias A., Livermore M. & Fischer G. (2004): Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* **14:** 53–67.

Patela, M. Kokb, K., Rothman, D.S. (2007): Participatory scenario construction in land use analysis: An insight into the experiences created by stakeholder involvement in the Northern Mediterranean, in *Land Use Policy* **24:** 546–561.

Paulo A.A. & Pereira L.S. (2006): Drought concepts and characterization. Comparing drought indices, *Water Int.* **31:** 37–49.

PCM (Presidency of the Council of Ministers) (2005): Programa Nacional para o Uso Eficiente da Água — Bases e Linhas Orientadoras (PNUEA). Resolução do Conselho de Ministros n. 113/2005, 5 June

Pellizzaro G., Cesaraccio C., Duce P., Ventura A., Zara P. (2007): Relationships between seasonal patterns of live fuel moisture and meteorological drought indices for Mediterranean shrubland species*. International Journal of Wildland Fire* **16(2):** 232-241

Pereira N., Domingues T.M, Vicente L. & Proença V. (2009): Ecossistemas e bem estar humano. Avaliação para Portugal do Millennium Ecosystem Assessment. Escolar Editora, 734 pp.

Polsky, C., Neff, R., Yarnal, B. (2007): Building comparable global change vulnerability assessments: The vulnerability scoping diagram, *Global Environmental Change*, **17**: 472-485.

Pope, V.D., Gallani, M., Rewntree, P.R., Stratton, R.A. (2000): The impact of new physical parametrisations in the Hadley Centre climate model HadCM3. *Climate Dynamics* **16**: 123-146.

Rivera-Urban, A. (2011): *Evaluación de la demanda agraria de agua en el ámbito territorial de la Confederación Hidrográfica del Júcar. Incertidumbres y consecuencias en la planificación hidrológica.*

Rounsevell M.D.A., Reginster I., Araújo M.B., Carter T.R.,Dendoncker N., Ewert F., House J.I., Kankaanpa S., Leemans R., Metzger M.J., Schmit C., Smith P. & Tuck G. (2006): A coherent set of future land use change scenarios for Europe. Agriculture, *Ecosystems and Environment* **114:** 57–68.

Rounsevell M. D. A. & Metzger M. J. (2010): Developing qualitative scenario storylines for environmental change assessment. WIREs *Climate Change* **1**: 606-619. http://dx.doi.org/10.1002/wcc.63

Saaty, T.L. (1980): The Analytic Hierarchy Process. New York: McGraw- Hill International.

Salvati, L., Zitti, M., Ceccarelli, T., Perini, L. (2009): Developing a Synthetic Index of Land Vulnerability to Drought and Desertification, *Geographical Research* **47(3)**: 280–291, doi: 10.1111/j.1745-5871.2009.00590.x.

Santos F.D., Forbes K. & Moita R. (eds), (2002): Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures – SIAM Project, Gradiva.

Santos, J. F., Pulido-Calvo I. & Portela M. M. (2010): Spatial and temporal variability of droughts in Portugal, *Water Resour. Res.*, **46**, W03503, doi:10.1029/2009WR008071.

Santos Pereira, L., Mexia, J.T. & Pires C. A. (eds) (2010): Gestão do risco em secas. Métodos, Tecnologias e desafios. Edições Colibri and CEER – Centro de Engenharia dos Biossistemas. (in portuguese)

Santos F. D., Stigter T. Y., Faysse N. & Lourenço T. C. (2013): Impacts and adaptation to climate change in the Mediterranean coastal areas: the CIRCLE-MED initiative. *Regional Environmental Change*. doi:10.1007/s10113-013-0551-2

Schweizer Eidgenossenschaft (2012): Bericht des Bundesrates zum Postulat "Wasser und Landwirtschaft. Zukünftige Herausforderungen". Bern.

Schweizer, V. J. & Kriegler, E. (2012): Improving environmental change research with systematic techniques for qualitative scenarios. *Environ. Res. Lett.*, 7-044011, 14, http://dx.doi.org/10.1088/1748-9326/7/4/044011.

Sena, J. A., Freitas, M. A. V., De Berredo, D., & Fernandes, L. C. (2012): Evaluation of Vulnerability to Extreme Climatic Events in the Brazilian Amazonia: Methodological Proposal to the Rio Acre Basin. *Water Resources Management* **26(15)**: 4553-4568. doi:10.1007/s11269-012-0166-2.

Segnestam, L. (2009): Division of Capitals—What Role Does It Play for Gender-Differentiated Vulnerability to Drought in Nicaragua?, *Community Development* **40(2)**: 154-176, doi:10.1080/15575330903001562.

Seneviratne, S.I., R. Orth, S. Jörg-Hess, S. Kruse, I. Seidl, M. Stähli, M. Zappa, J. Seibert, M. Staudinger, K. Stahl, and M. Weiler, (2013): Trockenheit in der Schweiz - Ergebnisse des NFP-61-Projekts DROUGHT-CH. Aqua & Gas, **9**: 38-47

Simelton, E., Fraser, E.D.G., Termansen, M., Forster, P.M., Dougill, A.J. (2009): Typologies of crop-drought vulnerability: an empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961–2001), *Environmental Science and Policy*, **12**: 438–452, doi:10.1016/j.envsci.2008.11.005.

Simões S., Seixas J., Fortes P., Dias L., Gouveia J. & Maurício B. (2011): The medium to long-term role of renewable energy sources in climate change mitigation in Portugal. World Renewable Energy congress, Sweden. *Climate change issues*. 724-731.

Smit, B., & Wandel, J. (2006): Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16(3)**: 282-292. doi:10.1016/j.gloenvcha.2006.03.008.

Smith, M., & Steduto, P. (2012): Yield response to water: the original FAO water production function, In Steduto P., Hsiao T. C. , Fereres E., Raes D. (Eds.).Crop yield response to water, FAO Irrigation and Drainage Paper No66, Rome: Food and Agriculture Organisation of the United Nations, 6-13.

Stagge J.H., Dias S., Rego F., Tallaksen L.M. (2014): Modeling the effect of climatological drought on European wildfire extent. Geophysical Research Abstracts (16), EGU2014-15745.

Stähli, M., Kruse, S., Fundel, F., Zappa, M., Stahl, K., Bernhard, L., Seidl, I. (2013): drought.ch - auf dem Weg zu einer Trockenheits-Informationsplattform für die Schweiz. Wasser Energie Luft **105(2):** 117-121.

Steduto, P., Hsiao, T., Fereres, E., Raes, D. (2012): *Crop yield response to water*. Irrigation and Drainage Paper 66, Food and Agriculture Organization of the United Nations, Rome.

Stigter T., Bento S., Varanda M., Nunes J. P. & Hugman R. (2013). Combined assessment of climate change and socio-economic development as drivers of freshwater availability in the South of Portugal. Transboundary water management across borders and interfaces: present and future challenges. Proceedings of the TWAM2013 International Conference & Workshops. 6 pp.

Stott, P.A., Tett, S.F.B. (1998) Scale-dependent detection of climate change. *Journal of Climate* **11**: 3282-3294.

Sullivan, C.A. (2011): Quantifying water vulnerability: a multi-dimensional approach, *Stoch Environ Res Risk Assess*, **25**: 627–640. doi: 10.1007/s00477-010-0426-8.

Sullivan, C.A. & C. Huntingford, (2009): Water resources, climate change and human vulnerability. *18th World IMACS / MODSIM Congress*, Cairns, Australia 13-17 July 2009 http://mssanz.org.au/modsim09.

Sullivan, C. & Meigh, J. (2005): Targeting attention on local vulnerabilities using an integrated index approach: the example of the Climate Vulnerability Index, *Water Science and Technology* **51(5)**: 69-78.

Swain, M., & Swain, M. (2011): Vulnerability to Agricultural Drought in Western Orissa: A Case Study of Representative Blocks, *Agricultural Economics Research Review* **24**: 47-56.

Rossi, G., & Cancelliere, A. (2013): Managing drought risk in water supply systems in Europe: a review, *International Journal of Water Resources Development* **29(2)**: 272-289, doi: 10.1080/07900627.2012.713848.

Taenzler, D., Carius, A., Maas, A. (2008): Assessing the susceptibility of societies to droughts: a political science perspective , *Journal of Reg Environ Change* **8(4)**:161–172.

Tol, R.S.J., Yohe, G.W. (2006): The weakest link hypothesis for adaptive capacity: an empirical test. *Global Environmental Change* **17**: 218–227.

Tsakiris, G. (2009): *A Paradigm for Applying Risk and Hazard Concepts in Proactive Planning, Chapter* 7, In Iglesias et al. (eds.), Coping with Drought Risk in Agriculture and Water Supply Systems, Advances in Natural and Technological Hazards Research 26, doi: 10.1007/978-1-4020-9045-57, Springer Science+Business Media B.V. 2009.

Vale, MJ (coord) (2014): Landyn: Land Use and Land Cover Change in Continental Portugal: characterization, driving forces and future scenarios. Direcão-Geral do Território (DGT). 115 pp (in portuguese).

van Berkel D.B., Carvalho-Ribeiro S., Verburg P. H. & Lovett A.(2011): Identifying assets and constraints for rural development with qualitative scenarios: a case study of Castro Laboreiro, Portugal. *Landscape and Urban Planning*, **102:** 127-141.

van der Heijden, K. (2005): Scenarios: The Art of Strategic Conversation, John Wiley & Sons: Chichester

van Lanen, H., Alderlieste, M., van der Heijden, A., Assimacopoulos, D., Dias, S., Gudmundsson, L., Haro Monteagudo, D., Andreu, J., Bifulco, C., Gero, F., Parede, J., Solera A. (2013): *Likelihood of future european drought: selected European case studies*. DROUGHT-R&SPI Technical Report No. 11 [available at: http://www.eu-drought.org/], Wageningen University, the Netherlands.

Van Ruijven, B., & Ebi, K. (2013):, Shared Socioeconomic Pathways: process and relevance for IAV research, *Impacts World Conference*, Potsdam, 29 May 2013; Available at: http://www.climate-impacts-2013.org/files/kristie_ebi.pdf.

van Vuuren, D.F., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K., Arnell, N. (2012):, A proposal for a new scenario framework to support research and assessment in different climate research communities, *Global Environmental Change* **22(1)**: 21–35, doi: 10.1016/j.gloenvcha.2011.08.002.

Vicente-Serrano S. M, Lopez-Moreno J.-I, Beguería S., Lorenzo-Lacruz J., Sanchez-Lorenzo A., García-Ruiz J. M, Azorin-Molina C., Morán-Tejeda E., Revuelto J., Trigo R., Coelho F. & Espejo F. (2014). Evidence of increasing drought severity caused by temperature rise in southern Europe. *Environmental Research Letters* **9(4):** 044001.

Weimer-Jehle, W. (2005): Cross-impact balances: A system-theoretical approach to cross-impact analysis. *Technological Forecasting & Social Change*, **73**: 334–361.

Wilhelmi, O. V., & Wilhite, D. A. (2002): Assessing Vulnerability to Agricultural Drought: A Nebraska Case Study. *Natural Hazards* **25(1)**: 37-58. doi:10.1023/A:1013388814894.

Wilhite, D.A., Svoboda, M.D, Hayes, M.J. (2007): Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness, *Water Resour Manage* **21**:763–774, doi: 10.1007/s11269-006-9076-5.

Wulf T., Brands C. & Meissner P. (2010): A Scenario-based Approach to Strategic Planning Tool Description – 360° Stakeholder Feedback, HHL – Leipzig Graduate School of Management, Working Paper: 101. 13 pp.

Wulf T., Brands C. & Meissner P. (2011a): A Scenario-based Approach to Strategic Planning – Tool Description – Scenario Matrix. HHL – Leipzig Graduate School of Management, Working Paper: 12. 23pp.

Wulf T., Brands C. & Meissner P. (2011b): A scenario-based approach to strategic Planning Tool description – Impact/Uncertainty Grid. HHL – Leipzig Graduate School of Management, Working Paper: 5. 10pp.

Wright G. & Cairns G. (2011): Scenario Thinking: Practical Approaches to the Future. Palgrave MacMillan: Houndmills.

UNEP (2009): *Methodologies Guidelines: Vulnerability Assessment of Freshwater Resources to Environmental Change*, Peking University.

UN/ISDR (2009): *Terminology on Disaster Risk Reduction* [Available from: http://www.unisdr.org/eng/terminology/UNISDR-terminology-2009-eng.pdf].

UN-ISDR (2004): *Living with Risk: A Global Review of Disaster Reduction Initiatives. Volume I*, New York & Geneva, Switzerland: Inter - Agency Secretariat of the International Strategy for Disaster Reduction. 457 pp.

Urwin, K., & Jordan, A. (2008): Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. *Global Environmental Change* **18(1)**: 180-191. doi:10.1016/j.gloenvcha.2007.08.002.

Annex A: Review of existing socio-economic development scenarios

Table A. 1: *The FP6 SCENES water scenarios (CRES, 2010).*

Scenario	Storyline
Economy First (EcF)	A globalised and liberalised economy pushes the use of all available energy sources and an intensification of agriculture where profitable. The adoption of new technologies and water-saving consciousness are low. Thus water use increases. Only water ecosystems providing ecological goods and services for economies are preserved and improved. Curtailed infrastructure, poor treatment and intensified agriculture lead to increased pollution. Poisoning incidents catch the interest of media and public. This and social tensions lead to upheaval in the 2040s. This triggers new cooperation to restore economic prosperity and make ground for social coherence.
Fortress Europe (FoE)	A high number of crises (energy, financial, and climatic) result in an increasing instability and terrorist activities throughout the world, as well as in Europe. Subsequently, Europe closes its borders and concentrates on a series of security issues, including a central goal on self-sufficiency. Cooperation is difficult and alliances change, but perceived threats keep the EU together. The WFD becomes the Water Security Framework Directive with much less public participation, to tackle the increase and intensification of water conflicts. Water policies focus on water demand, which is largely satisfied by 2050.
Policy Rules (PoR)	A stronger coordination of policies at EU level, but policies become slowly more ineffective. As a result, ecosystem services begin to deteriorate very significantly. Until 2030, EC becomes increasingly disappointed in the level of WFD compliance; issues of water quality and quantity are generally ignored; while there are emerging and increasing pressures on water resources. After 2030, climate change hits hard and changes public apathy, leading to WFD compliance that is higher than ever. By 2030, public participation increases, leading to local government support. By 2050, Europe is at the forefront of a new socio-economic paradigm of public/private partnerships and leads a global shift in this direction.
Sustainability Eventually (SuE)	This scenario sketches the transition from a globalising, market-oriented Europe to environmental sustainability, where local initiatives are leading and where the landscape becomes the basic unit. This fundamental change in human behaviour, governance structures, and level of decision making, is projected to come about through a phase of strong top-down policies (“quick change measures”), accompanied with a set of “slow-change” measures that bear fruit in the long run.

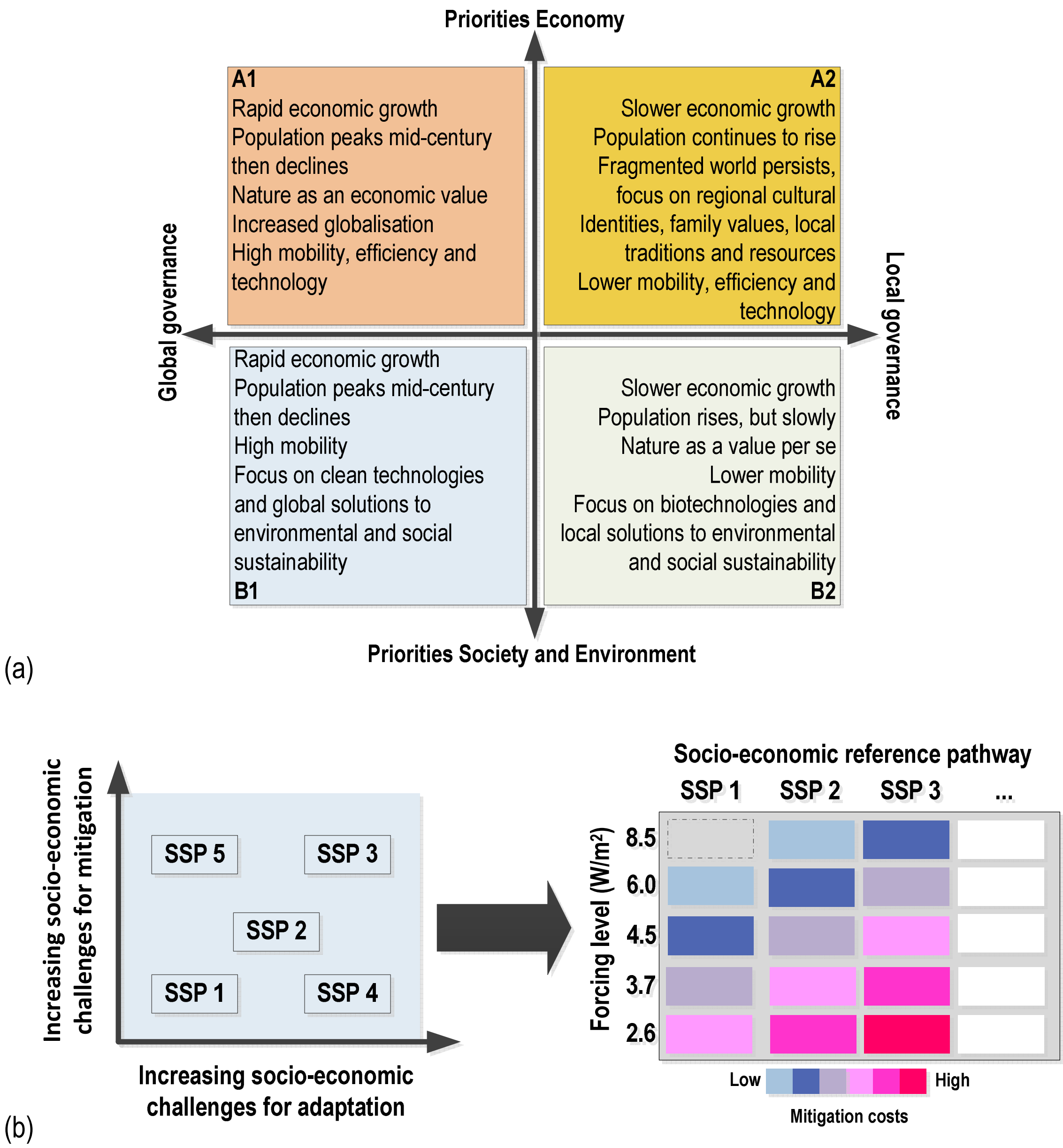


Figure A. 1: *The IPPC scenario framework: SRES scenarios (up; Aguiar, 2008), SSPs (down; ,IPCC, 2012).*

Annex B: Indicative list of indicators used in vulnerability assessments

Table B. 1: *Indicative list of indicators used for describing vulnerability – Exposure.*

Component	Variables/Indicators	Reference
Natural Hazard (Drought)	Average number of extreme events	Hahn et al. (2009)
	Intensity (Drought Indicators)	Swain & Swain (2011) Hahn et al. (2009)
	Frequency of events	Hahn et al. (2009)
	Return period	Hahn et al. (2009)
	Spatial impact (extend)	Hahn et al. (2009)
	SPI	Liu et al. (2013)
Climate variability	Mean standard deviation of monthly average precipitation	Hahn et al. (2009)
	Mean standard deviation of monthly average temperature	Hahn et al. (2009)
Affected population	Percent of households that did not receive a warning about the impending natural disasters	Hahn et al. (2009) Polsky et al. (2007)
	Rural population density	Hahn et al. (2009) Polsky et al. (2007)
	Percentage of population engaged in farming activity	Hahn et al. (2009) Polsky et al. (2007)
Water Scarcity	Water Exploitation Index (WEI)	Alcamo et al. (2000)
	Groundwater development stress indicator (GDSI)	FAO, AQUASTAT
	Water Scarcity Index (WSI)	Brown &Matlock (2011)
Land Topography	Land slope (%)	Swain & Swain (2011) Wilheim (2002)
	Geomorphology	Sena et al., (2012)
Exposed Activity	Percentage of rainfed agriculture	Bhattacharya & Das (2007)
	Size of agricultural sector	Bhattacharya & Das (2007)
	Degree of self water supply	Bhattacharya & Das (2007)
Water Resources and Ecosystems Affected	Stream flow variability (the ratio of standard deviation of unregulated mean of annual stream flow)	Hurd et al. (1999)
	Coefficient Variation of Precipitation for a long period (CV %)	Swain & Swain (2011)
	Waste water discharge as % of available water resources	UNEP, (2009)

Table B. 2: *Indicative list of indicators used for describing vulnerability – Sensitivity.*

Component	Variables/Indicators	Reference
Water Infrastructure	Physical size of Distribution Network	Polsky et al. (2007)
	Infrastructure Age	Polsky et al. (2007)
Ecosystems/ Environmental Sensitivity	Vegetation cover as % of Basin Area	Babel et al. (2011)
	Land uses	Wilhelmi & Wilhite (2002)
	Coefficient of variance of NDVI	Liu et al. (2013)
	Fertilizer use/cropland area	Gbetibouo & Ringler (2009)
Socio-Economic Characteristics	Income/ Household Expenditure	Bhattacharya & Das (2007)
	Coefficient of Inequality	Bhattacharya & Das (2007)
Livelihood	Income change	Eakin et al. (2008)
	Migrants change	Eakin et al. (2008)
Agriculture Water Use	Irrigation Coverage	Babel et al. (2011)
	Irrigation support	Wilhelmi & Wilhite (2002)
	Crop diversification index	Gbetibouo & Ringler (2009)
	Irrigated land as percentage of cultivated land	FAO, AQUASTAT
	Average plot size (share (%) of small-scale farming operations)	Gbetibouo & Ringler,(2009)
	Rural population density	Gbetibouo & Ringler (2009)
	Total amount of replenishable groundwater available annually	Gbetibouo & Ringler (2009)
	Share of water use by agriculture adjusted by the sector's share of GDP (The proportion of GDP derived from agriculture is divided by the proportion of water used by agriculture)	Lawrence et al. (2002)
	Share of fruits and vegetables in agricultural value added	Bhattacharya & Das (2007)
	Share of total oil seeds in agricultural value added	Bhattacharya & Das (2007)
	Pesticide use per hectare	Bhattacharya & Das (2007)
	Fertilizer per hectare	Bhattacharya & Das (2007)
	Extend of mechanisation (tractors per hectare)	Bhattacharya & Das (2007)
Domestic Water Use	Drinking Coverage	Babel et al. (2011)
	Percentage annual water demand for domestic use	Sullivan (2011)
	Distribution network efficiency	Sharma (2008)
Industrial Water Use	Share of water use by industry adjusted by the sector's share of GDP (The proportion of GDP derived from industry is divided by the proportion of water used by industry.)	Lawrence et al. (2002)
	Hydropower dependence (percent of total installed capacity dedicated to hydropower)	Blackshear et al. (2011)

Table B. 3: *Indicative list of indicators used for describing vulnerability – Adaptive capacity (De Stefano and Urquijo[9], 2013).*

Component	Variables/Indicators	Reference
Policy/ institutional - related		
Variety	Variety of problems frames	Nooteboom (2006a,b), Buckley (1968), Conant and Ashby (1970), Pollit and Bouckaert (2000) and Power (1999) in Gupta et al 2010.
	Multi-actor, multi-level, multi-sector	Pahl-Wostl (2009), Duit and Galaz (2008), Armitage (2008) and Folke et al. (2005); in Gupta et al 2010.
	Diversity of solutions	Ostrom (2005) and Verweij and Thompson (2006), in Gupta et al 2010.
	Redundancy (duplication)	Weick and Sutcliffe (2001), in Gupta et al 2010.
Learning capacity	Institutional memory	Ostrom (2005) and Gunderson and Holling (2002); in Gupta et al 2010.
Room for autonomous change	Continuous access to information	Folke et al. (2005), Milman and Short (2008) and Polsky et al. (2007) in Gupta et al 2010.
	Act according to plan	Smit et al. (2000). In Gupta et al 2010.
	Capacity to improvise	Armitage (2005), Folke et al. (2003, 2005), Pelling and High (2005), Smit et al. (2000), Weick and Sutcliffe (2001) and Orlikowski (1996) in Gupta et al 2010.
Ability to adjust	Flexibility	Smit & Wandel (2006)
	Learning and technological progress	Gallopín, 2006
Institutional capacity	Rule of law	Kaufmann et al (1999) in Tol & Yohe, 2007
Institutional	Participation in hazard reduction programs	Cutter et al (2008)
	Hazards mitigation plans	Cutter et al (2008)
	Emergency service	Cutter et al (2008)
	Emergency response plans	Cutter et al (2008)
	Interoperable communications	Cutter et al (2008)
	Continuity of operations plans	Cutter et al (2008)
Fair governance	Legitimacy	Haddad (2005) and Botchway (2001) in Gupta et al 2010
	Equity	Haddad (2005) and Botchway (2001) in Gupta et al 2010
	Responsiveness	Biermann (2007). In Gupta et al 2010.
	Accountability	Botchway (2001) and Biermann (2007) in Gupta et al 2010.
Types of response of human system	Reactive	Smither and Smit (1997) in Gallopín, 2006
	Proactive	Smither and Smit (1997) in Gallopín, 2006
Economic capacity		
Human resources	Dependency ratio	Moss et al (2001)
	Literacy	Moss et al (2001)
	Population density	Liu et al. (2013)

[9] Discussion document sent by the UCM on 15/4/2013

Component	Variables/Indicators	Reference
Resources	Human resource	Nelson et al (2010) in Gupta et al, 2010)
	Financial resources	Nelson et al (2010) in Gupta et al, 2010)
	Access to finance	Various references in Smit & Wandel (2006)
	Per capita GDP	Liu et al. (2013)
	Per capita savings deposit	Liu et al. (2013)
	Ratio of agriculture and industry output	Liu et al. (2013)
Infrastructure	Infrastructure	Cutter et al (2008)
	Infrastructures	Various references in Smit & Wandel (2006)
	Technological and information resources	Various references in Smit & Wandel (2006)
Social	Social networks and social embeddedness	Cutter et al (2008)
	Community values-cohesion	Cutter et al (2008)
Community competence	Local understanding of risk	Cutter et al (2008)
	Counselling services	Cutter et al (2008)
Organizational	Structure, capacity, leadership, training and experience	Tierney and Bruneau (2007) in Cutter et al, 2008.
Decision-making process	Authorities and mechanisms involved	Smit & Wandel (2006) (At social and institutional level)
	Access to information	
	Willingness to change	
	Participation	
	Learning	
Ecological		
Ecological capacity	Ecological capacity	Moss et al (2001)
		Various references in Smit & Wandel (2006)

Annex C: The Vulnerability Index Matrix

Table C. 1: *Matrix for the vulnerability assessment in the Case Studies – Exposure & sensitivity.*

Dimension	Component	Variable	Narrative description of scores	
			Low vulnerability (score 1)	**High vulnerability (score 5)**
Exposure (E)	Drought Hazard (input from Task 2.4)	Number of drought events	Low frequency of drought events	High frequency of drought events
		Drought duration	Short duration (e.g. week)	Long duration (e.g. multi-year)
		Drought intensity	Low intensity	High intensity
	Water scarcity	Water Exploitation Index	No water scarcity problems	Significant water scarcity problems
Sensitivity (S) (link to potential impacts)	Water sources	Groundwater levels	Low water usage, good quality	High water usage, poor quality
		Status of surface water storages	High storage capacity	Low storage capacity
		Transboundary (or regional) issues	Low dependency on transboundary water resources	High dependency on transboundary water resources
	Environment	Water quality	Good status	Poor status
		Wetlands/protected areas	Limited protected areas affected, minimum impacts	Large impacts on protected areas
	Urban sector	Population density	Few people affected	Large population affected
		Demand coverage	Increased coverage & reliability in supply	Water deficits & low reliability in supply
	Agriculture	Demand coverage	Increased coverage & reliability in supply	Water deficits & low reliability in supply
		% irrigated land	Low dependency on irrigation water	High demand for irrigation water
		Share of agricultural GDP	Minimum economic impacts due to drought	High economic impacts due to drought
		% Small-scale farming operations	Low % of Small-scale farming operations	High % of Small-scale farming operations
		Crop pattern/ diversity	High crop diversification	Low crop diversification
	Energy production	% Share of hydropower to total energy production	Low share	High share
	Other (please specify)	...		

Table C. 2: *Matrix for the vulnerability assessment in the Case Studies – Adaptive capacity.*

Dimension	Component	Variable	Narrative description of scores	
			High adaptive capacity (score 5)	**Low adaptive capacity (score 1)**
Adaptive Capacity (A)	Social	Access to information	People aware of drought risk & with access to information about drought conditions	Limited awareness of drought issues, Limited dissemination of drought-related information
		Willingness to change	People willing to change their habits/ activities	No willingness to change
		Conflicts	Participation in organisations, Participatory mechanisms in case of drought	Limited participation in organisations, Lack of cooperation in case of drought
	Policy	Drought Management	Drought planning in place - a policy priority (i.e. monitoring, DMPs, educated personnel, tools)	Lack of drought planning
		Actors & institutions	Well organised structure with clear jurisdictions	Many actors with fragmented responsibilities & conflicts
	Technology/ economic	Access to (water saving) technology	Users can easily buy/install water saving appliances. High technological base.	Users cannot easily buy/install water saving appliances. Use of out-to date technology.
		Access to alternative water sources	Users can afford/use other water sources	Users have no access to alternative water sources
		Infrastructure	Well-developed infrastructure	Poor status of infrastructure

Annex D: The Cross Impact Matrix for the Syros Case Study

Cross Impact Matrix	A		B		C		D			E			F		G		H		I	
	A1	A2	B1	B2	C1	C2	D1	D2	D3	E1	E2	E3	F1	F2	G1	G2	H1	H2	I1	I2
A. Traditional economic activities																				
A1 Preservation (no change in total cultivated area)			1	-1	0	0	0	0	0	1	1	-2	2	-2	0	0	-1	1	0	0
A2 Abandonment (30% decrease of cultivated area)			-1	1	-1	1	0	0	0	-1	-1	2	-2	2	0	0	1	-1	0	0
B. Livestock Production/Breeding																				
B1 No change	1	-1			-2	2	0	0	0	0	0	0	1	-1	0	0	0	0	0	0
B2 Only cattle breeding	-1	1			2	-2	0	0	0	0	0	0	-1	1	0	0	0	0	0	0
C. Groundwater use																				
C1 Increase (>100% groundwater use-over-exploitation)	0	0	0	0			0	0	0	0	0	0	-2	2	-1	1	-2	2	-2	2
C2 Decrease (< 80% groundwater use-protection)	0	0	0	0			0	0	0	0	0	0	3	-3	1	-1	1	-1	1	-1
D. Domestic water use																				
D1 Increase	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	2
D2 Stable	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	-2	2
D3 Decrease	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	1	-1
E. Water use for Irrigation																				
E1 Increase	1	-1	0	0	0	0	0	0	0				1	-1	0	0	0	0	0	0
E2 Stable	1	-1	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
E3 Decrease	-1	1	0	0	0	0	0	0	0				-1	1	0	0	0	0	0	0
F. Tourism development																				
F1 Control (tourism growth 2%)	2	-2	1	-1	3	-3	-2	1	1	-2	1	1			2	-2	-2	2	-1	1
F2 Expansion (tourism growth 5.9%)	-2	2	-1	1	-3	3	2	-1	-1	-3	1	2			-2	2	2	-2	-2	2
G. Drought Management Plan																				
G1 Yes	0	0	0	0	-3	3	-2	1	1	-2	1	1	1	-1			-2	2	1	-1
G2 No	0	0	0	0	1	-1	1	1	-2	1	1	-2	-1	1			2	-2	-2	2
H. Water resources (governance)																				
H1 Centralized water management	0	0	0	0	2	-2	2	-1	-1	1	1	-2	-1	1	0	0			0	0
H2 Decentralized water management	0	0	0	0	-2	2	-2	1	1	-2	1	1	1	-1	0	0			0	0
I. Water resources (management)																				
I1 Water demand management (increase of no. cisterns)	-1	1	0	0	0	0	0	0	0	0	0	0	-2	2	0	0	-1	1		
I2 Water supply enhancement (increase desalination capacity to meet demand)	-1	1	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	-1	1		

Annex E: Indicative values for some socio-ecological scenarios available for Portugal

Table E. 1: *Scenarios for Portugal.*

Indicator (%change)	Scenario references					
	INE, 2014	DDP,2011	SIAM I, 2002	DROUGHT, 2013	INAG, 2001	MA-Pt, 2009
Baseline year	2012	2006-11	2000	2012	2000	1995
Scenario year	2060	2050	2020	2050	2020	2050
Population	High:-13 low:-39.5 central:-20, no migration:-27	Welcome: -30; We cannot fail: 0	A1: 21 A2: 0 B1: 5 B2: 5			GO: 0 OF: -20 AM: - 15 TG: -10
GDP (%/year)		Welcome:1.4; W cannot fail:1.2-2.4	A1: 4 A2: 2 B1: 3 B2:1.75			GO: 3.7 OF: 1.5 AM: 2.2 TG: 3
Arable land area						GO: -5 OF: -10 AM: 0 TG: -10
Renewable energies			A1: 13 A2: 16 B1: 18 B2: 14			GO: 15 OF: -10 AM: - 15 TG: 10
Water consumption						GO: 20 OF: 30 AM: 10 TG: -10
Irrigated area					High: 28 Low: 18	
Average temperature increase			A2: 2.5-8.6 B2: 2-6	A2: 2-3 B1: 2-3		GO: 1.9 OF: 1.3 AM: 1.6 TG: 0.8

INE, 2014 – Four demographic scenarios, taking in to account a combination of more or positive or less positive developments in migration, fertility, longevity: High, Central and Low; a forth scenario correspond to the improbable absence of migration fluxes on the central conditions.

DDP, 2010 – Two socio-economic scenarios developend with the HybCO2 project: “We cannot fail” envisaging a more intense economic growth centred in high-tech domain (bio, cogno, nano) with clean energies, and “Welcome” a more moderate, centred in tourism/hospitality sector (Alvarenga et al. 2011).

SIAM, 2002 and DROUGHT 2013 used IPCC emission scenarios (SRES), adapted with forcing data from Portugal derived from different data sources: A1, B1, A2 and B2 families (Santos et al. 2002, van Lanen 2013).

INAG, 2001 – The National water management plan depict two levels of economic development, associated with DGP: High and Low.

MA-PT, 2009 – the adaptation of the Millennium ecosystem assessment to Portugal, with the participation of scholarly, stakeholders and end-users, resulted in four scenarios: GO – Global orchestration, OF – Order from Strength, AM – Adapting mosaic and TG – Technogarden (Pereira et al. 2009).

Annex F: Indicative results from the questionnaire survey on future vulnerability to drought for the Syros Case Study

Table F. 1: *Minimum scores assigned to the VI variables for Syros Island.*

Dimension	Component	Variable	Score - Current State	Score – Best case scenario	Score – Worst case scenario
Exposure (E)	Drought Hazard	Number of drought event	1	2	3
		Drought duration	1	2	4
		Drought intensity	1	2	3
	Water scarcity	Water Exploitation Index	2	2	4
Sensitivity (S)	Water sources	Groundwater level	2	2	4
	Environment	Water quality	3	2	4
	Urban sector	Population density	1	1	4
		Demand coverage	1	1	4
	Agriculture	Demand coverage	2	2	4
		% irrigated land	2	2	3
		Share of agricultural GDP	1	1	3
		Crop pattern/ diversity	2	1	4
	Tourism	Tourism intensity	2	2	3
Adaptive Capacity (A)	Social	Access to information	1	1	1
		Willingness to change	2	2	1
		Conflicts	2	3	1
	Policy	Existence of drought management policies	1	3	1
		Actors & institutions (jurisdictions, availability to resources)	1	2	2
	Technology/ economic	Access to (water saving) technology	2	4	1
		Access to alternative water sources	2	4	2
		Infrastructure	3	2	2

Table F. 2: *Maximum scores assigned to the VI variables for Syros Island.*

Dimension	Component	Variable	Score - Current State	Score – Best case scenario	Score – Worst case scenario
Exposure (E)	Drought Hazard	Number of drought event	3	3	5
		Drought duration	4	3	5
		Drought intensity	4	3	5
	Water scarcity	Water Exploitation Index	3	3	5
Sensitivity (S)	Water sources	Groundwater level	3	4	5
	Environment	Water quality	4	4	5
	Urban sector	Population density	3	3	4
		Demand coverage	3	3	5
	Agriculture	Demand coverage	3	3	5
		% irrigated land	3	3	4
		Share of agricultural GDP	2	3	5
		Crop pattern/ diversity	3	4	5
	Tourism	Tourism intensity	3	4	5
Adaptive Capacity (A)	Social	Access to information	3	4	3
		Willingness to change	2	4	4
		Conflicts	3	4	5
	Policy	Existence of drought management policies	2	4	2
		Actors & institutions (jurisdictions, availability to resources)	3	5	3
	Technology/ economic	Access to (water saving) technology	3	5	2
		Access to alternative water sources	4	5	4
		Infrastructure	4	5	4

Annex G: Matrices for discussing future vulnerability to drought with stakeholders

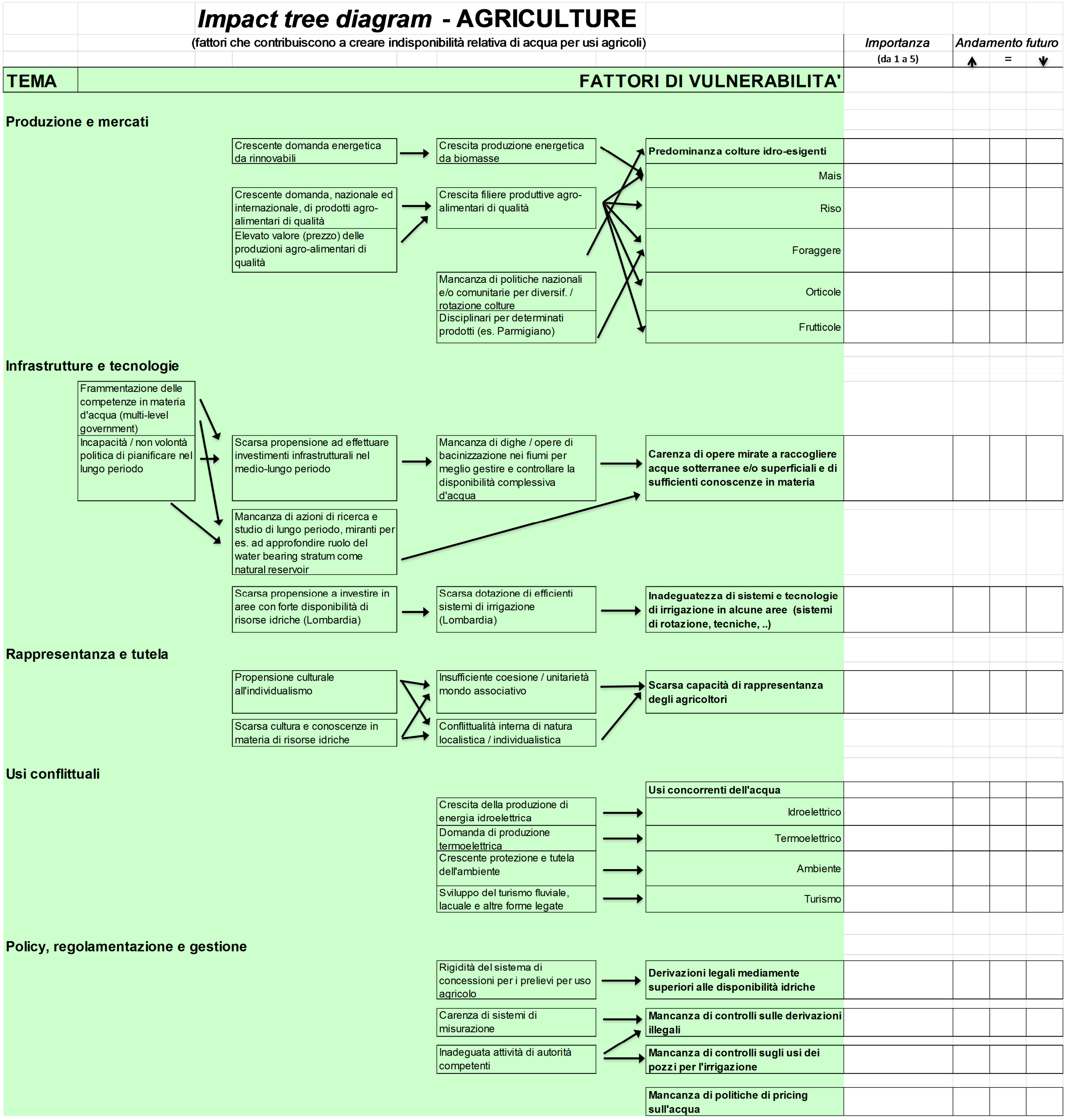


Figure G. 1: *Matrix for discussing future vulnerability of the agricultural sector.*

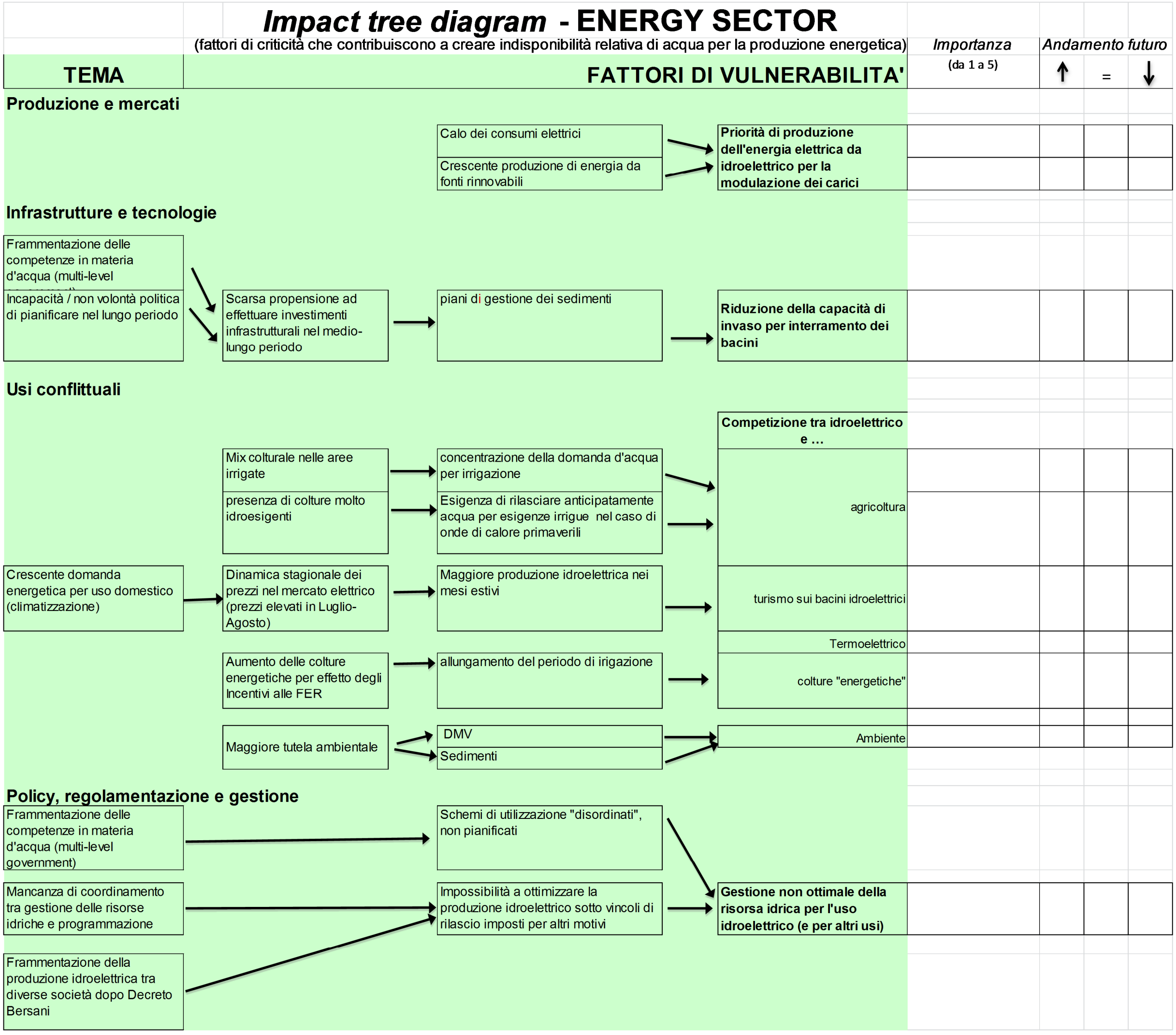


Figure G. 2: *Matrix for discussing future vulnerability of the energy production sector.*